JAMES D. HALDERMAN SIXTH EDITION

DIAGNOSIS AND TROUBLESHOOTING OF AUTOMOTIVE ELECTRICAL, ELECTRONIC, AND COMPUTER SYSTEMS

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PROFESSIONAL TECHNICIAN SERIES

DIAGNOSIS AND TROUBLESHOOTING OF AUTOMOTIVE ELECTRICAL, ELECTRONIC, AND COMPUTER SYSTEMS

SIXTH EDITION

James D. Halderman

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PREFACE

PROFESSIONAL TECHNICIAN SERIES Part of Pearson Automotive's Professional Technician Series, the sixth edition of *Diagnosis and Troubleshooting of Automotive Electrical, Electronic, and Computer Systems* represents the future of automotive textbooks. The series is a full-color, media-integrated solution for today's students and instructors. The series includes textbooks that cover all 8 areas of ASE certification, plus additional titles covering common courses.

Current revisions are written by a team of very experienced writers and teachers. The series is also peer reviewed for technical accuracy.

UPDATES TO THE SIXTH EDITION

- All content is correlated to the latest NATEF tasks.
- A dramatic, new full-color design enhances the subject material.
- One entirely new chapter **Electronic Throttle Control Systems** (chapter 36).
- Greatly expanded coverage on circuit testers (chapter 6), lighting and signalling (chapter 21) and oxygen sensors (chapter 32).
- Over 40 new color photos and line drawings have been added to this edition.
- Content has been streamlined for easier reading and comprehension.
- This text is fully integrated with MyAutomotiveKit, an online supplement for homework, quizzing, testing, multimedia activities, and videos.
- Unlike other textbooks, this book is written so that the theory, construction, diagnosis, and service of a particular component or system is presented in one location. There is no need to search through the entire book for other references to the same topic.

NATEF CORRELATED NATEF certified programs need to demonstrate that they use course material that covers NATEF tasks. All Professional Technician textbooks have been correlated to the appropriate NATEF task lists. These correlations can be found in an appendix to each book.

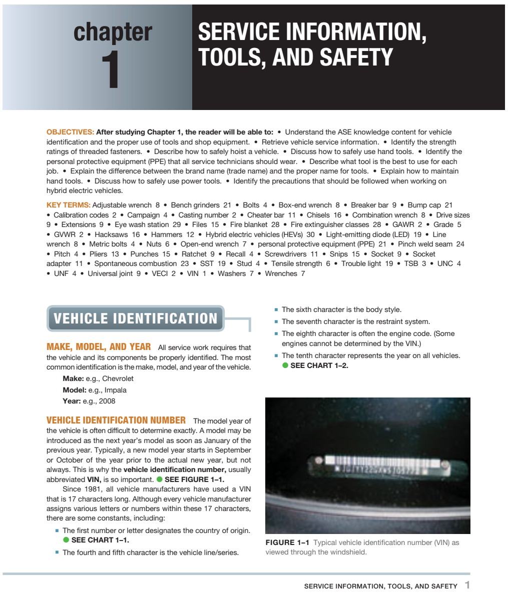
A COMPLETE INSTRUCTOR AND STUDENT SUPPLEMENTS PACKAGE All Professional Technician textbooks are accompanied by a full set of instructor and student supplements. Please see page vi for a detailed list of supplements.

A FOCUS ON DIAGNOSIS AND PROBLEM SOLVING

The Professional Technician Series has been developed to satisfy the need for a greater emphasis on problem diagnosis. Automotive instructors and service managers agree that students and beginning technicians need more training in diagnostic procedures and skill development. To meet this need and demonstrate how real-world problems are solved, "Real World Fix" features are included throughout and highlight how real-life problems are diagnosed and repaired.

The following pages highlight the unique core features that set the Professional Technician Series book apart from other automotive textbooks.

IN-TEXT FEATURES



chapter 1

SERVICE INFORMATION, TOOLS, AND SAFETY

OBJECTIVES: **After studying Chapter 1, the reader will be able to:** • Understand the ASE knowledge content for vehicle identification and the proper use of tools and shop equipment. • Retrieve vehicle service information. • Identify the strength ratings of threaded fasteners. • Describe how to safely hoist a vehicle. • Discuss how to safely use hand tools. • Identify the personal protective equipment (PPE) that all service technicians should wear. • Describe what tool is the best to use for each job. • Explain the difference between the brand name (trade name) and the proper name for tools. • Explain how to maintain hand tools. • Discuss how to safely use power tools. • Identify the precautions that should be followed when working on hybrid electric vehicles.

KEY TERMS: Adjustable wrench 8 • Bench grinders 21 • Bolts 4 • Box-end wrench 8 • Breaker bar 9 • Bump cap 21 • Calibration codes 2 • Campaign 4 • Casting number 2 • Cheater bar 11 • Chisels 16 • Combination wrench 8 • Drive sizes 9 • Extensions 9 • Eye wash station 29 • Files 15 • Fire blanket 28 • Fire extinguisher classes 28 • GAWR 2 • Grade 5 • GVWR 2 • Hacksaws 16 • Hammers 12 • Hybrid electric vehicles (HEVs) 30 • Light-emitting diode (LED) 19 • Line wrench 8 • Metric bolts 4 • Nuts 6 • Open-end wrench 7 • personal protective equipment (PPE) 21 • Pinch weld seam 24 • Pitch 4 • Pliers 13 • Punches 15 • Ratchet 9 • Recall 4 • Screwdrivers 11 • Snips 15 • Socket 9 • Socket adapter 11 • Spontaneous combustion 23 • SST 19 • Stud 4 • Tensile strength 6 • Trouble light 19 • TSB 3 • UNC 4 • UNF 4 • Universal joint 9 • VECI 2 • VIN 1 • Washers 7 • Wrenches 7

VEHICLE IDENTIFICATION

MAKE, MODEL, AND YEAR All service work requires that the vehicle and its components be properly identified. The most common identification is the make, model, and year of the vehicle.

Make: e.g., Chevrolet

Model: e.g., Impala

Year: e.g., 2008

VEHICLE IDENTIFICATION NUMBER The model year of the vehicle is often difficult to determine exactly. A model may be introduced as the next year's model as soon as January of the previous year. Typically, a new model year starts in September or October of the year prior to the actual new year, but not always. This is why the **vehicle identification number,** usually abbreviated **VIN,** is so important. **SEE FIGURE 1–1.**

Since 1981, all vehicle manufacturers have used a VIN that is 17 characters long. Although every vehicle manufacturer assigns various letters or numbers within these 17 characters, there are some constants, including:

- The first number or letter designates the country of origin. **SEE CHART 1–1.**
- The fourth and fifth character is the vehicle line/series.
- The sixth character is the body style.
- The seventh character is the restraint system.
- The eighth character is often the engine code. (Some engines cannot be determined by the VIN.)
- The tenth character represents the year on all vehicles. **SEE CHART 1–2.**

FIGURE 1–1 Typical vehicle identification number (VIN) as viewed through the windshield.

SERVICE INFORMATION, TOOLS, AND SAFETY 1

OBJECTIVES AND KEY TERMS appear at the beginning of each chapter to help students and instructors focus on the most important material in each chapter. The chapter objectives are based on specific ASE and NATEF tasks.

TECH TIP

Hide Those from the Boss

An apprentice technician started working for a dealership and put his top tool box on a workbench. Another technician observed that, along with a complete set of good-quality tools, the box contained several adjustable wrenches. The more experienced technician said, "Hide those from the boss." The boss does not want any service technician to use adjustable wrenches. If any adjustable wrench is used on a bolt or nut, the movable jaw often moves or loosens and starts to round the head of the fastener. If the head of the bolt or nut becomes rounded, it becomes that much more difficult to remove.

TECH TIPS feature real-world advice and "tricks of the trade" from ASE-certified master technicians.

SAFETY TIP

Shop Cloth Disposal

Always dispose of oily shop cloths in an enclosed container to prevent a fire. **SEE FIGURE 1-69.** Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur, which can ignite the cloth even without an open flame. This process of ignition without an open flame is called **spontaneous combustion**.

SAFETY TIPS alert students to possible hazards on the job and how to avoid them.

REAL WORLD FIX

Lightning Damage

A radio failed to work in a vehicle that was outside during a thunderstorm. The technician checked the fuses and verified that power was reaching the radio. Then the technician noticed the antenna. It had been struck by lightning. Obviously, the high voltage from the lightning strike traveled to the radio receiver and damaged the circuits. Both the radio and the antenna were replaced to correct the problem. **SEE FIGURE 26–26.**

REAL WORLD FIXES present students with actual automotive service scenarios and show how these common (and sometimes uncommon) problems were diagnosed and repaired.

FREQUENTLY ASKED QUESTION

How Many Types of Screw Heads Are Used in Automotive Applications?

There are many, including Torx, hex (also called Allen), plus many others used in custom vans and motor homes. **SEE FIGURE 1–9.**

FREQUENTLY ASKED QUESTIONS are based on the author's own experience and provide answers to many of the most common questions asked by students and beginning service technicians.

NOTE: Before applying Ohm's law, be sure that each unit of electricity is converted into base units. For example, 10 KΩ should be converted to 10,000 ohms and 10 mA should be converted into 0.010 A.

NOTES provide students with additional technical information to give them a greater understanding of a task or procedure.

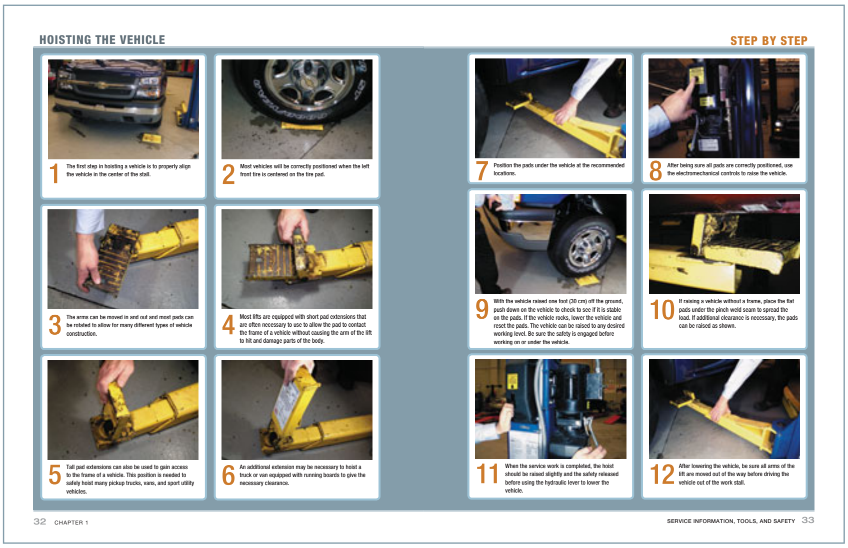
CAUTION: Do not use a screwdriver as a pry tool or chisel. Screwdrivers use hardened steel only at the tip and are not designed to be pounded on or used for prying because they could bend easily. Always use the proper tool for each application.

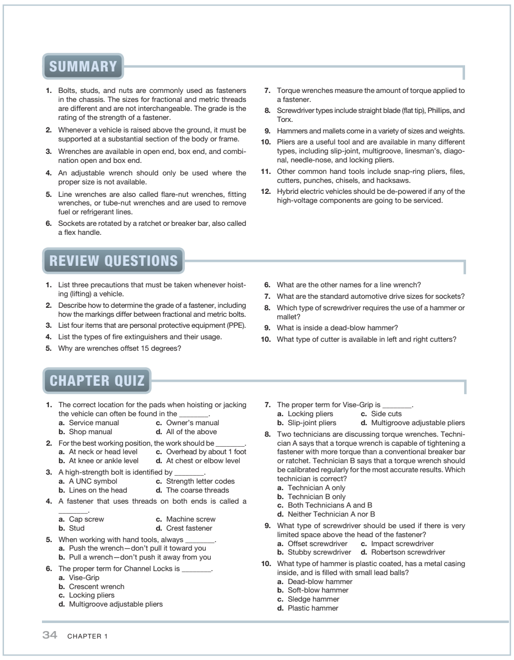
CAUTIONS alert students about potential to the vehicle that can occur during a specific task or service procedure.

WARNING

Always use impact sockets with impact wrenches, and always wear eye protection in case the socket or fastener shatters. Input sockets are thicker walled and constructed with premium alloy steel. They are hardened with a black oxide finish to help prevent corrosion and distinguish them from regular sockets. ● **SEE FIGURE 1–57.**

WARNINGS alert students to potential dangers to themselves during a specific task or service procedure.





SUMMARY

1. Bolts, studs, and nuts are commonly used as fasteners in the chassis. The sizes for fractional and metric threads are different and are not interchangeable. The grade is the rating of the strength of a fastener.
2. Whenever a vehicle is raised above the ground, it must be supported at a substantial section of the body or frame.
3. Wrenches are available in open end, box end, and combination open and box end.
4. An adjustable wrench should only be used where the proper size is not available.
5. Line wrenches are also called flare-nut wrenches, fitting wrenches, or tube-nut wrenches and are used to remove fuel or refrigerant lines.
6. Sockets are rotated by a ratchet or breaker bar, also called a flex handle.
7. Torque wrenches measure the amount of torque applied to a fastener.
8. Screwdriver types include straight blade (flat tip), Phillips, and Torx.
9. Hammers and mallets come in a variety of sizes and weights.
10. Pliers are a useful tool and are available in many different types, including slip-joint, multigroove, linesman's, diagonal, needle-nose, and locking pliers.
11. Other common hand tools include snap-ring pliers, files, cutters, punches, chisels, and hacksaws.
12. Hybrid electric vehicles should be de-powered if any of the high-voltage components are going to be serviced.

REVIEW QUESTIONS

1. List three precautions that must be taken whenever hoisting (lifting) a vehicle.
2. Describe how to determine the grade of a fastener, including how the markings differ between fractional and metric bolts.
3. List four items that are personal protective equipment (PPE).
4. List the types of fire extinguishers and their usage.
5. Why are wrenches offset 15 degrees?
6. What are the other names for a line wrench?
7. What are the standard automotive drive sizes for sockets?
8. Which type of screwdriver requires the use of a hammer or mallet?
9. What is inside a dead-blow hammer?
10. What type of cutter is available in left and right cutters?

CHAPTER QUIZ

1. The correct location for the pads when hoisting or jacking the vehicle can often be found in the ________.
   a. Service manual
   b. Shop manual
   c. Owner's manual
   d. All of the above
2. For the best working position, the work should be ________.
   a. At neck or head level
   b. At knee or ankle level
   c. Overhead by about 1 foot
   d. At chest or elbow level
3. A high-strength bolt is identified by ________.
   a. A UNC symbol
   b. Lines on the head
   c. Strength letter codes
   d. The coarse threads
4. A fastener that uses threads on both ends is called a ________.
   a. Cap screw
   b. Stud
   c. Machine screw
   d. Crest fastener
5. When working with hand tools, always ________.
   a. Push the wrench—don't pull it toward you
   b. Pull a wrench—don't push it away from you
6. The proper term for Channel Locks is ________.
   a. Vise-Grip
   b. Crescent wrench
   c. Locking pliers
   d. Multigroove adjustable pliers
7. The proper term for Vise-Grip is ________.
   a. Locking pliers
   b. Slip-joint pliers
   c. Side cuts
   d. Multigroove adjustable pliers
8. Two technicians are discussing torque wrenches. Technician A says that a torque wrench is capable of tightening a fastener with more torque than a conventional breaker bar or ratchet. Technician B says that a torque wrench should be calibrated regularly for the most accurate results. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. What type of screwdriver should be used if there is very limited space above the head of the fastener?
   a. Offset screwdriver
   b. Stubby screwdriver
   c. Impact screwdriver
   d. Robertson screwdriver
10. What type of hammer is plastic coated, has a metal casing inside, and is filled with small lead balls?
   a. Dead-blow hammer
   b. Soft-blow hammer
   c. Sledge hammer
   d. Plastic hammer

34 CHAPTER 1

THE SUMMARY, REVIEW QUESTIONS, AND CHAPTER QUIZ at the end of each chapter help students review the material presented in the chapter and test themselves to see how much they've learned.

STEP-BY-STEP photo sequences show in detail the steps involved in performing a specific task or service procedure.

SUPPLEMENTS

INSTRUCTOR SUPPLEMENTS The instructor supplement package has been completely revamped to reflect the needs of today's instructors. The all new **Online Instructor's Manual (ISBN: 0-13-255156-X)** is the cornerstone of the package.

To access supplementary materials online, instructors need to request an instructor access code. Go to **www.pearsonhighered.com/irc,** where you can register for an instructor access code. Within 48 hours after registering, you will receive a confirming e-mail, including an instructor access code. Once you have received your code, go to the site and log on for full instructions on downloading the materials you wish to use.

Here you will find:

- PowerPoint presentations*
- Image Library containing every image in the book for use in class or customized PowerPoints*
- My Test*
- Chapter Quizzes
- Chapter Review Questions
- English and Spanish Glossary*
- NATEF Correlated task Sheets* (also available as a printed supplement [ISBN: 0-13-255220-5])
- NATEF/ASE Correlation Charts

* All of these are available for download from www.pearsonhighered.com

STUDENT SUPPLEMENTS
As a result of extensive student input, Pearson is no longer binding CDs into automotive students' textbooks. Today's student has more access to the Internet than ever, so all supplemental materials are downloadable at the following site for no additional charge:

www.pearsoned.com/autostudent

On the site, students will find:

- PowerPoint presentations
- Chapter review questions and quizzes
- English and Spanish Glossary
- A full Spanish translation of the text

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—James D. Halderman

ABOUT THE AUTHOR

JIM HALDERMAN brings a world of experience, knowledge, and talent to his work. His automotive service experience includes working as a flat-rate technician, a business owner, and a professor of automotive technology at a leading U.S. community college for more than 20 years.

He has a Bachelor of Science Degree from Ohio Northern University and a Masters Degree in Education from Miami University in Oxford, Ohio. Jim also holds a U.S. Patent for an electronic transmission control device. He is an ASE certified Master Automotive Technician and Advanced Engine Performance (L1) ASE certified.

Jim is the author of many automotive textbooks all published by Prentice Hall.

Jim has presented numerous technical seminars to national audiences including the California Automotive Teachers (CAT) and the Illinois College Automotive Instructor Association (ICAIA). He is also a member and presenter at the North American Council of Automotive Teachers (NACAT). Jim was also named Regional Teacher of the Year by General Motors Corporation and an outstanding alumnus of Ohio Northern University.

Jim and his wife, Michelle, live in Dayton, Ohio. They have two children. You can reach Jim at

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BRIEF CONTENTS

CONTENTS

chapter 1

SERVICE INFORMATION, TOOLS, AND SAFETY

OBJECTIVES: After studying Chapter 1, the reader will be able to: • Understand the ASE knowledge content for vehicle identification and the proper use of tools and shop equipment. • Retrieve vehicle service information. • Identify the strength ratings of threaded fasteners. • Describe how to safely hoist a vehicle. • Discuss how to safely use hand tools. • Identify the personal protective equipment (PPE) that all service technicians should wear. • Describe what tool is the best to use for each job. • Explain the difference between the brand name (trade name) and the proper name for tools. • Explain how to maintain hand tools. • Discuss how to safely use power tools. • Identify the precautions that should be followed when working on hybrid electric vehicles.

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VEHICLE IDENTIFICATION

MAKE, MODEL, AND YEAR All service work requires that the vehicle and its components be properly identified. The most common identification is the make, model, and year of the vehicle.

Make: e.g., Chevrolet

Model: e.g., Impala

Year: e.g., 2008

VEHICLE IDENTIFICATION NUMBER The model year of the vehicle is often difficult to determine exactly. A model may be introduced as the next year's model as soon as January of the previous year. Typically, a new model year starts in September or October of the year prior to the actual new year, but not always. This is why the **vehicle identification number,** usually abbreviated **VIN,** is so important. ● **SEE FIGURE 1–1.**

Since 1981, all vehicle manufacturers have used a VIN that is 17 characters long. Although every vehicle manufacturer assigns various letters or numbers within these 17 characters, there are some constants, including:

- The first number or letter designates the country of origin. ● **SEE CHART 1–1.**
- The fourth and fifth character is the vehicle line/series.
- The sixth character is the body style.
- The seventh character is the restraint system.
- The eighth character is often the engine code. (Some engines cannot be determined by the VIN.)
- The tenth character represents the year on all vehicles. ● **SEE CHART 1–2.**

FIGURE 1–1 Typical vehicle identification number (VIN) as viewed through the windshield.

1 = United States	J = Japan	W = Germany
2 = Canada	K = Korea	X = Russia
3 = Mexico	L = China	Y = Sweden
4 = United States	R = Taiwan	Z = Italy
5 = United States	S = England	
6 = Australia	T = Czechoslovakia	
8 = Argentina	U = Romania	
9 = Brazil	V = France	

CHART 1–1

The first character in the VIN identifies the country where the vehicle was made.

A = 1980/2010	L = 1990/2020	Y = 2000/2030
B = 1981/2011	M = 1991/2021	1 = 2001/2031
C = 1982/2012	N = 1992/2022	2 = 2002/2032
D = 1983/2013	P = 1993/2023	3 = 2003/2033
E = 1984/2014	R = 1994/2024	4 = 2004/2034
F = 1985/2015	S = 1995/2025	5 = 2005/2035
G = 1986/2016	T = 1996/2026	6 = 2006/2036
H = 1987/2017	V = 1997/2027	7 = 2007/2037
J = 1988/2018	W = 1998/2028	8 = 2008/2038
K = 1989/2019	X = 1999/2029	9 = 2009/2039

CHART 1–2

The tenth digit of the VIN identifies the model year of the vehicle. The pattern repeats every 30 years for the year of manufacture.

VEHICLE SAFETY CERTIFICATION LABEL A vehicle safety certification label is attached to the left side pillar post on the rearward-facing section of the left front door. This label indicates the month and year of manufacture as well as the **gross vehicle weight rating (GVWR),** the **gross axle weight rating (GAWR),** and the VIN.

VECI LABEL The **vehicle emissions control information (VECI)** label under the hood of the vehicle shows informative settings and emission hose routing information. ● **SEE FIGURE 1–2.**

The VECI label (sticker) can be located on the bottom side of the hood, the radiator fan shroud, the radiator core support, or on the strut towers. The VECI label usually includes the following information.

- Engine identification
- Emissions standard that the vehicle meets
- Vacuum hose routing diagram
- Base ignition timing (if adjustable)
- Spark plug type and gap

FIGURE 1–2 The vehicle emissions control information (VECI) sticker is placed under the hood.

FIGURE 1–3 A typical calibration code sticker on the case of a controller. The information on the sticker is often needed when ordering parts or a replacement controller.

- Valve lash
- Emission calibration code

CALIBRATION CODES **Calibration codes** are usually located on powertrain control modules (PCMs) or other controllers. Whenever diagnosing an engine operating fault, it is often necessary to use the calibration code to be sure that the vehicle is the subject of a technical service bulletin or other service procedure. ● **SEE FIGURE 1–3.**

CASTING NUMBERS When an engine part such as a block is cast, a number is put into the mold to identify the casting. ● **SEE FIGURE 1–4.** These **casting numbers** can be used to identify the part and to check specifications, such as the cubic inch displacement, and other information, such as the year of manufacture. Sometimes changes are made to the mold, yet

FIGURE 1–4 Casting numbers on major components can be either cast or stamped.

FIGURE 1–5 Electronic service information is available from aftermarket sources such as ALLDATA and Mitchell-on-Demand, as well as on websites hosted by vehicle manufacturers.

the casting number is not changed. Most often the casting number is the best piece of identifying information that the service technician can use for identifying an engine.

SERVICE INFORMATION

SERVICE MANUALS Service information is used by the service technician to determine specifications and service procedures, and any needed special tools.

Factory and aftermarket service manuals contain specifications and service procedures. While factory service manuals cover just one year and one or more models of the same vehicle, most aftermarket service manufacturers cover multiple years and/or models in one manual.

Included in most service manuals are the following:

- Capacities and recommended specifications for all fluids
- Specifications including engine and routine maintenance items
- Testing procedures
- Service procedures including the use of special tools when needed

ELECTRONIC SERVICE INFORMATION Electronic service information is available mostly by subscription and provides access to an Internet site where service manual–type information is available. ● **SEE FIGURE 1–5.** Most vehicle manufacturers also offer electronic service information to their dealers and to most schools and colleges that offer corporate training programs.

TECHNICAL SERVICE BULLETINS **Technical service bulletins,** often abbreviated **TSBs,** sometimes called *technical service information bulletins (TSIBs)* are issued by the vehicle manufacturer to notify service technicians of a problem and include the necessary corrective action. Technical service bulletins are designed for dealership technicians but are republished by aftermarket companies and made available along with other service information to shops and vehicle repair facilities. ● **SEE FIGURE 1–6.**

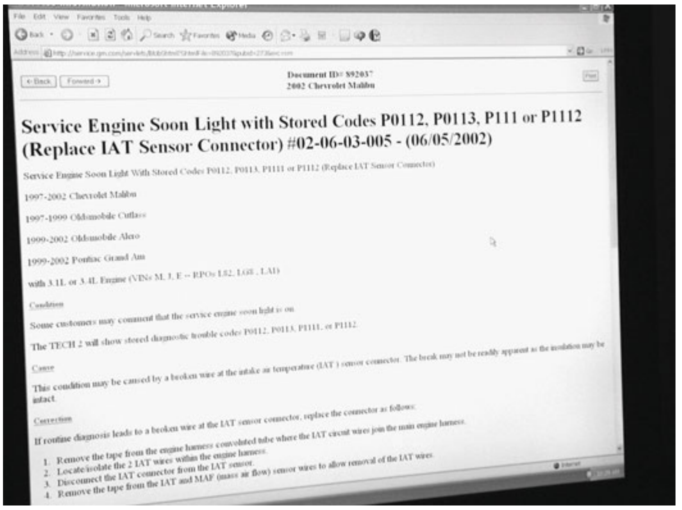


FIGURE 1–6 Technical service bulletins (TSBs) are issued by vehicle manufacturers when a fault occurs that affects many vehicles with the same problem. The TSB then provides the fix for the problem including any parts needed and detailed instructions.

INTERNET The Internet has opened the field for information exchange and access to technical advice. One of the most useful websites is the International Automotive Technician's Network at **www.iatn.net.** This is a free site but service technicians must register to join. For a small monthly sponsor fee, the shop or service technician can gain access to the archives, which include thousands of successful repairs in the searchable database.

FREQUENTLY ASKED QUESTION

What Should Be Included on a Work Order?

A work order is a legal document that should include the following information.

1. Customer information
2. Identification of the vehicle including the VIN
3. Related service history information
4. The "three Cs":
   - Customer concern (complaint)
   - Cause of the concern
   - Correction or repairs that the vehicle required to return it to proper operation

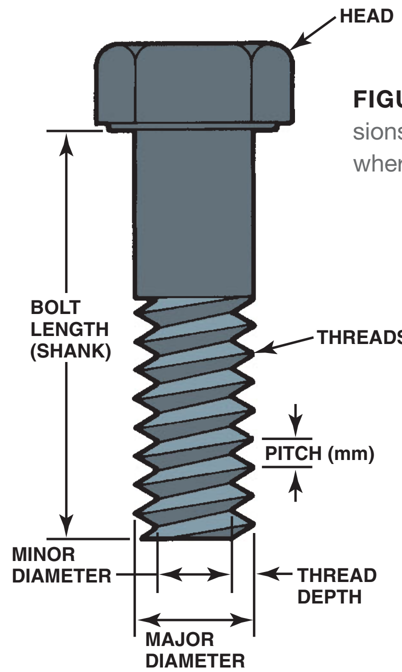


FIGURE 1–7 The dimensions of a typical bolt showing where sizes are measured.

RECALLS AND CAMPAIGNS A **recall** or **campaign** is issued by a vehicle manufacturer and a notice is sent to all owners in the event of a safety-related fault or concern. Although these faults may be repaired by shops, it is generally handled by a local dealer. Items that have created recalls in the past include potential fuel system leakage problems, exhaust leakage, or electrical malfunctions that could cause a possible fire or the engine to stall. Unlike technical service bulletins whose cost is only covered when the vehicle is within the warranty period, a recall or campaign is always done at no cost to the vehicle owner.

THREADED FASTENERS

BOLTS AND THREADS Most of the threaded fasteners used on vehicles are **bolts.** Bolts are called *cap screws* when they are threaded into a casting. Automotive service technicians usually refer to these fasteners as bolts, regardless of how they are used. In this chapter, they are called bolts. Sometimes, studs are used for threaded fasteners. A **stud** is a short rod with threads on both ends. Often, a stud will have coarse threads on one end and fine threads on the other end. The end of the stud with coarse threads is screwed into the casting. A nut is used on the opposite end to hold the parts together.

The fastener threads *must* match the threads in the casting or nut. The threads may be measured either in fractions of an inch (called fractional) or in metric units. The size is measured across the outside of the threads, called the major diameter or the *crest* of the thread. ● **SEE FIGURE 1–7.**

FIGURE 1–8 Thread pitch gauge used to measure the pitch of the thread. This bolt has 13 threads to the inch.

FREQUENTLY ASKED QUESTION

How Many Types of Screw Heads Are Used in Automotive Applications?

There are many, including Torx, hex (also called Allen), plus many others used in custom vans and motor homes. ● **SEE FIGURE 1–9.**

FRACTIONAL BOLTS Fractional threads are either coarse or fine. The coarse threads are called **Unified National Coarse (UNC),** and the fine threads are called **Unified National Fine (UNF).** Standard combinations of sizes and number of threads per inch (called **pitch**) are used. Pitch can be measured with a thread pitch gauge as shown in ● **FIGURE 1–8.** Bolts are identified by their diameter and length as measured from below the head, not by the size of the head or the size of the wrench used to remove or install the bolt.

Fractional thread sizes are specified by the diameter in fractions of an inch and the number of threads per inch. Typical UNC thread sizes would be 5/16-18 and 1/2-13. Similar UNF thread sizes would be 5/16-24 and 1/2-20. ● **SEE CHART 1–3.**

METRIC BOLTS The size of a **metric bolt** is specified by the letter *M* followed by the diameter in millimeters (mm) across the outside (crest) of the threads. Typical metric sizes would be M8 and M12. Metric threads are specified by the thread diameter

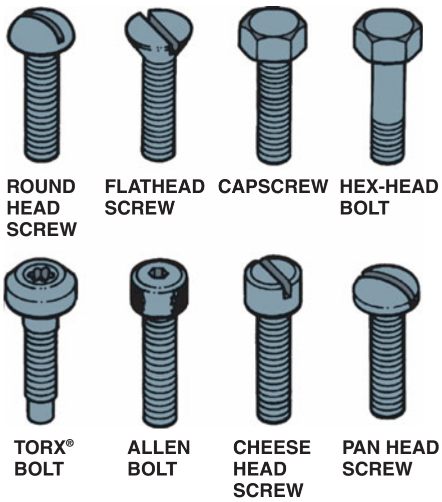
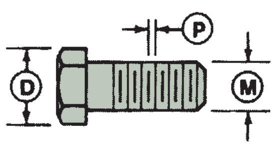


FIGURE 1–9 Bolts and screws have many different heads. The head determines what tool is needed.

METRIC HEXAGON HEAD CAP SCREWS

ALL MEASUREMENTS IN MILLIMETERS



M = NOMINAL THREAD DIAMETER
P = PITCH
D = HEAD SIZE ACROSS FLATS

M	P	D	M	P	D	M	P	D
1.6	0.35	3.2	10	1.00	17	20	1.50	30
1.7	0.35	3.5	10	1.25	17	20	2.50	30
2	0.40	4	10	1.50	17	22	1.50	32
2.3	0.40	4.5	12	1.25	19	22	2.50	32
2.5	0.45	5	12	1.50	19	24	2.00	36
3	0.50	5.5	12	1.75	19	24	3.00	36
3.5	0.60	6	14	1.50	22	27	3.00	41
4	0.70	7	14	2.00	22	30	3.50	46
5	0.80	8	16	1.50	24	33	3.50	50
6	1.00	10	16	2.00	24	36	4.00	55
7	1.00	11	18	1.50	27	39	4.00	60
8	1.00	13	18	2.50	27	42	4.50	65
8	1.25	13				45	4.50	70

FIGURE 1–10 The metric system specifies fasteners by diameter, length, and pitch.

followed by X and the distance between the threads measured in millimeters (M8 X 1.5). ● **SEE FIGURE 1–10.**

GRADES OF BOLTS Bolts are made from many different types of steel, and for this reason some are stronger than others. The strength or classification of a bolt is called the **grade.** The bolt heads are marked to indicate their grade strength.

The actual grade of bolts is two more than the number of lines on the bolt head. Metric bolts have a decimal number to indicate the grade. More lines or a higher grade number indicate a stronger bolt. Higher grade bolts usually have threads that are rolled rather than cut, which also makes them stronger. ● **SEE FIGURE 1–11.** In some cases, nuts and machine screws have similar grade markings.

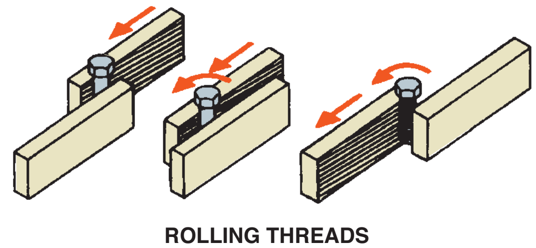


FIGURE 1–11 Stronger threads are created by cold-rolling a heat-treated bolt blank instead of cutting the threads, using a die.

	THREADS PER INCH		
SIZE	NC UNC	NF UNF	OUTSIDE DIAMETER INCHES
0	. .	80	0.0600
1	64	. .	0.0730
1	. .	72	0.0730
2	56	. .	0.0860
2	. .	64	0.0860
3	48	. .	0.0990
3	. .	56	0.0990
4	40	. .	0.1120
4	. .	48	0.1120
5	40	. .	0.1250
5	. .	44	0.1250
6	32	. .	0.1380
6	. .	40	0.1380
8	32	. .	0.1640
8	. .	36	0.1640
10	24	. .	0.1900
10	. .	32	0.1900
12	24	. .	0.2160
12	. .	28	0.2160
1/4	20	. .	0.2500
1/4	. .	28	0.2500
5/16	18	. .	0.3125
5/16	. .	24	0.3125
3/8	16	. .	0.3750
3/8	. .	24	0.3750
7/16	14	. .	0.4375
7/16	. .	20	0.4375
1/2	13	. .	0.5000
1/2	. .	20	0.5000
9/16	12	. .	0.5625
9/16	. .	18	0.5625
5/8	11	. .	0.6250
5/8	. .	18	0.6250
3/4	10	. .	0.7500
3/4	. .	16	0.7500
7/8	9	. .	0.8750
7/8	. .	14	0.8750
1	8	. .	1.0000
1	. .	12	1.0000

CHART 1–3

American Standard is one method of sizing fasteners.

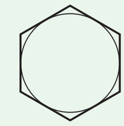
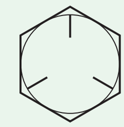
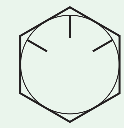
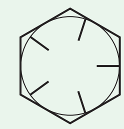
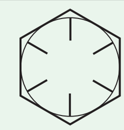
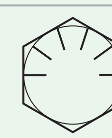
SAE BOLT DESIGNATIONS				
SAE GRADE NO.	SIZE RANGE	TENSILE STRENGTH, PSI	MATERIAL	HEAD MARKING
1 2	1/4 through 1 1/2 1/4 through 3/4 7/8 through 1 1/2	60,000 74,000 60,000	Low or medium carbon steel	
5	1/4 through 1 1 1/8 through 1 1/2	120,000 105,000	Medium carbon steel, quenched and tempered	
5.2	1/4 through 1	120,000	Low carbon martensite steel,* quenched and tempered	
7	1/4 through 1 1/2	133,000	Medium carbon alloy steel, quenched and tempered	
8	1/4 through 1 1/2	150,000	Medium carbon alloy steel, quenched and tempered	
8.2	1/4 through 1	150,000	Low carbon martensite steel,* quenched and tempered	

CHART 1–4

The tensile strength rating system as specified by the Society of Automotive Engineers (SAE).
*Martensite steel is steel that has been cooled rapidly, thereby increasing its hardness. It is named after a German metallurgist, Adolf Martens.

CAUTION: *Never* use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

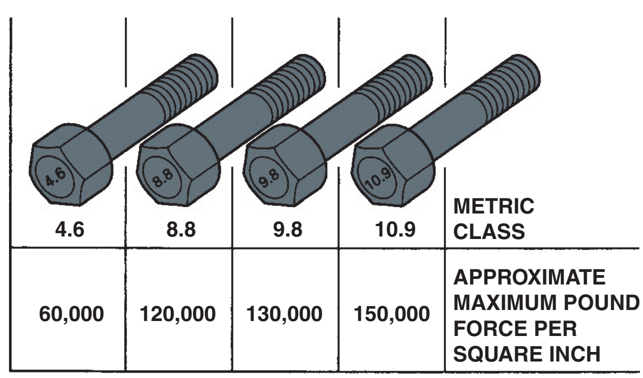


FIGURE 1–12 Metric bolt (cap screw) grade markings and approximate tensile strength.

TENSILE STRENGTH OF FASTENERS

Graded fasteners have a higher tensile strength than nongraded fasteners. **Tensile strength** is the maximum stress used under tension (lengthwise force) without causing failure of the fastener. Tensile strength is specified in pounds per square inch (psi).

The strength and type of steel used in a bolt is supposed to be indicated by a raised mark on the head of the bolt. The type of mark depends on the standard to which the bolt was manufactured. Most often, bolts used in machinery are made to SAE standard J429. ● **CHART 1–4** shows the grade and specified tensile strength.

Metric bolt tensile strength property class is shown on the head of the bolt as a number, such as 4.6, 8.8, 9.8, and 10.9; the higher the number, the stronger the bolt. ● **SEE FIGURE 1–12.**

NUTS

Nuts are the female part of a threaded fastener. Most nuts used on cap screws have the same hex size as the cap screw head. Some inexpensive nuts use a hex size larger than the cap screw head. Metric nuts are often marked with dimples to show their strength. More dimples indicate stronger nuts.

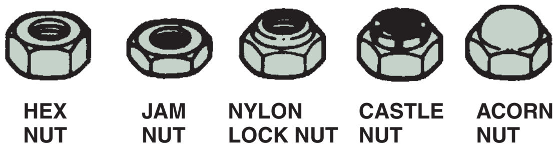


FIGURE 1–13 Nuts come in a variety of styles, including locking (prevailing torque) types, such as the distorted thread and nylon insert type.

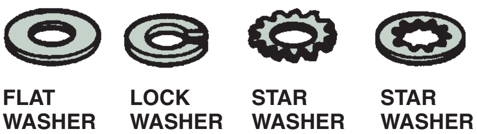


FIGURE 1–14 Washers come in a variety of styles, including flat and star (serrated), used to help prevent a fastener from loosening.

TECH TIP

A 1/2 Inch Wrench Does Not Fit a 1/2 Inch Bolt

A common mistake made by persons new to the automotive field is to think that the size of a bolt or nut is the size of the head. The size of the bolt or nut (outside diameter of the threads) is usually smaller than the size of the wrench or socket that fits the head of the bolt or nut. Examples are given in the following table.

Wrench Size	Thread Size
7/16 in.	1/4 in.
1/2 in.	5/16 in.
9/16 in.	3/8 in.
5/8 in.	7/16 in.
3/4 in.	1/2 in.
10 mm	6 mm
12 mm or 13 mm*	8 mm
14 mm or 17 mm*	10 mm

* European (Systeme International d'Unites, or SI) metric

Some nuts and cap screws use interference fit threads to keep them from accidentally loosening. This means that the shape of the nut is slightly distorted or that a section of the threads is deformed. Nuts can also be kept from loosening with a nylon washer fastened in the nut or with a nylon patch or strip on the threads. ● **SEE FIGURE 1–13.**

NOTE: Most of these "locking nuts" are grouped together and are commonly referred to as *prevailing torque nuts*. This means that the nut will hold its tightness or torque and not loosen with movement or vibration. Most prevailing torque nuts should be replaced whenever removed to ensure that the nut will not loosen during service. Always follow the manufacturer's recommendations. Anaerobic sealers, such as Loctite, are used on the threads where the nut or cap screw must be both locked and sealed.

WASHERS **Washers** are often used under cap screw heads and under nuts. ● **SEE FIGURE 1–14.** Plain flat washers are used to provide an even clamping load around the fastener. Lock washers are added to prevent accidental loosening. In some accessories, the washers are locked onto the nut to provide easy assembly.

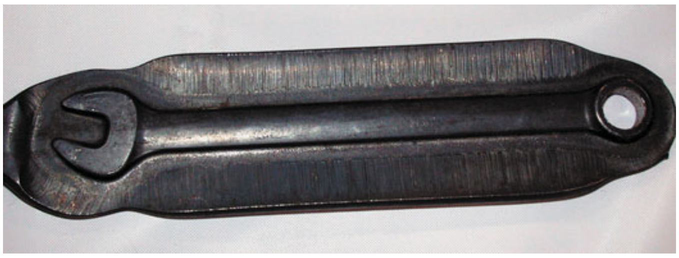


FIGURE 1–15 A forged wrench after it has been forged but before the flashing (extra material around the wrench) has been removed.

TECH TIP

It Just Takes a Second

Whenever removing any automotive component, it is wise to screw the bolts back into the holes a couple of threads by hand. This ensures that the right bolt will be used in its original location when the component or part is put back on the vehicle. Often, the same diameter of fastener is used on a component, but the length of the bolt may vary. Spending just a couple of seconds to put the bolts and nuts back where they belong when the part is removed can save a lot of time when the part is being reinstalled. Besides making certain that the right fastener is being installed in the right place, this method helps prevent bolts and nuts from getting lost or kicked away. How much time have you wasted looking for that lost bolt or nut?

HAND TOOLS

WRENCHES Wrenches are the most used hand tool by service technicians. **Wrenches** are used to grasp and rotate threaded fasteners. Most wrenches are constructed of forged alloy steel, usually chrome-vanadium steel. ● **SEE FIGURE 1–15.**

After the wrench is formed, it is hardened, and then tempered to reduce brittleness, and then chrome plated. There are several types of wrenches.

- An **open-end wrench** is often used to loosen or tighten bolts or nuts that do not require a lot of torque. Because of the *open* end, this type of wrench can be easily placed on

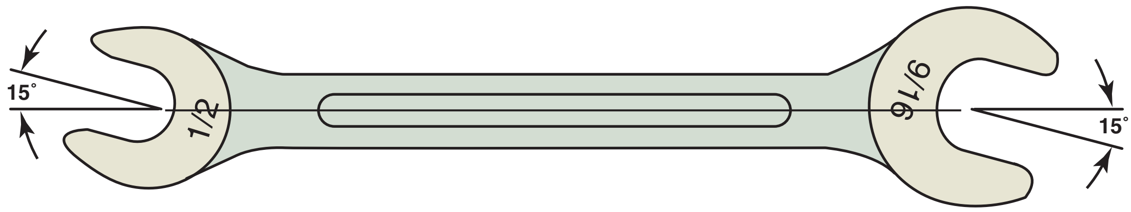


FIGURE 1–16 A typical open-end wrench. Note the size difference on each end and that the head is angled 15 degrees at the end.

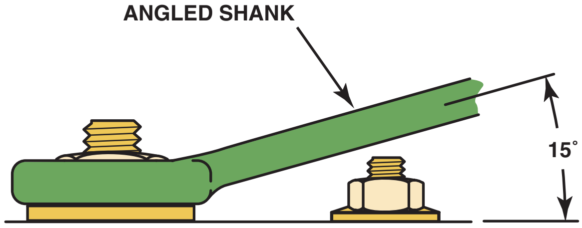


FIGURE 1–17 The end of a box-end wrench is angled 15 degrees to allow clearance for nearby objects or other fasteners.

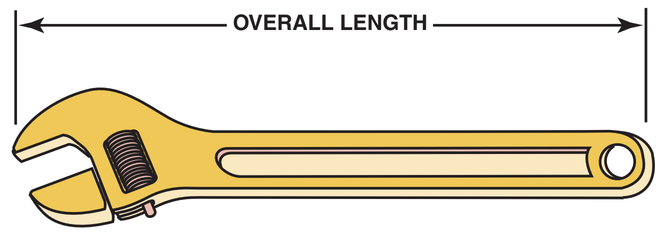


FIGURE 1–19 An adjustable wrench. Adjustable wrenches are sized by the overall length of the wrench, not by how far the jaws open. Common sizes of adjustable wrenches include 8 in., 10 in., and 12 in.

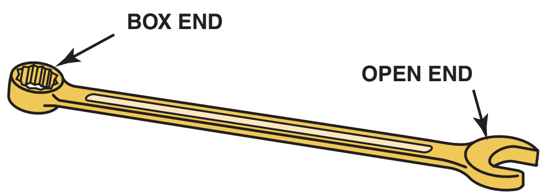


FIGURE 1–18 A combination wrench has an open end at one end and a box end at the other end.

FIGURE 1–20 The end of a typical line wrench, which shows that it is capable of grasping most of the head of the fitting.

a bolt or nut with an angle of 15 degrees, which allows the wrench to be flipped over and used again to continue to rotate the fastener. The major disadvantage of an open-end wrench is the lack of torque that can be applied due to the fact that the open jaws of the wrench only contact two flat surfaces of the fastener. An open-end wrench has two different sizes, one at each end. ● **SEE FIGURE 1–16.**

- A **box-end wrench,** also called a *closed-end wrench,* is placed over the top of the fastener and grips the points of the fastener. A box-end wrench is angled 15 degrees to allow it to clear nearby objects.

  Therefore, a box-end wrench should be used to loosen or to tighten fasteners because it grasps around the entire head of the fastener. A box-end wrench has two different sizes, one at each end. ● **SEE FIGURE 1–17.**
- Most service technicians purchase *combination wrenches,* which have the open end at one end and the same size box end on the other end. ● **SEE FIGURE 1–18.**
- A **combination wrench** allows the technician to loosen or tighten a fastener using the box end of the wrench, turn it around, and use the open end to increase the speed of rotating the fastener.
- An **adjustable wrench** is often used where the exact size wrench is not available or when a large nut, such as a wheel spindle nut, needs to be rotated but not tightened. An adjustable wrench should not be used to loosen or tighten fasteners because the torque applied to the wrench can cause the movable jaws to loosen their grip on the fastener, causing it to become rounded. ● **SEE FIGURE 1–19.**
- **Line wrenches,** also called *flare-nut wrenches, fitting wrenches,* or *tube-nut wrenches,* are designed to grip almost all the way around a nut used to retain a fuel, brake, or refrigerant line, and yet be able to be installed over the line. ● **SEE FIGURE 1–20.**

SAFE USE OF WRENCHES Wrenches should be inspected before use to be sure they are not cracked, bent, or damaged. All wrenches should be cleaned after use before being returned to the tool box. Always use the correct size of wrench for the fastener being loosened or tightened to help prevent the rounding of the flats of the fastener. When attempting to loosen a fastener, pull a wrench—do not push it. If you push a wrench, your knuckles may be hurt when forced into another object if the fastener breaks loose or if the wrench slips. Always keep wrenches and all hand tools clean to help prevent rust and to

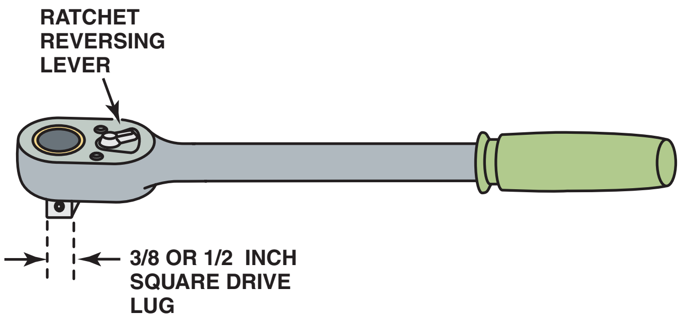


FIGURE 1–21 A typical ratchet used to rotate a socket. A ratchet makes a ratcheting noise when it is being rotated in the opposite direction from loosening or tightening. A knob or lever on the ratchet allows the technician to switch directions.

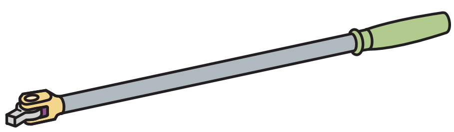


FIGURE 1–22 A typical flex handle used to rotate a socket; also called a breaker bar, because it usually has a longer handle than a ratchet and, therefore, can be used to apply more torque to a fastener than a ratchet.

TECH TIP

Hide Those from the Boss

An apprentice technician started working for a dealership and put his top tool box on a workbench. Another technician observed that, along with a complete set of good-quality tools, the box contained several adjustable wrenches. The more experienced technician said, "Hide those from the boss." The boss does not want any service technician to use adjustable wrenches. If any adjustable wrench is used on a bolt or nut, the movable jaw often moves or loosens and starts to round the head of the fastener. If the head of the bolt or nut becomes rounded, it becomes that much more difficult to remove.

allow for a better, firmer grip. Never expose any tool to excessive heat. High temperatures can reduce the strength ("draw the temper") of metal tools.

Never use a hammer on any wrench unless you are using a special *staking face wrench* designed to be used with a hammer. Replace any tools that are damaged or worn.

RATCHETS, SOCKETS, AND EXTENSIONS A **socket** fits over the fastener and grips the points and/or flats of the bolt or nut. The socket is rotated (driven) using either a long bar called a **breaker bar** (flex handle) or a ratchet. ● **SEE FIGURES 1–21 AND 1–22.**

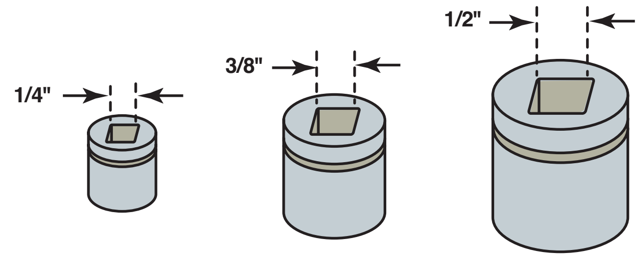


FIGURE 1–23 The most commonly used socket drive sizes include 1/4 in., 3/8 in., and 1/2 in. drive.

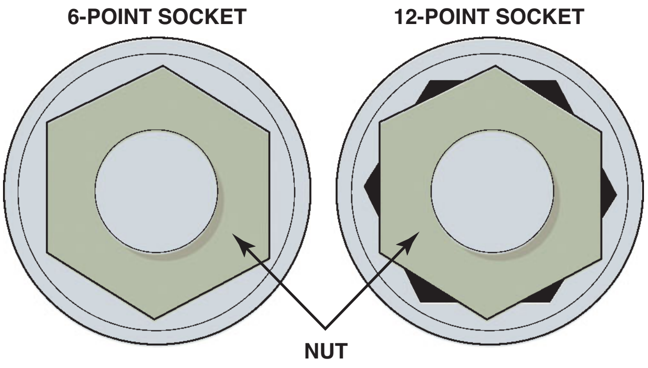


FIGURE 1–24 A 6-point socket fits the head of a bolt or nut on all sides. A 12-point socket can round off the head of a bolt or nut if great force is applied.

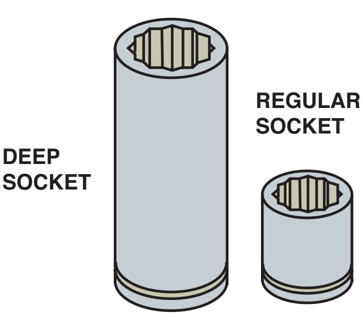


FIGURE 1–25 Allows access to the nut that has a stud plus other locations needing great depth, such as spark plugs.

A **ratchet** is a tool that turns the socket in only one direction and allows the rotating of the ratchet handle back and forth in a narrow space. Socket **extensions** and **universal joints** are also used with sockets to allow access to fasteners in restricted locations.

DRIVE SIZE. Sockets are available in various **drive sizes,** including 1/4 in., 3/8 in., and 1/2 in. sizes for most automotive use. ● **SEE FIGURES 1–23 AND 1–24.**

Many heavy-duty truck and/or industrial applications use 3/4 in. and 1 in. sizes. The drive size is the distance of each side of the square drive. Sockets and ratchets of the same size are designed to work together.

Regular and deep well sockets are available in regular length for use in most applications or in a deep well design that allows for access to a fastener that uses a long stud or other similar conditions. ● **SEE FIGURE 1–25.**

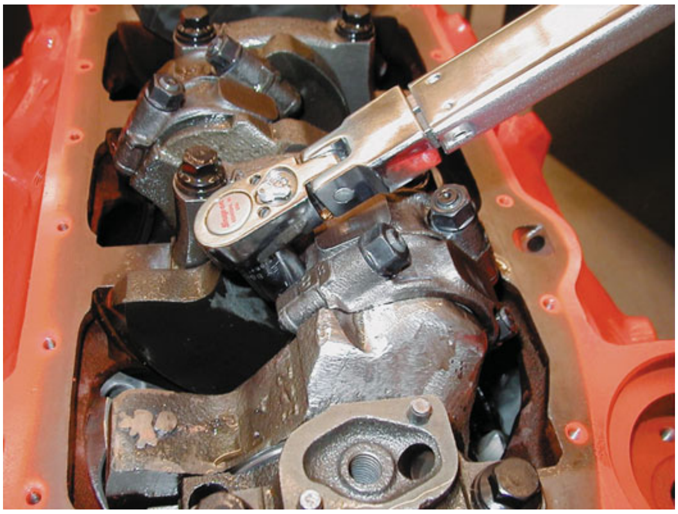


FIGURE 1–26 Using a torque wrench to tighten connecting rod nuts on an engine.

TECH TIP

Right to Tighten

It is sometimes confusing which way to rotate a wrench or screwdriver, especially when the head of the fastener is pointing away from you. To help visualize while looking at the fastener, say "righty tighty, lefty loosey."

FIGURE 1–27 A beam-type torque wrench that displays the torque reading on the face of the dial. The beam display is read as the beam deflects, which is in proportion to the amount of torque applied to the fastener.

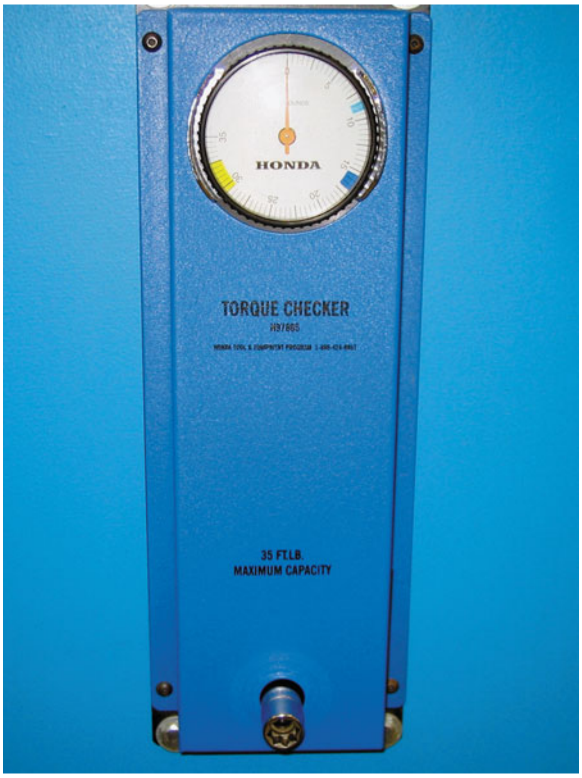


FIGURE 1–28 Torque wrench calibration checker.

TECH TIP

Check Torque Wrench Calibration Regularly

Torque wrenches should be checked regularly. For example, Honda has a torque wrench calibration setup at each training center. It is expected that a torque wrench be checked for accuracy before every use. Most experts recommend that torque wrenches be checked and adjusted as needed at least every year and more often if possible. ● **SEE FIGURE 1–28.**

TORQUE WRENCHES Torque wrenches are socket turning handles designed to apply a known amount of force to the fastener. The two basic types of torque wrenches include:

1. **Clicker type.** This type of torque wrench is first set to the specified torque and then it "clicks" when the set torque value has been reached. When force is removed from the torque wrench handle, another click is heard. The setting on a clicker-type torque wrench should be set back to zero after use and checked for proper calibration regularly. ● **SEE FIGURE 1–26.**
2. **Beam or dial type.** This type of torque wrench is used to measure torque, but instead of presenting the value, the actual torque is displayed on the dial of the wrench as the fastener is being tightened. Beam or dial-type torque wrenches are available in 1/4 in., 3/8 in., and 1/2 in. drives and both English (standard) and metric units. ● **SEE FIGURE 1–27.**

SAFE USE OF SOCKETS AND RATCHETS Always use the proper size socket that correctly fits the bolt or nut. All sockets and ratchets should be cleaned after use before being placed back into the tool box. Sockets are available in short and deep well designs. Never expose any tool to excessive heat. High temperatures can reduce the strength ("draw the temper") of metal tools.

Do not hit sockets or socket drivers with a hammer. Replace any tools that are damaged or worn.

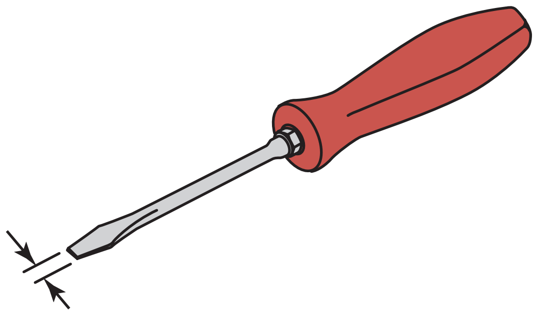


FIGURE 1–29 A flat-tip (straight-blade) screwdriver. The width of the blade should match the width of the slot in the fastener being loosened or tightened.

TECH TIP

Use Socket Adapters with Caution

A **socket adapter** allows the use of one size of socket and another drive size ratchet or breaker bar. Socket adapters are available and can be used for different drive size sockets on a ratchet. Combinations include:

1/4 in. drive – 3/8 in. sockets
3/8 in. drive – 1/4 in. sockets
3/8 in. drive – 1/2 in. sockets
1/2 in. drive – 3/8 in. sockets

Using a larger drive ratchet or breaker bar on a smaller size socket can cause the application of too much force to the socket, which could crack or shatter. Using a smaller size drive tool on a larger socket will usually not cause any harm, but would greatly reduce the amount of torque that can be applied to the bolt or nut.

Also select the appropriate drive size. For example, for small work, such as on the dash, select a 1/4 in. drive. For most general service work, use a 3/8 in. drive and for suspension and steering and other large fasteners, select a 1/2 in. drive. When loosening a fastener, always pull the ratchet toward you rather than push it outward.

SCREWDRIVERS

- **Straight-blade screwdriver.** Many smaller fasteners are removed and installed using a **screwdriver.** Screwdrivers are available in many sizes and tip shapes. The most commonly used screwdriver is called a *straight blade* or *flat tip.*

  Flat-tip screwdrivers are sized by the width of the blade, and this width should match the width of the slot in the screw. ● **SEE FIGURE 1–29.**

FIGURE 1–30 Two stubby screwdrivers used to access screws that have limited space above. A straight blade is on top and a #2 Phillips screwdriver is on the bottom.

TECH TIP

Avoid Using "Cheater Bars"

Whenever a fastener is difficult to remove, some technicians will insert the handle of a ratchet or a breaker bar into a length of steel pipe sometimes called a **cheater bar.** The extra length of the pipe allows the technician to exert more torque than can be applied using the drive handle alone. However, the extra torque can easily overload the socket and ratchet, causing them to break or shatter, which could cause personal injury.

CAUTION: Do not use a screwdriver as a pry tool or chisel. Screwdrivers use hardened steel only at the tip and are not designed to be pounded on or used for prying because they could bend easily. Always use the proper tool for each application.

- **Phillips screwdriver.** Another type of commonly used screwdriver is the Phillips screwdriver, named for Henry F. Phillips, who invented the crosshead screw in 1934. Due to the shape of the crosshead screw and screwdriver, a Phillips screw can be driven with more torque than can be achieved with a slotted screw.

  A Phillips head screwdriver is specified by the length of the handle and the size of the point at the tip. A #1 tip has a sharp point, a #2 tip is the most commonly used, and a #3 tip is blunt and is only used for larger sizes of Phillips head fasteners. For example, a #2 × 3 in. Phillips screwdriver would typically measure 6 in. from the tip of the blade to the end of the handle (3 in. long handle and 3 in. long blade) with a #2 tip.

  Both straight-blade and Phillips screwdrivers are available with a short blade and handle for access to fasteners with limited room. ● **SEE FIGURE 1–30.**

- **Offset screwdriver.** Offset screwdrivers are used in places where a conventional screwdriver cannot fit. An

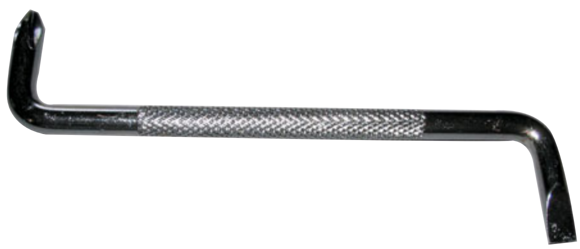


FIGURE 1–31 An offset screwdriver is used to install or remove fasteners that do not have enough space above to use a conventional screwdriver.

FIGURE 1–32 An impact screwdriver used to remove slotted or Phillips head fasteners that cannot be broken loose using a standard screwdriver.

offset screwdriver is bent at the ends and is used similar to a wrench. Most offset screwdrivers have a straight blade at one end and a Phillips head at the opposite end. ● **SEE FIGURE 1–31.**

- **Impact screwdriver.** An *impact screwdriver* is used to break loose or tighten a screw. A hammer is used to strike the end after the screwdriver holder is placed in the head of the screw and rotated in the desired direction. The force from the hammer blow does two things: It applies a force downward holding the tip of the screwdriver in the slot and then applies a twisting force to loosen (or tighten) the screw. ● **SEE FIGURE 1–32.**

SAFE USE OF SCREWDRIVERS Always use the proper type and size screwdriver that matches the fastener. Always make sure that the work is properly secured, because if it slips, the screwdriver tip could penetrate your hand, causing serious personal injury. All screwdrivers should be cleaned after use. Do not use a screwdriver as a pry bar; always use the correct tool for the job.

HAMMERS AND MALLETS **Hammers** and mallets are used to force objects together or apart. The shape of the back part of the hammer head (called the *peen*) usually determines the name. For example, a ball-peen hammer has a rounded end like a ball and is used to straighten oil pans and valve covers, using the hammer head, and to shape metal, using the ball peen. ● **SEE FIGURE 1–33.**

FIGURE 1–33 A typical ball-peen hammer.

FIGURE 1–34 A rubber mallet used to deliver a force to an object without harming the surface.

? FREQUENTLY ASKED QUESTION

What Is a Torx and a Robertson Screwdriver?

TORX—A Torx is a six-pointed star shaped tip that was developed by Camcar (formerly Textron) to offer higher loosening and tightening torque than is possible with a straight (flat tip) or Phillips. Torx is very commonly used in the automotive field for many components.

Robertson—P. L. Robertson invented the Robertson screw and screwdriver in 1908, which uses a square-shaped tip with a slight taper. The Robertson screwdriver uses color-coded handles because different size screws require different tip sizes. Robertson screws are commonly used in Canada and in the recreational vehicle (RV) industry in the United States.

NOTE: A claw hammer has a claw used to remove nails; therefore, it is not for automotive service.

A hammer is usually sized by the weight of the hammer's head and the length of the handle. For example, a commonly used ball-peen hammer has an 8 oz head and 11 in. handle.

- **Mallets.** *Mallets* are a type of hammer with a large striking surface, which allows the technician to exert force over a larger area than a hammer, so as not to harm the part or component. Mallets are made from a variety of materials including rubber, plastic, or wood. ● **SEE FIGURE 1–34.**

FIGURE 1–35 A dead-blow hammer that was left outside in freezing weather. The plastic covering was damaged, which destroyed this hammer. The lead shot is encased in the metal housing and then covered.

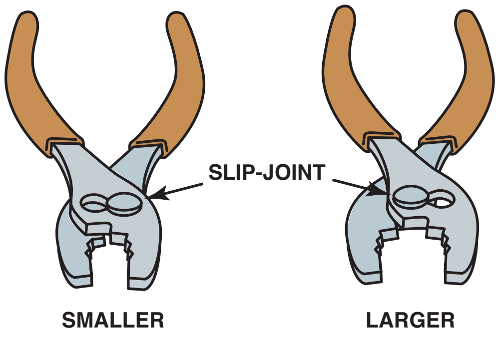


FIGURE 1–36 Typical slip-joint pliers are common household pliers. The slip joint allows the jaws to be opened to two different settings.

- **Dead-blow hammer.** A shot-filled plastic hammer is called a *dead-blow hammer.* The small lead balls (shot) inside a plastic head prevent the hammer from bouncing off of the object when struck. ● **SEE FIGURE 1–35.**

SAFE USE OF HAMMERS AND MALLETS

All mallets and hammers should be cleaned after use and not exposed to extreme temperatures. Never use a hammer or mallet that is damaged in any way and always use caution to avoid doing damage to the components and the surrounding area. Always follow the hammer manufacturer's recommended procedures and practices.

PLIERS

- **Slip-joint pliers. Pliers** are capable of holding, twisting, bending, and cutting objects and are an extremely useful classification of tools. The common household type of pliers is called the *slip-joint pliers.* There are two different positions where the junction of the handles meets to achieve a wide range of sizes of objects that can be gripped. ● **SEE FIGURE 1–36.**

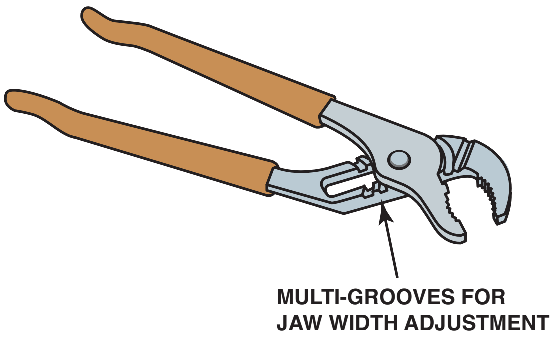


FIGURE 1–37 Multigroove adjustable pliers are known by many names, including the trade name "Channel Locks."

TECH TIP

Pound with Something Softer

If you must pound on something, be sure to use a tool that is softer than what you are about to pound on to avoid damage. Examples are given in the following table.

The Material Being Pounded	What to Pound With
Steel or cast iron	Brass or aluminum hammer or punch
Aluminum	Plastic or rawhide mallet or plastic-covered dead-blow hammer
Plastic	Rawhide mallet or plastic dead-blow hammer

- **Multigroove adjustable pliers.** For gripping larger objects, a set of *multigroove adjustable pliers* is a commonly used tool of choice by many service technicians. Originally designed to remove the various size nuts holding rope seals used in water pumps, the name *water pump pliers* is also used. ● **SEE FIGURE 1–37.**
- **Linesman's pliers.** *Linesman's pliers* are specifically designed for cutting, bending, and twisting wire. While commonly used by construction workers and electricians, linesman's pliers are a very useful tool for the service technician who deals with wiring. The center parts of the jaws are designed to grasp round objects such as pipe or tubing with slipping. ● **SEE FIGURE 1–38.**
- **Diagonal pliers.** *Diagonal pliers* are designed to cut only. The cutting jaws are set at an angle to make it easier to cut wires. Diagonal pliers are also called *side cuts* or *dikes.* These pliers are constructed of hardened steel and they are used mostly for cutting wire. ● **SEE FIGURE 1–39.**
- **Needle-nose pliers.** *Needle-nose pliers* are designed to grip small objects or objects in tight locations.

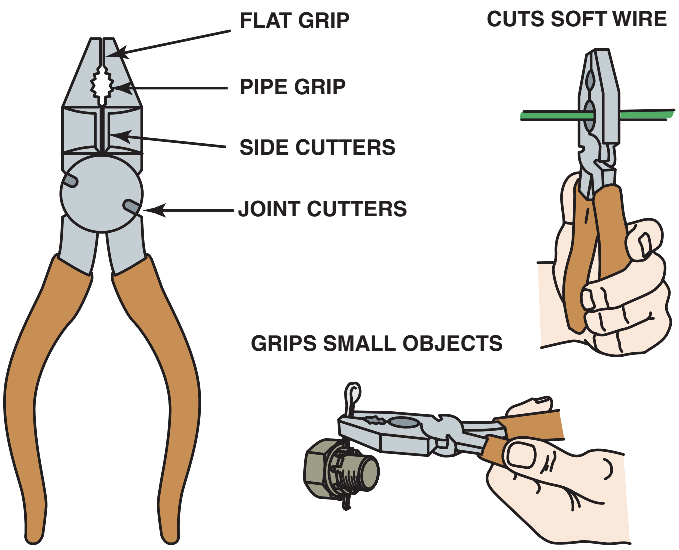


FIGURE 1–38 Linesman's pliers are very useful because they can help perform many automotive service jobs.

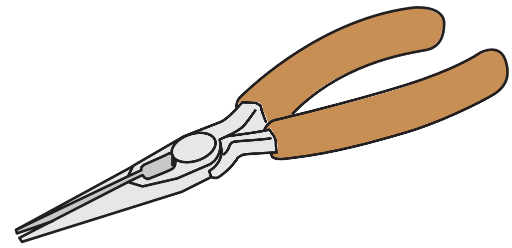


FIGURE 1–40 Needle-nose pliers are used where there is limited access to a wire or pin that needs to be installed or removed.

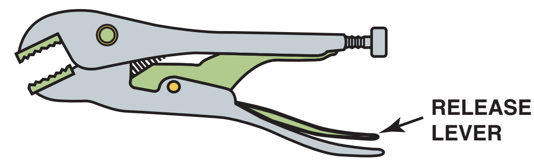


FIGURE 1–41 Locking pliers are best known by the trade name Vise-Grip®.

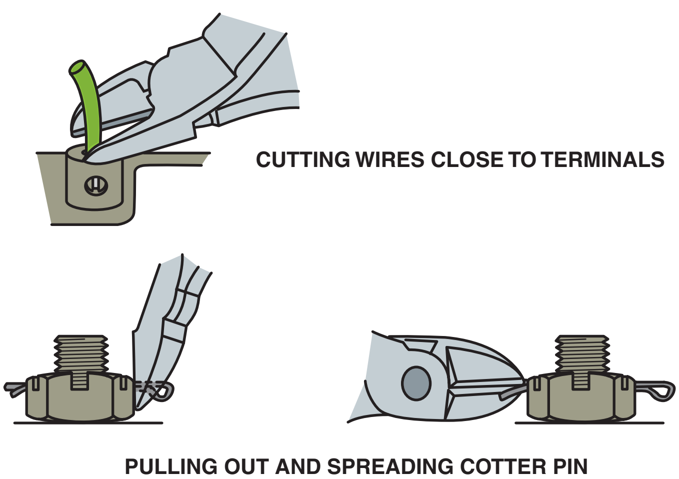


FIGURE 1–39 The diagonal-cut pliers is another common tool that has many names.

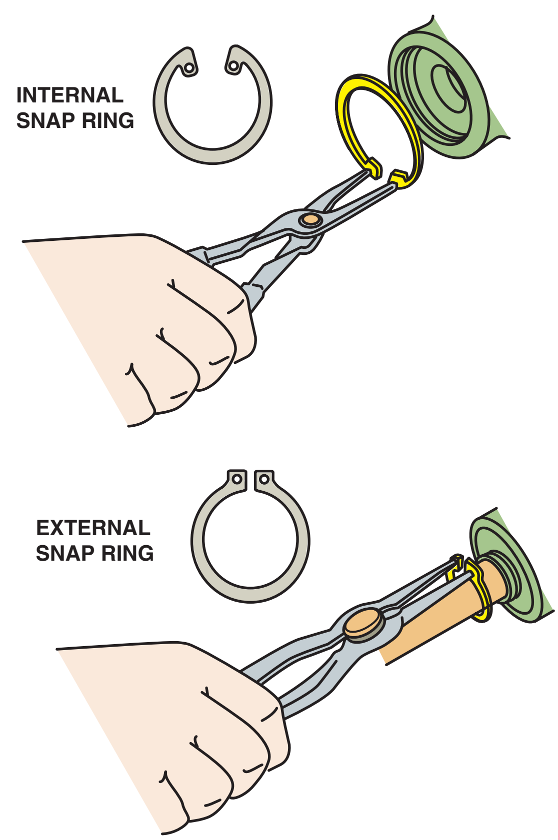


FIGURE 1–42 Snap-ring pliers are also called lock-ring pliers, and most are designed to remove internal and external snap rings (lock rings).

Needle-nose pliers have long, pointed jaws to allow the tips to reach into narrow openings or groups of small objects. ● **SEE FIGURE 1–40.**

Most needle-nose pliers have a wire cutter located at the base of the jaws near the pivot. There are several variations of needle-nose pliers, including right angle jaws or slightly angled jaws to allow access to certain cramped areas.

- **Locking pliers.** *Locking pliers* are adjustable pliers that can be locked to hold objects from moving. Most locking pliers also have wire cutters built into the jaws near the pivot point. Locking pliers come in a variety of styles and sizes and are commonly referred to by the trade name Vise-Grip®. The size is the length of the pliers, not how far the jaws open. ● **SEE FIGURE 1–41.**
- **Snap-ring pliers.** *Snap-ring pliers* are used to remove and install snap rings. Many snap-ring pliers are designed to be able to remove and install both inward and outward expanding snap rings. Snap-ring pliers can be equipped with serrated-tipped jaws for grasping the opening in the snap ring, while others are equipped with points, which are inserted into the holes in the snap ring. ● **SEE FIGURE 1–42.**

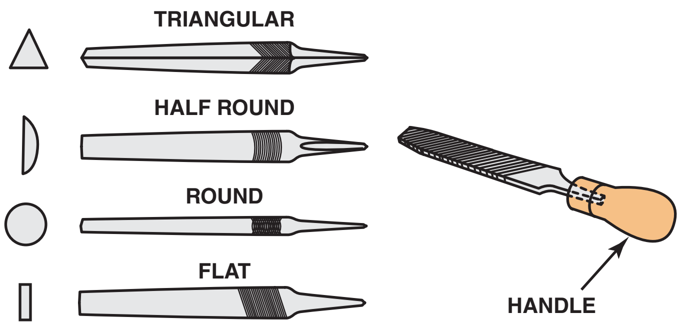


FIGURE 1–43 Files come in many different shapes and sizes. Never use a file without a handle.

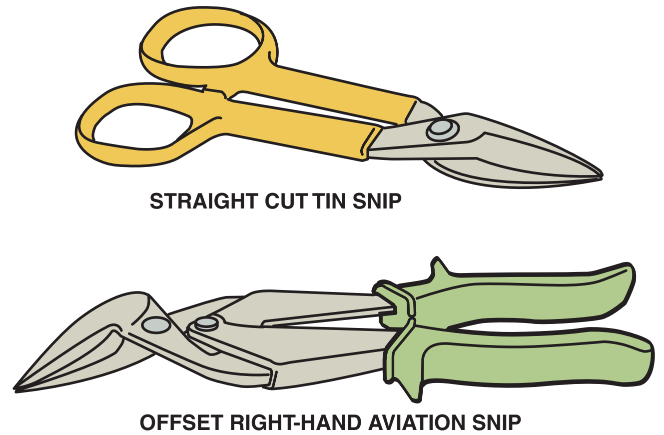


FIGURE 1–44 Tin snips are used to cut thin sheets of metal or carpet.

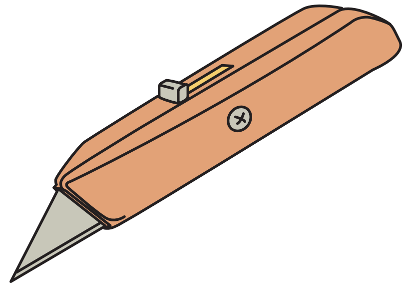


FIGURE 1–45 A utility knife uses replaceable blades and can cut carpet and other materials.

TECH TIP

Brand Name versus Proper Term

Technicians often use slang or brand names of tools rather than the proper term. This results in confusion for new technicians. Some examples are given in the following table.

Brand Name	Proper Term	Slang Name
Crescent wrench	Adjustable wrench	Monkey wrench
Vise-Grip®	Locking pliers	Pump pliers
Channel Locks	Water pump pliers or multigroove adjustable pliers	
	Diagonal cutting pliers	Dikes or side cuts

SAFE USE OF PLIERS Pliers should not be used to remove any bolt or other fastener. Pliers should only be used when specified for use by the vehicle manufacturer.

FILES **Files** are used to smooth metal and are constructed of hardened steel with diagonal rows of teeth. Files are available with a single row of teeth called a *single cut file,* as well as two rows of teeth cut at an opposite angle called a *double cut file.* Files are available in a variety of shapes and sizes including small flat files, half-round files, and triangular files. ● **SEE FIGURE 1–43.**

SAFE USE OF FILES Always use a file with a handle. Because files only cut when moved forward, a handle must be attached to prevent possible personal injury. After making a forward stroke, lift the file and return the file to the starting position; avoid dragging the file backward.

SNIPS Service technicians are often asked to fabricate sheet metal brackets or heat shields and need to use one or more types of cutters available called **snips.** The simplest cutter is called a *tin snips,* designed to make straight cuts in a variety of materials such as sheet steel, aluminum, or even fabric. A variation of the tin snips is called the *aviation tin snips.* There are three designs of aviation snips including one designed to cut straight (called a *straight cut aviation snip*), one designed to cut left (called an *offset left aviation snip*), and one designed to cut right (called an *offset right aviation snip*). The handles are color coded for easy identification. These include yellow for straight, red for left, and green for right. ● **SEE FIGURE 1–44.**

UTILITY KNIFE A *utility knife* uses a replaceable blade and can cut a variety of materials such as carpet, plastic, wood, and paper products such as cardboard. ● **SEE FIGURE 1–45.**

SAFE USE OF CUTTERS Whenever using cutters, always wear eye protection or a face shield to guard against the possibility of metal pieces being ejected during the cut. Always follow recommended procedures.

PUNCHES A **punch** is a small diameter steel rod that has a smaller diameter ground at one end. A punch is used to drive a pin out that is used to retain two components. Punches come

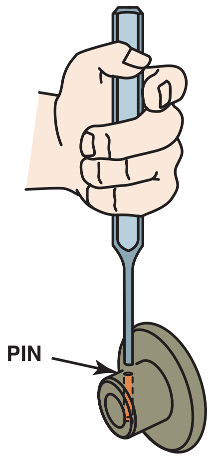


FIGURE 1–46 A punch used to drive pins from assembled components. This type of punch is also called a pin punch.

FIGURE 1–47 Warning stamped in the side of a punch that goggles should be worn when using this tool. Always follow safety warnings.

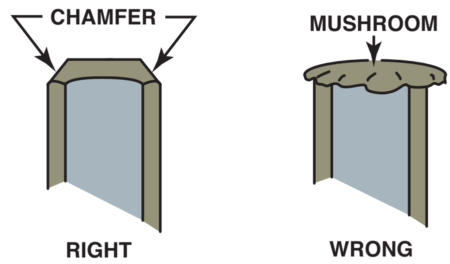


FIGURE 1–48 Use a grinder or a file to remove the mushroom material on the end of a punch or chisel.

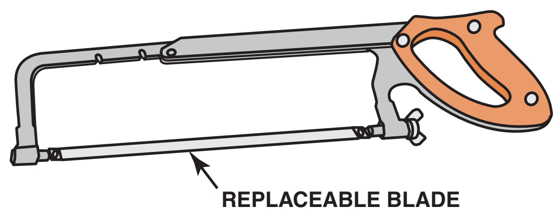


FIGURE 1–49 A typical hacksaw that is used to cut metal. If cutting sheet metal or thin objects, then use a blade with more teeth.

in a variety of sizes, which are measured across the diameter of the machined end. Sizes include 1/16 in., 1/8 in., 3/16 in., and 1/4 in. ● **SEE FIGURE 1–46.**

CHISELS A **chisel** has a straight, sharp cutting end that is used for cutting off rivets or to separate two pieces of an assembly. The most common design of chisel used for automotive service work is called a *cold chisel.*

SAFE USE OF PUNCHES AND CHISELS Always wear eye protection when using a punch or a chisel because the harden steel is brittle and parts of the punch could fly off and cause serious personal injury. See the warning stamped on the side of the automotive punch in ● **FIGURE 1–47.**

The tops of punches and chisels that become rounded off from use are referred to as being "mushroomed." This material must be ground off to help prevent the overhanging material from becoming loosened and airborne during use. ● **SEE FIGURE 1–48.**

HACKSAWS A **hacksaw** is used to cut metals such as steel, aluminum, brass, or copper. The cutting blade of a hacksaw is replaceable and the sharpness and number of teeth can be varied to meet the needs of the job. Use 14 or 18 teeth per inch (TPI) for cutting plaster or soft metals such as aluminum and copper. Use 24 or 32 TPI for steel or pipe. Hacksaw blades should be installed with the teeth pointing away from the handle. This means that a hacksaw only cuts while the blade is pushed in the forward direction. ● **SEE FIGURE 1–49.**

SAFE USE OF HACKSAWS Check that the hacksaw is equipped with the correct blade for the job and that the teeth are pointed away from the handle. When using a hacksaw, move the hacksaw slowly away from you, then lift slightly and return for another cut.

BASIC HAND TOOL LIST

The following is a list of hand tools every automotive technician should possess. Specialty tools are not included.

- Safety glasses
- Tool chest
- 1/4 in. drive socket set (1/4 to 9/16 in. standard and deep sockets; 6 to 15 mm standard and deep sockets)
- 1/4 in. drive ratchet
- 1/4 in. drive, 2 in. extension
- 1/4 in. drive, 6 in. extension
- 1/4 in. drive handle
- 3/8 in. drive socket set (3/8 to 7/8 in. standard and deep sockets; 10 to 19 mm standard and deep sockets)
- 3/8 in. drive Torx set (T40, T45, T50, and T55)
- 3/8 in. drive, 13/16 in. plug socket
- 3/8 in. drive, 5/8 in. plug socket
- 3/8 in. drive ratchet

FIGURE 1–50 A typical beginning technician tool set that includes the basic tools to get started.

FIGURE 1–51 A typical large tool box, showing just one of many drawers.

3/8 in. drive, 1 1/2 in. extension
3/8 in. drive, 3 in. extension
3/8 in. drive, 6 in. extension
3/8 in. drive, 18 in. extension
3/8 in. drive universal
1/2 in. drive socket set (1/2 to 1 in. standard and deep sockets)
1/2 in. drive ratchet
1/2 in. drive breaker bar
1/2 in. drive, 5 in. extension
1/2 in. drive, 10 in. extension
3/8 to 1/4 in. adapter
1/2 to 3/8 in. adapter
3/8 to 1/2 in. adapter
Crowfoot set (fractional inches)
Crowfoot set (metric)
3/8 to 1 in. combination wrench set
10 to 19 mm combination wrench set
1/16 to 1/4 in. hex wrench set
2 to 12 mm hex wrench set
3/8 in. hex socket
13 to 14 mm flare nut wrench
15 to 17 mm flare nut wrench
5/16 to 3/8 in. flare nut wrench
7/16 to 1/2 in. flare nut wrench
1/2 to 9/16 in. flare nut wrench
Diagonal pliers
Needle pliers
Adjustable-jaw pliers
Locking pliers
Snap-ring pliers
Stripping or crimping pliers
Ball-peen hammer
Rubber hammer
Dead-blow hammer
Five-piece standard screwdriver set
Four-piece Phillips screwdriver set
#15 Torx screwdriver
#20 Torx screwdriver
Awl
Mill file
Center punch
Pin punches (assorted sizes)
Chisel
Utility knife
Valve core tool
Filter wrench (large filters)
Filter wrench (smaller filters)
Test light
Feeler gauge
Scraper
Pinch bar
Magnet

TOOL SETS AND ACCESSORIES

A beginning service technician may wish to start with a small set of tools before purchasing an expensive tool set. ● **SEE FIGURES 1–50 AND 1–51.**

FIGURE 1–52 A typical 12 volt test light.

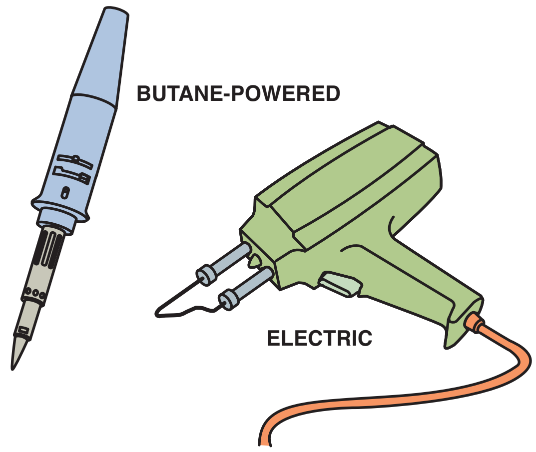


FIGURE 1–53 Electric and butane-powered soldering guns used to make electrical repairs. Soldering guns are sold by the wattage rating: The higher the wattage, the greater the amount of heat created. Most solder guns used for automotive electrical work usually fall within the 60 to 160 watt range.

TECH TIP

Need to Borrow a Tool More Than Twice? Buy It!

Most service technicians agree that it is okay for a beginning technician to borrow a tool occasionally. However, if a tool has to be borrowed more than twice, then be sure to purchase it as soon as possible. Also, whenever you borrow a tool, be sure that you clean the tool and let the technician you borrowed the tool from know that you are returning it. These actions will help in any future dealings with other technicians.

ELECTRICAL WORK HAND TOOLS

TEST LIGHT A test light is used to test for electricity. A typical automotive test light consists of a clear plastic screwdriver-like handle that contains a light bulb. A wire is attached to one terminal of the bulb, which the technician connects to a clean metal part of the vehicle. The other end of the bulb is attached to a point that can be used to test for electricity at a connector or wire. When there is power at the point and a good connection at the other end, the light bulb lights. ● **SEE FIGURE 1–52.**

ELECTRIC SOLDERING GUNS This type of soldering gun is usually powered by 110 volt AC and often has two power settings expressed in watts. A typical electric soldering gun will produce from 85 to 300 watts of heat at the tip, which is more than adequate for soldering.

- **Electric soldering pencil.** This type of soldering iron is less expensive and creates less heat than an electric soldering gun. A typical electric soldering pencil (iron) creates 30 to 60 watts of heat and is suitable for soldering smaller wires and connections.
- **Butane-powered soldering iron.** A butane-powered soldering iron is portable and very useful for automotive service work because an electrical cord is not needed. Most butane-powered soldering irons produce about 60 watts of heat, which is enough for most automotive soldering. ● **SEE FIGURE 1–53.**

ELECTRICAL WORK HAND TOOLS In addition to a soldering iron, most service technicians who do electrical-related work should have the following:

- Wire cutters
- Wire strippers
- Wire crimpers
- Heat gun for heat shrink tubing

DIGITAL METER A digital meter is a necessary tool for electrical diagnosis and troubleshooting. A digital multimeter, abbreviated DMM, is usually capable of measuring the following units of electricity.

- DC volts
- AC volts
- Ohms
- Amperes

HAND TOOL MAINTENANCE

Most hand tools are constructed of rust-resistant metals but they can still rust or corrode if not properly maintained. For best results and long tool life, the following steps should be taken.

- Clean each tool before placing it back into the tool box.
- Keep tools separated. Moisture on metal tools will start to rust more readily if the tools are in contact with another metal tool.

FIGURE 1–54 A fluorescent trouble light operates cooler and is safer to use in the shop because it is protected against accidental breakage where gasoline or other flammable liquids would happen to come in contact with the light.

? FREQUENTLY ASKED QUESTION

What Is an SST?

Vehicle manufacturers often specify a **special service tool (SST)** to properly disassemble and assemble components such as transmissions. These tools are also called special tools and are available from the vehicle manufacturer or its tool supplier, such as Kent-Moore or Miller Tools. Many service technicians do not have access to special service tools so they use generic versions that are available from aftermarket sources.

- Line the drawers of the tool box with a material that will prevent the tools from moving as the drawers are opened and closed. This helps to quickly locate the proper tool and size.
- Release the tension on all clicker-type torque wrenches.
- Keep the tool box secure.

TROUBLE LIGHTS

INCANDESCENT *Incandescent lights* use a filament that produces light when electric current flows through the bulb. This was the standard **trouble light,** also called a *work light,* for many years until safety issues caused most shops to switch to safer fluorescent or LED lights. If incandescent light bulbs are used, try to locate bulbs that are rated "rough service," which is designed to withstand shock and vibration more than conventional light bulbs.

FIGURE 1–55 A typical 1/2 in. drive air impact wrench. The direction of rotation can be changed to loosen or tighten a fastener.

WARNING

Do not use incandescent trouble lights around gasoline or other flammable liquids. The liquids can cause the bulb to break and the hot filament can ignite the flammable liquid, which can cause personal injury or even death.

FLUORESCENT A trouble light is an essential piece of shop equipment, and for safety, should be fluorescent rather than incandescent. Incandescent light bulbs can scatter or break if gasoline were to be splashed onto the bulb, creating a serious fire hazard. Fluorescent light tubes are not as likely to be broken and are usually protected by a clear plastic enclosure. Trouble lights are usually attached to a retractor, which can hold 20 to 50 feet of electrical cord. ● **SEE FIGURE 1–54.**

LED TROUBLE LIGHT **Light-emitting diode (LED)** trouble lights are excellent to use because they are shock resistant, long lasting, and do not represent a fire hazard. Some trouble lights are battery powered and therefore can be used in places where an attached electrical cord could present problems.

AIR AND ELECTRICALLY OPERATED TOOLS

IMPACT WRENCH An impact wrench, either air or electrically powered, is used to remove and install fasteners. The air-operated 1/2 in. drive impact wrench is the most commonly used unit. ● **SEE FIGURE 1–55.**

FIGURE 1–56 A typical battery-powered 3/8 in. drive impact wrench.

FIGURE 1–58 An air ratchet is a very useful tool that allows fast removal and installation of fasteners, especially in areas that are difficult to reach or do not have room enough to move a hand ratchet or wrench.

FIGURE 1–57 A black impact socket. Always use an impact-type socket whenever using an impact wrench to avoid the possibility of shattering the socket, which could cause personal injury.

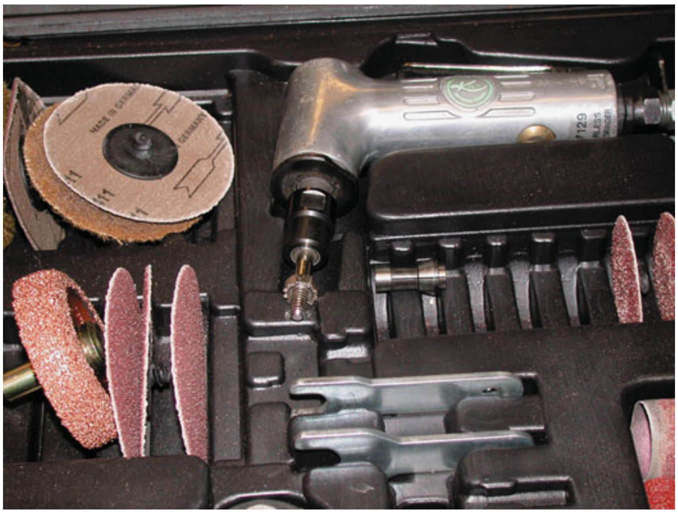


FIGURE 1–59 This typical die grinder surface preparation kit includes the air-operated die grinder and a variety of sanding disks for smoothing surfaces or removing rust.

Electrically powered impact wrenches commonly include:

- Battery-powered units. ● **SEE FIGURE 1–56.**
- 110 volt AC-powered units. This type of impact is very useful, especially if compressed air is not readily available.

WARNING

Always use impact sockets with impact wrenches, and always wear eye protection in case the socket or fastener shatters. Input sockets are thicker walled and constructed with premium alloy steel. They are hardened with a black oxide finish to help prevent corrosion and distinguish them from regular sockets. ● **SEE FIGURE 1–57.**

AIR RATCHET An air ratchet is used to remove and install fasteners that would normally be removed or installed using a ratchet and a socket. ● **SEE FIGURE 1–58.**

DIE GRINDER A die grinder is a commonly used air-powered tool which can also be used to sand or remove gaskets and rust. ● **SEE FIGURE 1–59.**

BENCH-MOUNTED OR PEDESTAL-MOUNTED GRINDER

These high-powered grinders can be equipped with a wire brush wheel and/or a stone wheel.

- **Wire brush wheel.** This type is used to clean steel or sheet metal parts.
- **Stone wheel.** This type is used to grind metal and to remove the mushroom from the top of punches or chisels. ● **SEE FIGURE 1–60.**

FIGURE 1–60 A typical pedestal grinder with a wire wheel on the left side and a stone wheel on the right side. Even though this machine is equipped with guards, safety glasses or a face shield should always be worn whenever using a grinder or wire wheel.

WARNING

Always wear a face shield when using a wire wheel or a grinder.

Most **bench grinders** are equipped with a grinder wheel (stone) on one end or the other of a wire brush. A bench grinder is a useful piece of shop equipment, and the wire wheel end can be used for the following:

- Cleaning threads of bolts
- Cleaning gaskets from sheet metal parts, such as steel valve covers

CAUTION: Only use a steel wire brush on steel or iron components. If a steel wire brush is used on aluminum or copper-based metal parts, it can remove metal from the part.

The grinding stone end of the bench grinder can be used for the following:

- Sharpening blades and drill bits
- Grinding off the heads of rivets or parts
- Sharpening sheet metal parts for custom fitting

PERSONAL PROTECTIVE EQUIPMENT

Service technicians should wear protective devices to prevent personal injury. **Personal protective equipment (PPE)** includes the following:

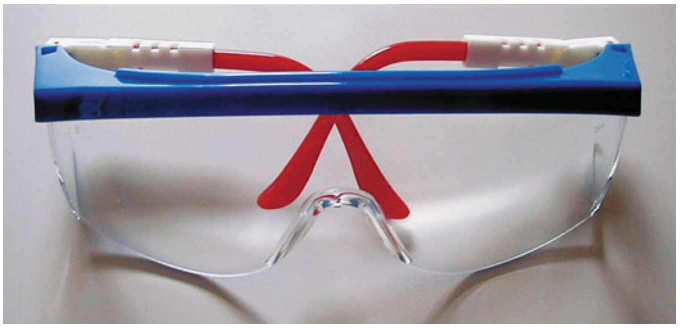


FIGURE 1–61 Safety glasses should be worn at all times when working on or around any vehicle or servicing any components.

FIGURE 1–62 Steel-toed shoes are a worthwhile investment to help prevent foot injury due to falling objects. Even these well-worn shoes can protect the feet of this service technician.

SAFETY GLASSES Be sure that safety glasses meet standard ANSI Z87.1. They should be worn at all times while servicing any vehicle. ● **SEE FIGURE 1–61.**

STEEL-TOED SAFETY SHOES Steel-toed safety shoes help prevent foot injury due to falling objects. ● **SEE FIGURE 1–62.** If safety shoes are not available, then leather-topped shoes offer more protection than canvas or cloth.

BUMP CAP Service technicians working under a vehicle should wear a **bump cap** to protect the head against under-vehicle objects and pads of the lift. ● **SEE FIGURE 1–63.**

HEARING PROTECTION Hearing protection should be worn if the sound around you requires that you raise your voice (sound level higher than 90 dB). For example, a typical lawnmower produces noise at a level of about 110 dB. This means that everyone who uses a lawnmower or other lawn or garden equipment should wear ear protection.

GLOVES Many technicians wear gloves not only to help keep their hands clean but also to help protect their skin from the effects of dirty engine oil and other possibly hazardous materials.

FIGURE 1–63 One version of a bump cap is a molded plastic insert worn inside a regular cloth cap.

FIGURE 1–64 Protective gloves are available in several sizes and materials.

Several types of gloves and their characteristics are as follows:

- **Latex surgical gloves.** These gloves are relatively inexpensive, but tend to stretch, swell, and weaken when exposed to gas, oil, or solvents.
- **Vinyl gloves.** These gloves are also inexpensive and are not affected by gas, oil, or solvents.
- **Polyurethane gloves.** These gloves are more expensive, yet strong. Even though these gloves are also not affected by gas, oil, or solvents, they tend to be slippery.
- **Nitrile gloves.** These gloves are exactly like latex gloves, but are not affected by gas, oil, or solvents, yet they tend to be expensive.
- **Mechanic's gloves.** These gloves are usually made of synthetic leather and spandex and provide thermo protection, as well as protection from dirt and grime.

● **SEE FIGURE 1–64.**

FIGURE 1–65 Remove all jewelry before performing service work on any vehicle.

SAFETY PRECAUTIONS

Besides wearing personal safety equipment, the following actions should be performed to keep safe in the shop.

- Remove jewelry that may get caught on something or act as a conductor to an exposed electrical circuit. ● **SEE FIGURE 1–65.**
- Take care of your hands. Keep your hands clean by washing with soap and hot water that is at least 110°F (43°C).
- Tie back long hair to keep from getting it caught in moving components.
- Avoid loose or dangling clothing.
- When lifting any object, get a secure grip with solid footing. Keep the load close to your body to minimize the strain. Lift with your legs and arms, not your back.
- Do not twist your body when carrying a load. Instead, pivot your feet to help prevent strain on the spine.
- Ask for help when moving or lifting heavy objects.
- Push a heavy object rather than pull it. (This is opposite to the way you should work with tools—never push a wrench! If you do and a bolt or nut loosens, your entire weight is used to propel your hand(s) forward. This usually results in cuts, bruises, or other painful injury.)
- Always connect an exhaust hose to the tailpipe of any running vehicle to help prevent the buildup of carbon monoxide inside a closed garage space. ● **SEE FIGURE 1–66.**
- When standing, keep your objects, parts, and tools between chest height and waist height. If seated, work at tasks that are at elbow height.
- Always be sure the hood is securely held open.

FIGURE 1–66 Always connect an exhaust hose to the tailpipe of a vehicle to be run inside a building.

FIGURE 1–67 A binder clip keeps a fender cover from falling off.

VEHICLE PROTECTION

FENDER COVERS Whenever working under the hood of any vehicle be sure to use fender covers. They not only help protect the vehicle from possible damage but also provide a clean surface to place parts and tools. The major problem with using fender covers is that they tend to move and often fall off the vehicle. To help prevent the fender covers from falling off, secure them to a lip of the fender using a *binder clip* available at most office supply stores. ● **SEE FIGURE 1–67.**

INTERIOR PROTECTION Always protect the interior of the vehicle from accidental damage or dirt and grease by covering the seat, steering wheel, and floor with a protective covering. ● **SEE FIGURE 1–68.**

FIGURE 1–68 Covering the interior as soon as the vehicle comes in for service helps improve customer satisfaction.

SAFETY TIP

Shop Cloth Disposal

Always dispose of oily shop cloths in an enclosed container to prevent a fire. ● **SEE FIGURE 1–69.** Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur, which can ignite the cloth even without an open flame. This process of ignition without an open flame is called **spontaneous combustion.**

SAFETY IN LIFTING (HOISTING) A VEHICLE

Many chassis and underbody service procedures require that the vehicle be hoisted or lifted off the ground. The simplest methods involve the use of drive-on ramps or a floor jack and safety (jack) stands, whereas in-ground or surface-mounted lifts provide greater access.

Setting the lifting pads is a critical part of this hoisting procedure. Owner's, shop, and service manuals include recommended locations to be used when hoisting (lifting) a vehicle.

FIGURE 1–69 All oily shop cloths should be stored in a metal container equipped with a lid to help prevent spontaneous combustion.

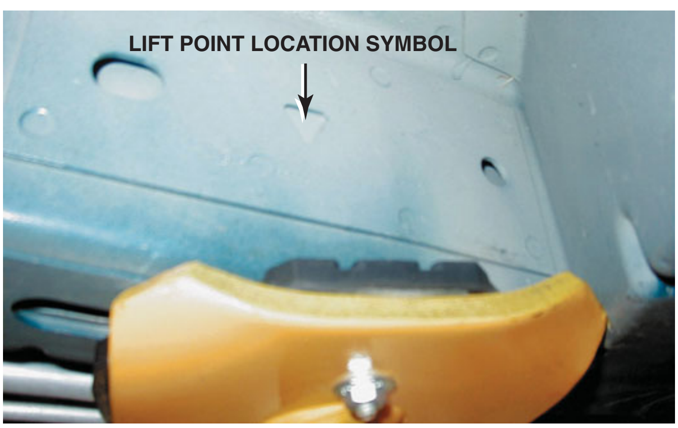
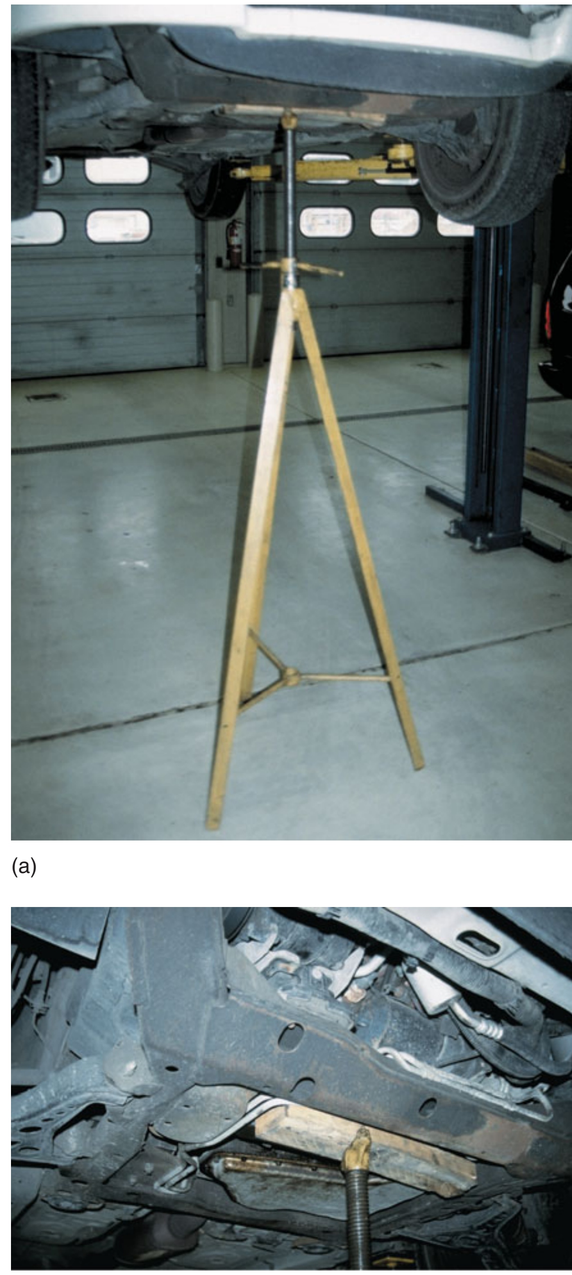


FIGURE 1–70 Most newer vehicles have a triangle symbol indicating the recommended hoisting lift location.

Newer vehicles have a decal on the driver's door indicating the recommended lift points. The recommended standards for the lift points and lifting procedures are found in SAE standard JRP- 2184. ● **SEE FIGURE 1–70.**

These recommendations typically include the following points:

1. The vehicle should be centered on the lift or hoist so as not to overload one side or put too much force either forward or rearward. ● **SEE FIGURE 1–71.**
2. The pads of the lift should be spread as far apart as possible to provide a stable platform.
3. Each pad should be placed under a portion of the vehicle that is strong and capable of supporting the weight of the vehicle.
   a. Pinch welds at the bottom edge of the body are generally considered to be strong.



(a)

(b)

FIGURE 1–71 (a) Tall safety stands can be used to provide additional support for the vehicle while on the hoist. (b) A block of wood should be used to avoid the possibility of doing damage to components supported by the stand.

CAUTION: Even though pinch weld seams are the recommended location for hoisting many vehicles with unitized bodies (unit-body), care should be taken not to place the pad(s) too far forward or rearward. Incorrect placement of the vehicle on the lift could cause the vehicle to be imbalanced, and the vehicle could fall. This is exactly what happened to the vehicle in ● FIGURE 1–72.

   b. Boxed areas of the body are the best places to position the pads on a vehicle without a frame. Be careful

FIGURE 1–72 This training vehicle fell from the hoist because the pads were not set correctly. No one was hurt, but the vehicle was damaged.

to note whether the arms of the lift might come into contact with other parts of the vehicle before the pad touches the intended location. Commonly damaged areas include the following:

(1) Rocker panel moldings

(2) Exhaust system (including catalytic converter)

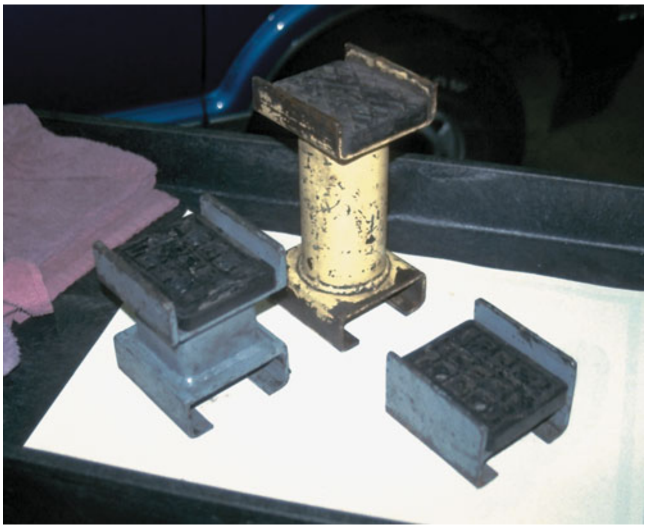
(3) Tires or body panels (● **SEE FIGURES 1–73 AND 1–74.**)

4. As soon as the pads touch the vehicle, check for proper pad placement. The vehicle should be raised about 1 foot (30 centimeters [cm]) off the floor, then stopped and shaken to check for stability. If the vehicle seems to be stable when checked at a short distance from the floor, continue raising the vehicle and continue to view the vehicle until it has reached the desired height. The hoist should be lowered onto the mechanical locks, and then raised off of the locks before lowering.

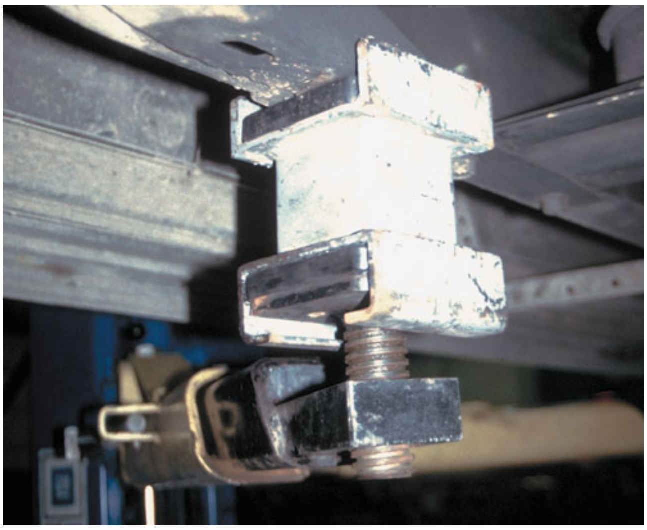
CAUTION: Do not look away from the vehicle while it is being raised (or lowered) on a hoist. Often one side or one end of the hoist can stop or fail, resulting in the vehicle being slanted enough to slip or fall, creating physical damage not only to the vehicle and/or hoist but also to the technician or others who may be nearby.

HINT: Most hoists allow the vehicle to be safely placed at any desired height. For ease while working, the area where you are working should be at chest level. When working on brakes or suspension components, it is not necessary to work on them down near the floor or over your head. Raise the hoist so that the components are at chest level.

5. Before lowering the hoist, you must release the safety latch(es) and reverse the direction of the controls. The speed downward is often adjusted to be as slow as possible for additional safety.



(a)



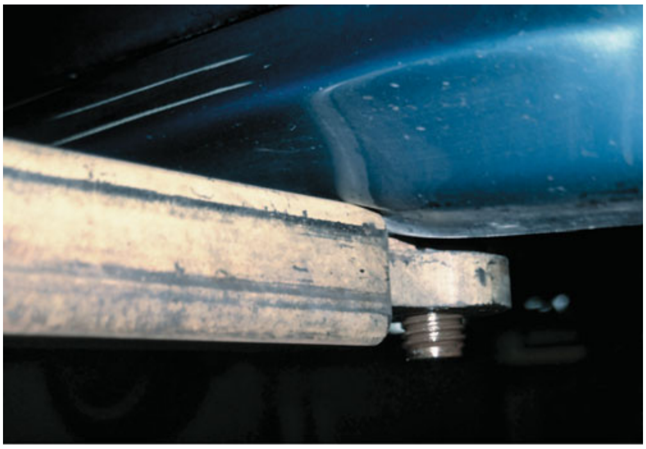
(b)

FIGURE 1–73 (a) An assortment of hoist pad adaptors that are often needed to safely hoist many pickup trucks, vans, and sport utility vehicles (SUVs). (b) A view from underneath a Chevrolet pickup truck showing how the pad extensions are used to attach the hoist lifting pad to contact the frame.

FLOOR JACKS

DESCRIPTION Floor jacks are used to lift one side or end of a vehicle. They are portable and relatively inexpensive and must be used with safety (jack) stands.

OPERATING PRINCIPLES A floor jack uses an hydraulic cylinder to raise a vehicle. ● **SEE FIGURE 1–75.**



(a)

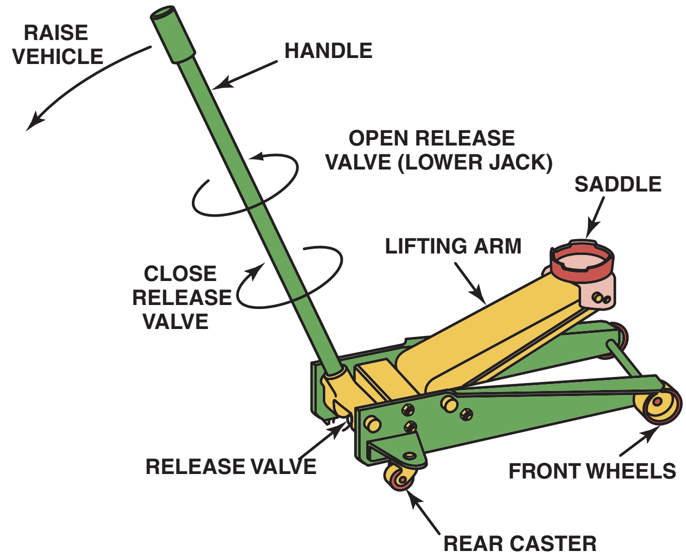
(b)

FIGURE 1–74 (a) The pad arm is just contacting the rocker panel of the vehicle. (b) The pad arm has dented the rocker panel on this vehicle because the pad was set too far inward underneath the vehicle.

A jack operates as follows:

- When the jack handle is twisted clockwise, the release valve is closed.
- When the jack handle is moved upward, hydraulic oil is drawn from the reservoir into the pump assembly.
- When the jack handle is moved downward, the oil is forced into the hydraulic cylinder, which forces the ram out and the lifting pad upward.
- When the cylinder ram reaches its maximum height, a bypass valve opens, which directs the oil back into the reservoir.
- When the jack handle is twisted counterclockwise, the release valve opens and allows the oil to flow back into the reservoir.

CAUTION: The valve must be closed to allow the jack lifting arm to remain in the upright position. If the release valve is opened, the jack lifting arm will drop toward the floor.



(a)

(b)

FIGURE 1–75 (a) A typical 3 ton (6,000 lb) capacity hydraulic jack. (b) Whenever a vehicle is raised off the ground, a safety stand should be placed under the frame, axle, or body to support the weight of the vehicle.

SAFE USE OF A FLOOR JACK

To safely use a floor jack, perform the following steps.

STEP 1 Read, understand, and follow all operating and safety items listed in the instructions.

STEP 2 Be sure the vehicle is on a flat, level, and hard surface.

STEP 3 Chock (block) the wheels of the vehicle to prevent it from moving during the lifting operation.

STEP 4 Check vehicle service information to determine the specified lifting point under the vehicle.

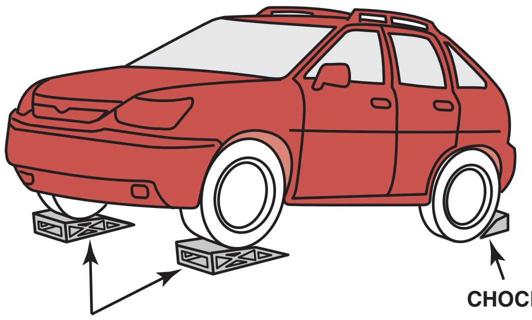


FIGURE 1–76 Drive-on ramps are dangerous to use. The wheels on the ground level must be chocked (blocked) to prevent accidental movement down the ramp.

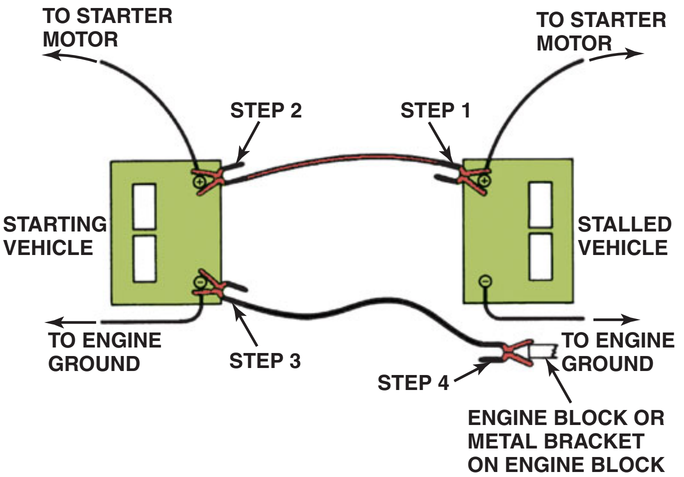


FIGURE 1–77 Jumper cable usage guide. Follow the same connections if using a portable jump box.

STEP 5 Place the lifting pad of the jack under the specified lifting point.

STEP 6 Close the release valve of the jack by rotating the jack handle clockwise. Move the jack handle up and down until the lifting pad contacts the vehicle lifting point. Double check that the jack is located in the specified location.

STEP 7 Continue to move the jack handle downward, and then up and down again until the vehicle has been raised to the desired height.

STEP 8 Place safety (jack) stand(s) under the vehicle.

STEP 9 To lower the vehicle, raise the vehicle just enough to remove the safety stands, and then rotate the jack handle *slowly* counterclockwise.

DRIVE-ON RAMPS Ramps are an inexpensive way to raise the front or rear of a vehicle. ● **SEE FIGURE 1–76.** Ramps are easy to store, but may be dangerous because they can "kick out" when driving the vehicle onto the ramps.

CAUTION: Professional repair shops do not use ramps because they are dangerous. Use only with extreme care.

ELECTRICAL CORD SAFETY

Use correctly grounded three-prong sockets and extension cords to operate power tools. Some tools use only two-prong plugs. Make sure these are double insulated and repair or replace any electrical cords that are cut or damaged to prevent the possibility of an electrical shock. When not in use, keep electrical cords off the floor to prevent tripping over them. Tape the cords down if they are placed in high foot traffic areas.

JUMP STARTING AND BATTERY SAFETY

To jump start another vehicle with a dead battery, connect either good quality copper jumper cables as indicated in ● **FIGURE 1–77** or a jump box. The last connection made should always be on the engine block or an engine bracket on the dead vehicle as far from the battery as possible. It is normal for a spark to be created when the jumper cables finally complete the jumping circuit, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground connections built away from the battery just for the purpose of jump starting. Check the owner's manual or service information for the exact location.

Batteries contain acid and should be handled with care to avoid tipping them greater than a 45-degree angle. Always remove jewelry when working around a battery to avoid the possibility of electrical shock or burns, which can occur when the metal comes in contact with a 12 volt circuit and ground, such as the body of the vehicle.

SAFETY TIP

Air Hose Safety

Improper use of an air nozzle can cause blindness or deafness. Compressed air must be reduced to less than 30 psi (206 kPa). ● **SEE FIGURE 1–78.** If an air nozzle is used to dry and clean parts, make sure the air stream is directed away from anyone else in the immediate area. Always use an OSHA-approved nozzle with side slits that limit the maximum pressure at the nozzle to 30 PSI. Coil and store air hoses when they are not in use.

FIGURE 1–78 The air pressure going to the nozzle should be reduced to 30 PSI or less to help prevent personal injury.

FIGURE 1–79 A typical fire extinguisher designed to be used on type A, B, or C fires.

FIRE EXTINGUISHERS

There are four **fire extinguisher classes.** Each class should be used on specific fires only, as follows:

- **Class A** is designed for use on general combustibles, such as cloth, paper, and wood.
- **Class B** is designed for use on flammable liquids and greases, including gasoline, oil, thinners, and solvents.
- **Class C** is used only on electrical fires.
- **Class D** is effective only on combustible metals such as powdered aluminum, sodium, or magnesium.

The class rating is clearly marked on the side of every fire extinguisher. Many extinguishers are good for multiple types of fires. ● **SEE FIGURE 1–79.**

When using a fire extinguisher, remember the word “PASS.”

P = Pull the safety pin.

A = Aim the nozzle of the extinguisher at the base of the fire.

S = Squeeze the lever to actuate the extinguisher.

S = Sweep the nozzle from side to side.

● **SEE FIGURE 1–80.**

FIGURE 1–80 A CO_2 fire extinguisher being used on a fire set in an open drum during a demonstration at a fire training center.

TYPES OF FIRE EXTINGUISHERS Types of fire extinguishers include the following:

- **Water.** A water fire extinguisher, usually in a pressurized container, is good to use on Class A fires by reducing the temperature to the point where a fire cannot be sustained.
- **Carbon dioxide (CO_2).** A carbon dioxide fire extinguisher is good for almost any type of fire, especially Class B or Class C materials. A CO_2 fire extinguisher works by removing the oxygen from the fire and the cold CO_2 also helps reduce the temperature of the fire.
- **Dry chemical (yellow).** A dry chemical fire extinguisher is good for Class A, B, or C fires by coating the flammable materials, which eliminates the oxygen from the fire. A dry chemical fire extinguisher tends to be very corrosive and will cause damage to electronic devices.

FIRE BLANKETS

Fire blankets are required to be available in the shop areas. If a person is on fire, a fire blanket should be removed from its storage bag and thrown over and around the victim to smother the fire. ● **SEE FIGURE 1–81** showing a typical fire blanket.

FIGURE 1–81 A treated wool blanket is kept in an easy-to-open, wall-mounted holder and should be placed in a central location in the shop.

FIGURE 1–82 A first aid box should be centrally located in the shop and kept stocked with the recommended supplies.

FIRST AID AND EYE WASH STATIONS

All shop areas must be equipped with a first aid kit and an eye wash station that are centrally located and kept stocked with emergency supplies. ● **SEE FIGURE 1–82.**

FIRST AID KIT A first aid kit should include:

- Bandages (variety)
- Gauze pads
- Roll gauze
- Iodine swab sticks
- Antibiotic ointment
- Hydrocortisone cream
- Burn gel packets
- Eye wash solution
- Scissors
- Tweezers
- Gloves
- First aid guide

Every shop should have a person trained in first aid. If there is an accident, call for help immediately.

EYE WASH STATION An **eye wash station** should be centrally located and used whenever any liquid or chemical gets into the eyes. If such an emergency does occur, keep eyes in a constant stream of water and call for professional assistance. ● **SEE FIGURE 1–83.**

FIGURE 1–83 A typical eye wash station. Often a thorough flushing of the eyes with water is the first and often the best treatment in the event of eye contamination.

FIGURE 1–84 A warning label on a Honda hybrid warns that a person can be killed due to the high-voltage circuits under the cover.

FIGURE 1–85 The high-voltage disconnect switch is in the trunk area on a Toyota Prius. High-voltage lineman's gloves should be worn when removing this plug. (*Courtesy of Tony Martin*)

SAFETY TIP

Infection Control Precautions

Working on a vehicle can result in personal injury including the possibility of being cut or hurt enough to cause bleeding. Some infections such as hepatitis B, HIV (which can cause acquired immunodeficiency syndrome, or AIDS), hepatitis C virus, and others are transmitted in the blood. These infections are commonly called blood-borne pathogens. Report any injury that involves blood to your supervisor and take the necessary precautions to avoid coming in contact with blood from another person.

WARNING

Some vehicle manufacturers specify that rubber-insulated *lineman's gloves* be used whenever working around the high-voltage circuits to prevent the danger of electrical shock.

HYBRID ELECTRIC VEHICLE SAFETY ISSUES

Hybrid electric vehicles (HEVs) use a high-voltage (HV) battery pack and electric motor(s) to help propel the vehicle. ● **SEE FIGURE 1–84** for an example of a typical warning label on a hybrid electric vehicle. The gasoline or diesel engine also is equipped with a generator or a combination starter and an integrated starter generator (ISG) or integrated starter alternator (ISA). To safely work around a hybrid electric vehicle, the high-voltage battery and circuits should be shut off following these steps:

STEP 1 Turn off the ignition key (if equipped) and remove the key from the ignition switch. (This will shut off all high-voltage circuits if the relay[s] is [are] working correctly.)

STEP 2 Disconnect the high-voltage circuits.

TOYOTA PRIUS The cutoff switch is located in the trunk on the Toyota Prius. To gain access, remove three clips holding the upper left portion of the trunk side cover. To disconnect the high-voltage system, pull the orange handled plug while wearing insulated rubber lineman's gloves. ● **SEE FIGURE 1–85.**

FORD ESCAPE AND MERCURY MARINER Ford and Mercury specify that the following steps should be included when working with the high-voltage (HV) systems of a hybrid vehicle:

- Four orange cones are to be placed at the four corners of the vehicle to create a buffer zone.
- High-voltage insulated gloves are to be worn with an outer leather glove to protect the inner rubber glove from possible damage.
- The service technician should also wear a face shield, and a fiberglass hook should be in the area and used to move a technician in the event of electrocution.

The high-voltage shut-off switch is located in the rear of the vehicle under the right side carpet. ● **SEE FIGURE 1–86.** Rotate the handle to the "service shipping" position, lift it out to disable the high-voltage circuit, and wait five minutes before removing high-voltage cables.

FIGURE 1–86 The high-voltage shut-off switch on a Ford Escape hybrid. The switch is located under the carpet at the rear of the vehicle.

FIGURE 1–87 The shut-off switch on a GM parallel hybrid truck is green because this system uses 42 volts instead of higher, and possible fatal, voltages used in other hybrid vehicles.

HONDA CIVIC To totally disable the high-voltage system on a Honda Civic, remove the main fuse (labeled number 1) from the driver's side underhood fuse panel. This should be all that is necessary to shut off the high-voltage circuit. If this is not possible, then remove the rear seat cushion and seat back. Remove the metal switch cover labeled "up" and remove the red locking cover. Move the "battery module switch" down to disable the high-voltage system.

CHEVROLET SILVERADO AND GMC SIERRA PICKUP TRUCK The high-voltage shut-off switch is located under the rear passenger seat on these Chevrolet and GMC vehicles. Remove the cover marked "energy storage box" and turn the green service disconnect switch to the horizontal position to turn off the high-voltage circuits. ● **SEE FIGURE 1–87.**

WARNING

Do not touch any orange wiring or component without following the vehicle manufacturer's procedures and wearing the specified personal protective equipment.

HOISTING THE VEHICLE

1 The first step in hoisting a vehicle is to properly align the vehicle in the center of the stall.

2 Most vehicles will be correctly positioned when the left front tire is centered on the tire pad.

3 The arms can be moved in and out and most pads can be rotated to allow for many different types of vehicle construction.

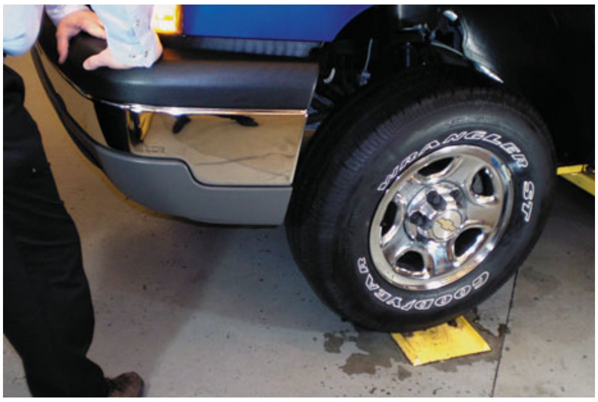
4 Most lifts are equipped with short pad extensions that are often necessary to use to allow the pad to contact the frame of a vehicle without causing the arm of the lift to hit and damage parts of the body.

5 Tall pad extensions can also be used to gain access to the frame of a vehicle. This position is needed to safely hoist many pickup trucks, vans, and sport utility vehicles.

6 An additional extension may be necessary to hoist a truck or van equipped with running boards to give the necessary clearance.

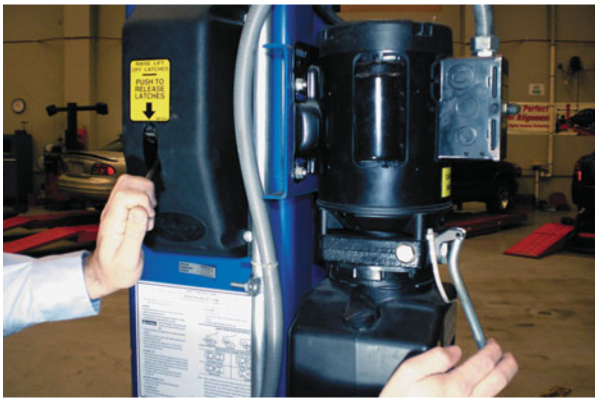
7 Position the pads under the vehicle at the recommended locations.

8 After being sure all pads are correctly positioned, use the electromechanical controls to raise the vehicle.



9 With the vehicle raised one foot (30 cm) off the ground, push down on the vehicle to check to see if it is stable on the pads. If the vehicle rocks, lower the vehicle and reset the pads. The vehicle can be raised to any desired working level. Be sure the safety is engaged before working on or under the vehicle.

10 If raising a vehicle without a frame, place the flat pads under the pinch weld seam to spread the load. If additional clearance is necessary, the pads can be raised as shown.



11 When the service work is completed, the hoist should be raised slightly and the safety released before using the hydraulic lever to lower the vehicle.

12 After lowering the vehicle, be sure all arms of the lift are moved out of the way before driving the vehicle out of the work stall.

SUMMARY

1. Bolts, studs, and nuts are commonly used as fasteners in the chassis. The sizes for fractional and metric threads are different and are not interchangeable. The grade is the rating of the strength of a fastener.
2. Whenever a vehicle is raised above the ground, it must be supported at a substantial section of the body or frame.
3. Wrenches are available in open end, box end, and combination open and box end.
4. An adjustable wrench should only be used where the proper size is not available.
5. Line wrenches are also called flare-nut wrenches, fitting wrenches, or tube-nut wrenches and are used to remove fuel or refrigerant lines.
6. Sockets are rotated by a ratchet or breaker bar, also called a flex handle.
7. Torque wrenches measure the amount of torque applied to a fastener.
8. Screwdriver types include straight blade (flat tip), Phillips, and Torx.
9. Hammers and mallets come in a variety of sizes and weights.
10. Pliers are a useful tool and are available in many different types, including slip-joint, multigroove, linesman's, diagonal, needle-nose, and locking pliers.
11. Other common hand tools include snap-ring pliers, files, cutters, punches, chisels, and hacksaws.
12. Hybrid electric vehicles should be de-powered if any of the high-voltage components are going to be serviced.

REVIEW QUESTIONS

1. List three precautions that must be taken whenever hoisting (lifting) a vehicle.
2. Describe how to determine the grade of a fastener, including how the markings differ between fractional and metric bolts.
3. List four items that are personal protective equipment (PPE).
4. List the types of fire extinguishers and their usage.
5. Why are wrenches offset 15 degrees?
6. What are the other names for a line wrench?
7. What are the standard automotive drive sizes for sockets?
8. Which type of screwdriver requires the use of a hammer or mallet?
9. What is inside a dead-blow hammer?
10. What type of cutter is available in left and right cutters?

CHAPTER QUIZ

1. The correct location for the pads when hoisting or jacking the vehicle can often be found in the ________.
   - **a.** Service manual
   - **b.** Shop manual
   - **c.** Owner's manual
   - **d.** All of the above
2. For the best working position, the work should be ________.
   - **a.** At neck or head level
   - **b.** At knee or ankle level
   - **c.** Overhead by about 1 foot
   - **d.** At chest or elbow level
3. A high-strength bolt is identified by ________.
   - **a.** A UNC symbol
   - **b.** Lines on the head
   - **c.** Strength letter codes
   - **d.** The coarse threads
4. A fastener that uses threads on both ends is called a ________.
   - **a.** Cap screw
   - **b.** Stud
   - **c.** Machine screw
   - **d.** Crest fastener
5. When working with hand tools, always ________.
   - **a.** Push the wrench—don't pull it toward you
   - **b.** Pull a wrench—don't push it away from you
6. The proper term for Channel Locks is ________.
   - **a.** Vise-Grip
   - **b.** Crescent wrench
   - **c.** Locking pliers
   - **d.** Multigroove adjustable pliers
7. The proper term for Vise-Grip is ________.
   - **a.** Locking pliers
   - **b.** Slip-joint pliers
   - **c.** Side cuts
   - **d.** Multigroove adjustable pliers
8. Two technicians are discussing torque wrenches. Technician A says that a torque wrench is capable of tightening a fastener with more torque than a conventional breaker bar or ratchet. Technician B says that a torque wrench should be calibrated regularly for the most accurate results. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. What type of screwdriver should be used if there is very limited space above the head of the fastener?
   - **a.** Offset screwdriver
   - **b.** Standard screwdriver
   - **c.** Impact screwdriver
   - **d.** Robertson screwdriver
10. What type of hammer is plastic coated, has a metal casing inside, and is filled with small lead balls?
    - **a.** Dead-blow hammer
    - **b.** Soft-blow hammer
    - **c.** Sledge hammer
    - **d.** Plastic hammer

chapter 2

ENVIRONMENTAL AND HAZARDOUS MATERIALS

OBJECTIVES: After studying Chapter 2, the reader will be able to: • Prepare for the ASE assumed knowledge content required by all service technicians to adhere to environmentally appropriate actions and behavior. • Define the Occupational Safety and Health Act (OSHA). • Explain the term material safety data sheet (MSDS). • Identify hazardous waste materials in accordance with state and federal regulations and follow proper safety precautions while handling and disposing of hazardous waste materials. • Define the steps required to safely handle and store automotive chemicals and waste.

KEY TERMS: Aboveground storage tank (AGST) 38 • Asbestosis 37 • BCI 41 • CAA 36 • CFR 35 • EPA 35 • Hazardous waste materials 35 • HEPA vacuum 37 • Mercury 42 • MSDS 36 • OSHA 35 • RCRA 36 • Right-to-know laws 36 • Solvent 37 • Used oil 38 • UST 38 • WHMIS 36

HAZARDOUS WASTE

When handling hazardous waste material, one must always wear the proper protective clothing and equipment detailed in the right-to-know laws. This includes respirator equipment. All recommended procedures must be followed accurately. Personal injury may result from improper clothing, equipment, and procedures when handling hazardous materials. **Hazardous waste materials** are chemicals, or components, that the shop no longer needs that pose a danger to the environment and people if they are disposed of in ordinary garbage cans or sewers. However, no material is considered hazardous waste until the shop has finished using it and is ready to dispose of it.

FEDERAL AND STATE LAWS

OCCUPATIONAL SAFETY AND HEALTH ACT The United States Congress passed the **Occupational Safety and Health Act (OSHA)** in 1970. This legislation was designed to assist and encourage the citizens of the United States in their efforts to ensure the following:

- Safe and healthful working conditions, by providing research, information, education, and training in the field of occupational safety and health
- Safe and healthful working conditions for working men and women, by authorizing enforcement of the standards developed under the act

Because about 25% of workers are exposed to health and safety hazards on the job, the OSHA standards are necessary to monitor, control, and educate workers regarding health and safety in the workplace.

EPA The **Environmental Protection Agency (EPA)** publishes a list of hazardous materials that is included in the **Code of Federal Regulations (CFR)**. The EPA considers waste hazardous if it is included on their list of hazardous materials, or it has one or more of the following characteristics.

- **Reactive.** Any material that reacts violently with water or other chemicals is considered hazardous.
- **Corrosive.** If a material burns the skin, or dissolves metals and other materials, a technician should consider it hazardous. A pH scale is used, with the number 7 indicating neutral. Pure water has a pH of 7. Lower numbers indicate an acidic solution and higher numbers indicate a caustic solution. If a material releases cyanide gas, hydrogen sulfide gas, or similar gases when exposed to low pH acid solutions, it is considered hazardous.
- **Toxic.** Materials are hazardous if they leak one or more of eight different heavy metals in concentrations greater than 100 times the primary drinking water standard.
- **Ignitable.** A liquid is hazardous if it has a flash point below 140°F (60°C), and a solid is hazardous if it ignites spontaneously.
- **Radioactive.** Any substance that emits measurable levels of radiation is radioactive. When individuals bring containers of a highly radioactive substance into the shop environment, qualified personnel with the appropriate equipment must test them.

WARNING

Hazardous waste disposal laws include serious penalties for anyone responsible for breaking these laws.

RIGHT-TO-KNOW LAWS The **right-to-know laws** state that employees have a right to know when the materials they use at work are hazardous. The right-to-know laws started with the Hazard Communication Standard published by the Occupational Safety and Health Administration (OSHA) in 1983. Originally, this document was intended for chemical companies and manufacturers that required employees to handle hazardous materials in their work situation, but the federal courts have decided to apply these laws to all companies, including automotive service shops. Under the right-to-know laws, the employer has responsibilities regarding the handling of hazardous materials by their employees. All employees must be trained about the types of hazardous materials they will encounter in the workplace. The employees must be informed about their rights under legislation regarding the handling of hazardous materials.

MATERIAL SAFETY DATA SHEETS (MSDS) All hazardous materials must be properly labeled, and information about each hazardous material must be posted on **material safety data sheets (MSDS)** available from the manufacturer. In Canada, MSDS are called **workplace hazardous materials information systems (WHMIS)**.

The employer has a responsibility to place MSDS where they are easily accessible by all employees. These sheets provide the following information about the hazardous material: chemical name, physical characteristics, protective handling equipment, explosion/fire hazards, incompatible materials, health hazards, medical conditions aggravated by exposure, emergency and first aid procedures, safe handling, and spill/leak procedures.

The employer also has a responsibility to ensure that all hazardous materials are properly labeled. The label information must include health, fire, and reactivity hazards posed by the material, as well as the protective equipment necessary to handle the material. The manufacturer must supply all warning and precautionary information about hazardous materials. This information must be read and understood by the employee before handling the material. ● **SEE FIGURE 2–1.**

RESOURCE CONSERVATION AND RECOVERY ACT Federal and state laws control the disposal of hazardous waste materials and every shop employee must be familiar with these laws. Hazardous waste disposal laws include the **Resource Conservation and Recovery Act (RCRA)**. This law states that hazardous material users are responsible for hazardous materials from the time they become a waste until the proper waste disposal is completed. Many shops hire an independent hazardous waste hauler to dispose of hazardous waste material. The shop owner, or manager, should have a written contract with the hazardous waste hauler. Rather than have hazardous waste material hauled to an approved hazardous waste disposal site, a shop may choose to recycle the material in the shop. Therefore, the user must store hazardous waste material properly and safely, and be responsible for the transportation of this material until it arrives at an approved hazardous waste disposal site, where it can be processed according to the law. The RCRA controls the following types of automotive waste:

- Paint and body repair products waste
- Solvents for parts and equipment cleaning
- Batteries and battery acid
- Mild acids used for metal cleaning and preparation
- Waste oil, and engine coolants or antifreeze
- Air-conditioning refrigerants and oils
- Engine oil filters

FIGURE 2–1 Material safety data sheets (MSDS) should be readily available for use by anyone in the area who may come into contact with hazardous materials.

CLEAN AIR ACT Air-conditioning (A/C) systems and refrigerant are regulated by the **Clean Air Act (CAA),** Title VI, Section 609. Technician certification and service equipment is also regulated. Any technician working on automotive A/C systems must be certified. A/C refrigerants must not be released or vented into the atmosphere, and used refrigerants must be recovered.

ASBESTOS HAZARDS

Friction materials such as brake and clutch linings often contain asbestos. While asbestos has been eliminated from most original equipment friction materials, the automotive service technician cannot know whether the vehicle being serviced is or is not equipped with friction materials containing asbestos. It is important that all friction materials be handled as if they contain asbestos.

Asbestos exposure can cause scar tissue to form in the lungs. This condition is called **asbestosis**. It gradually causes increasing shortness of breath, and the scarring to the lungs is permanent.

Even low exposures to asbestos can cause *mesothelioma*, a type of fatal cancer of the lining of the chest or abdominal cavity. Asbestos exposure can also increase the risk of *lung cancer* as well as cancer of the voice box, stomach, and large intestine. It usually takes 15 to 30 years or more for cancer or asbestos lung scarring to show up after exposure. (Scientists call this the *latency period*.)

Government agencies recommend that asbestos exposure be eliminated or controlled to the lowest level possible. These agencies have developed recommendations and standards that the automotive service technician and equipment manufacturer should follow. These U.S. federal agencies include the National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and Environmental Protection Agency (EPA).

ASBESTOS OSHA STANDARDS The Occupational Safety and Health Administration (OSHA) has established three levels of asbestos exposure. Any vehicle service establishment that does either brake or clutch work must limit employee exposure to asbestos to less than 0.2 fibers per cubic centimeter (cc) as determined by an air sample.

If the level of exposure to employees is greater than specified, corrective measures must be performed and a large fine may be imposed.

NOTE: Research has found that worn asbestos fibers such as those from automotive brakes or clutches may not be as hazardous as first believed. Worn asbestos fibers do not have sharp flared ends that can latch on to tissue, but rather are worn down to a dust form that resembles talc. Grinding or sawing operations on unworn brake shoes or clutch discs *will* contain *harmful* asbestos fibers. To limit health damage, always use proper handling procedures while working around any component that may contain asbestos.

ASBESTOS EPA REGULATIONS The federal Environmental Protection Agency (EPA) has established procedures for the removal and disposal of asbestos. The EPA procedures require that products containing asbestos be "wetted" to prevent the asbestos fibers from becoming airborne. According to the EPA, asbestos-containing materials can be disposed of as regular waste. Only when asbestos becomes airborne is it considered to be hazardous.

ASBESTOS HANDLING GUIDELINES The air in the shop area can be tested by a testing laboratory, but this can be expensive. Tests have determined that asbestos levels can easily be kept below the recommended levels by using a liquid, like water, or a special vacuum.

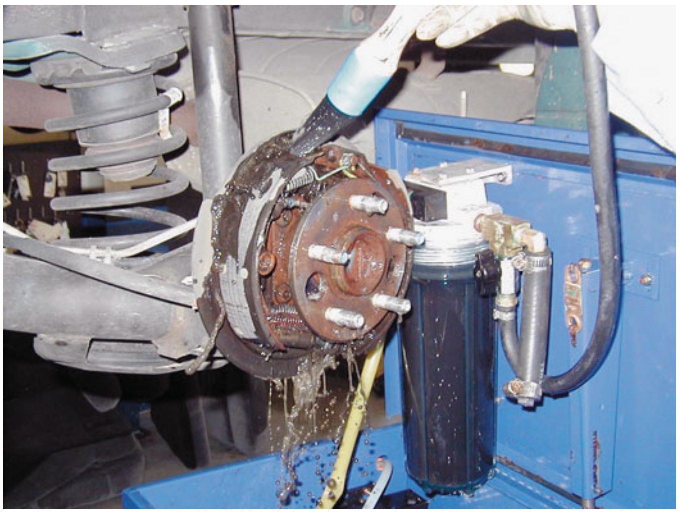


FIGURE 2–2 All brakes should be moistened with water or solvent to help prevent brake dust from becoming airborne.

NOTE: Even though asbestos is being removed from brake and clutch lining materials, the service technician cannot tell whether the old brake pads, shoes, or clutch discs contain asbestos. Therefore, to be safe, the technician should assume that all brake pads, shoes, or clutch discs contain asbestos.

- **HEPA vacuum.** A special **high-efficiency particulate air (HEPA) vacuum** system has been proven to be effective in keeping asbestos exposure levels below 0.1 fibers per cubic centimeter.
- **Solvent spray.** Many technicians use an aerosol can of brake cleaning solvent to wet the brake dust and prevent it from becoming airborne. A **solvent** is a liquid used to dissolve dirt, grime, or solid particles. Commercial brake cleaners are available that use a concentrated cleaner mixed with water. ● **SEE FIGURE 2–2.**

The waste liquid is filtered, and when dry, the filter can be disposed of as solid waste.

CAUTION: Never use compressed air to blow brake dust. The fine, talclike brake dust can create a health hazard even if asbestos is not present or is present in dust rather than fiber form.

- **Disposal of brake dust and brake shoes.** The hazard of asbestos occurs when asbestos fibers are airborne. Once the asbestos has been wetted down, it is then considered to be solid waste, rather than hazardous waste. Old brake shoes and pads should be enclosed, preferably in a plastic bag, to help prevent any of the brake material from becoming airborne. *Always follow current federal and local laws concerning disposal of all waste.*

USED BRAKE FLUID

Most brake fluid is made from polyglycol, is water soluble, and can be considered hazardous if it has absorbed metals from the brake system.

STORAGE AND DISPOSAL OF BRAKE FLUID

- Collect brake fluid in containers clearly marked to indicate that it is dedicated for that purpose.
- If your waste brake fluid is hazardous, manage it appropriately and use only an authorized waste receiver for its disposal.
- If your waste brake fluid is nonhazardous (such as old, but unused), determine from your local solid waste collection provider what should be done for its proper disposal.
- Do not mix brake fluid with used engine oil.
- Do not pour brake fluid down drains or onto the ground.
- Recycle brake fluid through a registered recycler.

USED OIL

Used oil is any petroleum-based or synthetic oil that has been used. During normal use, impurities such as dirt, metal scrapings, water, or chemicals can get mixed in with the oil. Eventually, this used oil must be replaced with virgin or re-refined oil. The EPA's used oil management standards include a three-pronged approach to determine if a substance meets the definition of *used oil*. To meet the EPA's definition of used oil, a substance must meet each of the following three criteria.

- **Origin.** The first criterion for identifying used oil is based on the oil's origin. Used oil must have been refined from crude oil or made from synthetic materials. Animal and vegetable oils are excluded from the EPA's definition of used oil.
- **Use.** The second criterion is based on whether and how the oil is used. Oils used as lubricants, hydraulic fluids, heat transfer fluids, and for other similar purposes are considered used oil. Unused oil, such as bottom clean-out waste from virgin fuel oil storage tanks or virgin fuel oil recovered from a spill, does not meet the EPA's definition of used oil because these oils have never been "used." The EPA's definition also excludes products used as cleaning agents, as well as certain petroleum-derived products like antifreeze and kerosene.
- **Contaminants.** The third criterion is based on whether or not the oil is contaminated with either physical or chemical impurities. In other words, to meet the EPA's definition, used oil must become contaminated as a result of being used. This aspect of the EPA's definition includes residues and contaminants generated from handling, storing, and processing used oil.

FIGURE 2–3 A typical aboveground oil storage tank.

NOTE: The release of only 1 gallon of used oil (a typical oil change) can make 1 million gallons of fresh water undrinkable.

If used oil is dumped down the drain and enters a sewage treatment plant, concentrations as small as 50 to 100 parts per million (PPM) in the waste water can foul sewage treatment processes. Never mix a listed hazardous waste, gasoline, waste water, halogenated solvent, antifreeze, or an unknown waste material with used oil. Adding any of these substances will cause the used oil to become contaminated, which classifies it as hazardous waste.

STORAGE AND DISPOSAL OF USED OIL Once oil has been used, it can be collected, recycled, and used over and over again. An estimated 380 million gallons of used oil are recycled each year. Recycled used oil can sometimes be used again for the same job or can take on a completely different task. For example, used engine oil can be re-refined and sold at the store as engine oil or processed for furnace fuel oil. After collecting used oil in an appropriate container, such as a 55-gallon steel drum, the material must be disposed of in one of two ways:

1. Shipped offsite for recycling
2. Burned in an onsite or offsite EPA-approved heater for energy recovery

Used oil must be stored in compliance with an existing **underground storage tank (UST)** or an **aboveground storage tank (AGST)** standard, or kept in separate containers. ● **SEE FIGURE 2–3.** Containers are portable receptacles, such as a 55-gallon steel drum.

- **Keep used oil storage drums in good condition.** This means that they should be covered, secured from vandals, properly labeled, and maintained in compliance with local fire codes. Frequent inspections for leaks, corrosion, and spillage are an essential part of container maintenance.
- **Never store used oil in anything other than tanks and storage containers.** Used oil may also be stored in units that are permitted to store regulated hazardous waste.

- **Follow used oil filter disposal regulations.** Used oil filters contain used engine oil that may be hazardous. Before an oil filter is placed into the trash or sent to be recycled, it must be drained using one of the following hot draining methods approved by the EPA.
  - Puncture the filter antidrain back valve or filter dome end and hot drain for at least 12 hours
  - Hot drain and crush
  - Dismantle and hot drain
  - Use another hot draining method to remove all used oil from the filter

After the oil has been drained from the oil filter, the filter housing can be disposed of in any of the following ways:

- Sent for recycling
- Picked up by a service contract company
- Disposed of in regular trash

SOLVENTS

The major sources of chemical danger are liquid and aerosol brake cleaning fluids that contain chlorinated hydrocarbon solvents. Several other chemicals that do not deplete the ozone, such as heptane, hexane, and xylene, are now being used in nonchlorinated brake cleaning solvents. Some manufacturers are also producing solvents they describe as environmentally responsible, which are biodegradable and noncarcinogenic (not cancer causing).

There is no specific standard for physical contact with chlorinated hydrocarbon solvents or the chemicals replacing them. All contact should be avoided whenever possible. The law requires an employer to provide appropriate protective equipment and ensure proper work practices by an employee handling these chemicals.

EFFECTS OF CHEMICAL POISONING

The effects of exposure to chlorinated hydrocarbon and other types of solvents can take many forms. Short-term exposure at low levels can cause one or more of the following symptoms.

- Headache
- Nausea
- Drowsiness

SAFETY TIP

Hand Safety

Service technicians should wash their hands with soap and water after handling engine oil or differential or transmission fluids, or wear protective rubber gloves. Another safety hint is that the service technician should not wear watches, rings, or other jewelry that could come in contact with electrical or moving parts of a vehicle. ● **SEE FIGURE 2–4.**

FIGURE 2–4 Washing hands and removing jewelry are two important safety habits all service technicians should practice.

- Dizziness
- Lack of coordination
- Unconsciousness

It may also cause irritation of the eyes, nose, and throat, and flushing of the face and neck. Short-term exposure to higher concentrations can cause liver damage with symptoms such as yellow jaundice or dark urine. Liver damage may not become evident until several weeks after the exposure.

SOLVENT HAZARDOUS AND REGULATORY STATUS

Most solvents are classified as hazardous wastes. Other characteristics of solvents include the following:

- Solvents with flash points below 140°F (25°C) are considered flammable and, like gasoline, are federally regulated by the Department of Transportation (DOT).
- Solvents and oils with flash points above 140°F (25°C) are considered combustible and, like engine oil, are also regulated by the DOT. All flammable items must be stored in a fireproof container. ● **SEE FIGURE 2–5.**

It is the responsibility of the repair shop to determine if its spent solvent is hazardous waste. Waste solvents that are considered hazardous waste have a flash point below 140°F (60°C). Hot water or aqueous parts cleaners may be used to avoid disposing of spent solvent as hazardous waste. Solvent-type parts cleaners with filters are available to greatly extend solvent life and reduce spent solvent disposal costs. Solvent reclaimers are available that clean and restore the solvent so it lasts indefinitely.

USED SOLVENTS

Used or spent solvents are liquid materials that have been generated as waste and may contain xylene, methanol, ethyl ether, and methyl isobutyl ketone (MIBK). These materials must be stored in OSHA-approved safety containers with the lids or caps closed tightly. These storage receptacles must show no signs of leaks or significant damage due to dents or rust. In addition, the containers must be stored in a protected area

FIGURE 2–5 Typical fireproof flammable storage cabinet.

equipped with secondary containment or a spill protector, such as a spill pallet. Additional requirements include the following:

- Containers should be clearly labeled “Hazardous Waste” and the date the material was first placed into the storage receptacle should be noted.
- Labeling is not required for solvents being used in a parts washer.
- Used solvents will not be counted toward a facility’s monthly output of hazardous waste if the vendor under contract removes the material.
- Used solvents may be disposed of by recycling with a local vendor, such as SafetyKleen®, to have the used solvent removed according to specific terms in the vendor agreement. ● **SEE FIGURE 2–6**.
- Use aqueous-based (nonsolvent) cleaning systems to help avoid the problems associated with chemical solvents.

FIGURE 2–6 Using a water-based cleaning system helps reduce the hazards from using strong chemicals.

COOLANT DISPOSAL

Coolant is a mixture of antifreeze and water. New antifreeze is not considered to be hazardous even though it can cause death if ingested. Used antifreeze may be hazardous due to dissolved metals from the engine and other components of the cooling system. These metals can include iron, steel, aluminum, copper, brass, and lead (from older radiators and heater cores).

- Coolant should be recycled either onsite or offsite.
- Used coolant should be stored in a sealed and labeled container. ● **SEE FIGURE 2–7.**
- Used coolant can often be disposed of into municipal sewers with a permit. Check with local authorities and obtain a permit before discharging used coolant into sanitary sewers.

FIGURE 2–7 Used antifreeze coolant should be kept separate and stored in a leakproof container until it can be recycled or disposed of according to federal, state, and local laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside barrel.

LEAD-ACID BATTERY WASTE

About 70 million spent lead-acid batteries are generated each year in the United States alone. Lead is classified as a toxic metal and the acid used in lead-acid batteries is highly corrosive. The vast majority (95% to 98%) of these batteries are recycled through lead reclamation operations and secondary lead smelters for use in the manufacture of new batteries.

BATTERY DISPOSAL Used lead-acid batteries must be reclaimed or recycled in order to be exempt from hazardous waste regulations. Leaking batteries must be stored and transported as hazardous waste. Some states have more strict regulations, which require special handling procedures and transportation. According to the **Battery Council International (BCI),** battery laws usually include the following rules.

1. Lead-acid battery disposal is prohibited in landfills or incinerators. Batteries are required to be delivered to a battery retailer, wholesaler, recycling center, or lead smelter.
2. All retailers of automotive batteries are required to post a sign that displays the universal recycling symbol and indicates the retailer's specific requirements for accepting used batteries.
3. Battery electrolyte contains sulfuric acid, which is a very corrosive substance capable of causing serious personal injury, such as skin burns and eye damage. In addition, the battery plates contain lead, which is highly poisonous. For this reason, disposing of batteries improperly can cause environmental contamination and lead to severe health problems.

BATTERY HANDLING AND STORAGE

Batteries, whether new or used, should be kept indoors if possible. The storage location should be an area specifically designated for battery storage and must be well ventilated (to the outside). If outdoor storage is the only alternative, a sheltered and secured area with acid-resistant secondary containment is strongly recommended. It is also advisable that acid-resistant secondary containment be used for indoor storage. In addition, batteries should be placed on acid-resistant pallets and never stacked!

FUEL SAFETY AND STORAGE

Gasoline is a very explosive liquid. The expanding vapors that come from gasoline are extremely dangerous. These vapors are present even in cold temperatures. Vapors formed in gasoline tanks on many vehicles are controlled, but vapors from gasoline storage may escape from the can, resulting in a hazardous situation. Therefore, place gasoline storage containers in a well-ventilated space. Although diesel fuel is not as volatile as gasoline, the same basic rules apply to diesel fuel and gasoline storage. These rules include the following:

1. Use storage cans that have a flash arresting screen at the outlet. These screens prevent external ignition sources from igniting the gasoline within the can when someone pours the gasoline or diesel fuel.
2. Use only a red approved gasoline container to allow for proper hazardous substance identification. ● **SEE FIGURE 2–8**.

FIGURE 2–8 This red gasoline container holds about 30 gallons of gasoline and is used to fill vehicles used for training.

3. Do not fill gasoline containers completely full. Always leave the level of gasoline at least 1 inch from the top of the container. This action allows expansion of the gasoline at higher temperatures. If gasoline containers are completely full, the gasoline will expand when the temperature increases. This expansion forces gasoline from the can and creates a dangerous spill. If gasoline or diesel fuel containers must be stored, place them in a designated storage locker or facility.
4. Never leave gasoline containers open, except while filling or pouring gasoline from the container.
5. Never use gasoline as a cleaning agent.
6. Always connect a ground strap to containers when filling or transferring fuel or other flammable products from one container to another to prevent static electricity that could result in explosion and fire. These ground wires prevent the buildup of a static electric charge, which could result in a spark and disastrous explosion.

AIRBAG DISPOSAL

Airbag modules are pyrotechnic devices that can be ignited if exposed to an electrical charge or if the body of the vehicle is subjected to a shock. Airbag safety should include the following precautions.

1. Disarm the airbag(s) if you will be working in the area where a discharged bag could make contact with any part of your body. Consult service information for the exact procedure to follow for the vehicle being serviced.

2. If disposing of an airbag, the usual procedure is to deploy the airbag using a 12 volt power supply, such as a jump start box, using long wires to connect to the module to ensure a safe deployment.
3. Do not expose an airbag to extreme heat or fire.
4. Always carry an airbag pointing away from your body.
5. Place an airbag module facing upward.
6. Always follow the manufacturer's recommended procedure for airbag disposal or recycling, including the proper packaging to use during shipment.
7. Wear protective gloves if handling a deployed airbag.
8. Always wash your hands or body well if exposed to a deployed airbag. The chemicals involved can cause skin irritation and possible rash development.

USED TIRE DISPOSAL

Used tires are an environmental concern because of several reasons, including the following:

1. In a landfill, they tend to "float" up through the other trash and rise to the surface.
2. The inside area traps and holds rainwater, which is a breeding ground for mosquitoes. Mosquito-borne diseases include encephalitis and dengue fever.
3. Used tires present a fire hazard and, when burned, create a large amount of black smoke that contaminates the air.

Used tires should be disposed of in one of the following ways.

1. Used tires can be reused until the end of their useful life.
2. Tires can be retreaded.
3. Tires can be recycled or shredded for use in asphalt.
4. Derimmed tires can be sent to a landfill. (Most landfill operators will shred the tires because it is illegal in many states to landfill whole tires.)
5. Tires can be burned in cement kilns or other power plants where the smoke can be controlled.
6. A registered scrap tire handler should be used to transport tires for disposal or recycling.

AIR-CONDITIONING REFRIGERANT OIL DISPOSAL

Air-conditioning refrigerant oil contains dissolved refrigerant and is therefore considered to be hazardous waste. This oil must be kept separated from other waste oil or the entire amount of oil must be treated as hazardous. Used refrigerant oil must be sent to a licensed hazardous waste disposal company for recycling or disposal. ● **SEE FIGURE 2–9.**

FIGURE 2–9 Air-conditioning refrigerant oil must be kept separated from other oils because it contains traces of refrigerant and must be treated as hazardous waste.

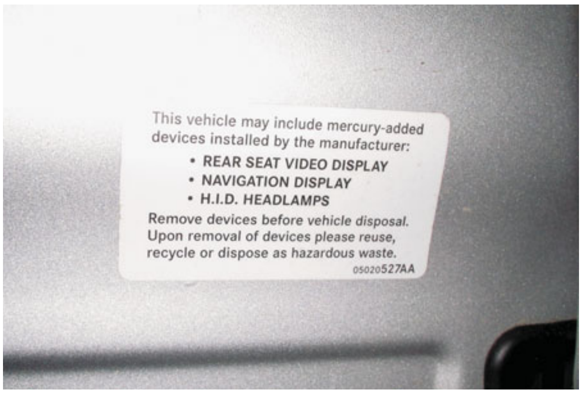


FIGURE 2–10 Placard near driver's door, including what devices in the vehicle contain mercury.

TECH TIP

Remove Components That Contain Mercury

Some vehicles have a placard near the driver's side door that lists the components that contain the heavy metal, mercury. **Mercury** can be absorbed through the skin and is a heavy metal that once absorbed by the body does not leave. ● **SEE FIGURE 2–10.**

These components should be removed from the vehicle before the rest of the body is sent to be recycled to help prevent releasing mercury into the environment.

WASTE CHART All automotive service facilities create some waste, and while most of it is handled properly, it is important that all hazardous and nonhazardous waste be accounted for and properly disposed. ● **SEE CHART 2–1** for a list of typical wastes generated at automotive shops, plus a checklist for keeping track of how these wastes are handled.

Waste Stream	Typical Wastes: Typical Category If Not Mixed with Other Hazardous Waste	Typical Wastes: If Disposed in Landfill and Not Mixed with a Hazardous Waste	If Recycled
Used oil	Used oil	Hazardous waste	Used oil
Used oil filters	Nonhazardous solid waste, if completely drained	Nonhazardous solid waste, if completely drained	Used oil, if not drained
Used transmission fluid	Used oil	Hazardous waste	Used oil
Used brake fluid	Used oil	Hazardous waste	Used oil
Used antifreeze	Depends on characterization	Depends on characterization	Depends on characterization
Used solvents	Hazardous waste	Hazardous waste	Hazardous waste
Used citric solvents	Nonhazardous solid waste	Nonhazardous solid waste	Hazardous waste
Lead-acid automotive batteries	Not a solid waste if returned to supplier	Hazardous waste	Hazardous waste
Shop rags used for oil	Used oil	Depends on used oil characterization	Used oil
Shop rags used for solvent or gasoline spills	Hazardous waste	Hazardous waste	Hazardous waste
Oil spill absorbent material	Used oil	Depends on used oil characterization	Used oil
Spill material for solvent and gasoline	Hazardous waste	Hazardous waste	Hazardous waste
Catalytic converter	Not a solid waste if returned to supplier	Nonhazardous solid waste	Nonhazardous solid waste
Spilled or unused fuels	Hazardous waste	Hazardous waste	Hazardous waste
Spilled or unusable paints and thinners	Hazardous waste	Hazardous waste	Hazardous waste
Used tires	Nonhazardous solid waste	Nonhazardous solid waste	Nonhazardous solid waste

CHART 2–1

Typical wastes generated at auto repair shops and typical category (hazardous or nonhazardous) by disposal method.

TECH TIP

What Every Technician Should Know

The Hazardous Materials Identification Guide (HMIG) is the standard labeling for all materials. The service technician should be aware of the meaning of the label. ● **SEE FIGURE 2–11.**

Hazardous Materials Identification Guide (HMIG)

TYPE HAZARD		DEGREE	
	HEALTH		4 - Extreme
	FLAMMABILITY		3 - Serious
	REACTIVITY		2 - Moderate
	PROTECTIVE EQUIPMENT		1 - Slight
			0 - Minimal

HAZARD RATING AND PROTECTIVE EQUIPMENT

Health		Flammable		Reactive	
Type of Possible Injury		Susceptibility of materials to burn		Susceptibility of materials to release energy	
4	Highly Toxic. May be fatal on short-term exposure. Special protective equipment required.	4	Extremely flammable gas or liquid. Flash Point below 73°F.	4	Extreme. Explosive at room temperature.
3	Toxic. Avoid inhalation or skin contact.	3	Flammable. Flash Point 73°F to 100°F.	3	Serious. May explode if shocked, heated under confinement or mixed w/ water.
2	Moderately Toxic. May be harmful if inhaled or absorbed.	2	Combustible. Requires moderate heating to ignite. Flash Point 100°F to 200°F.	2	Moderate. Unstable, may react with water.
1	Slightly Toxic. May cause slight irritation.	1	Slightly Combustible. Requires strong heating to ignite.	1	Slight. May react if heated or mixed with water.
0	Minimal. All chemicals have a slight degree of toxicity.	0	Minimal. Will not burn under normal conditions.	0	Minimal. Normally stable, does not react with water.

Protective Equipment

A	Safety Glasses	E	Safety Glasses + Gloves + Dust Respirator	I	Safety Glasses + Gloves + Combination Dust & Vapor Respirator
B	Safety Glasses + Gloves	F	Safety Glasses + Gloves + Apron + Dust Respirator	J	Chemical Goggles + Gloves + Apron + Combination Dust & Vapor Respirator
C	Safety Glasses + Gloves + Apron	G	Safety Glasses + Gloves + Vapor Respirator	K	Apron + Gloves + Full Protection Suit + Boots
D	Faceshield + Gloves + Apron	H	Chemical Goggles + Gloves + Apron + Vapor Respirator	X	Ask your supervisor for guidance.

FIGURE 2–11 The Environmental Protection Agency (EPA) Hazardous Materials Identification Guide is a standardized listing of the hazards and the protective equipment needed.

SUMMARY

1. Hazardous materials include common automotive chemicals, liquids, and lubricants, especially those whose ingredients contain *chlor* or *fluor* in their name.
2. Right-to-know laws require that all workers have access to material safety data sheets (MSDS).
3. Asbestos fibers should be avoided and removed according to current laws and regulations.
4. Used engine oil contains metals worn from parts and should be handled and disposed of properly.
5. Solvents represent a serious health risk and should be avoided as much as possible.
6. Coolant should be disposed of properly or recycled.
7. Batteries are considered to be hazardous waste and should be discarded to a recycling facility.

REVIEW QUESTIONS

1. List five common automotive chemicals or products that may be considered hazardous materials.
2. List five precautions to which every technician should adhere when working with automotive products and chemicals.

CHAPTER QUIZ

1. Hazardous materials include all of the following *except* ________.
   - **a.** Engine oil
   - **b.** Asbestos
   - **c.** Water
   - **d.** Brake cleaner
2. To determine if a product or substance being used is hazardous, consult ________.
   - **a.** A dictionary
   - **b.** An MSDS
   - **c.** SAE standards
   - **d.** EPA guidelines
3. Exposure to asbestos dust can cause what condition?
   - **a.** Asbestosis
   - **b.** Mesothelioma
   - **c.** Lung cancer
   - **d.** All of the above are possible
4. Wetted asbestos dust is considered to be ________.
   - **a.** Solid waste
   - **b.** Hazardous waste
   - **c.** Toxic
   - **d.** Poisonous
5. An oil filter should be hot drained for how long before disposing of the filter?
   - **a.** 30 to 60 minutes
   - **b.** 4 hours
   - **c.** 8 hours
   - **d.** 12 hours
6. Used engine oil should be disposed of by all *except* one of the following methods.
   - **a.** Disposed of in regular trash
   - **b.** Shipped offsite for recycling
   - **c.** Burned onsite in a waste oil-approved heater
   - **d.** Burned offsite in a waste oil-approved heater
7. All of the following are the proper ways to dispose of a drained oil filter *except* ________.
   - **a.** Sent for recycling
   - **b.** Picked up by a service contract company
   - **c.** Disposed of in regular trash
   - **d.** Considered to be hazardous waste and disposed of accordingly
8. Which act or organization regulates air-conditioning refrigerant?
   - **a.** Clean Air Act (CAA)
   - **b.** MSDS
   - **c.** WHMIS
   - **d.** Code of Federal Regulations (CFR)
9. Gasoline should be stored in approved containers that include what color(s)?
   - **a.** Red container with yellow lettering
   - **b.** Red container
   - **c.** Yellow container
   - **d.** Yellow container with red lettering
10. What automotive devices may contain mercury?
    - **a.** Rear seat video displays
    - **b.** Navigation displays
    - **c.** HID headlights
    - **d.** All of the above

chapter
3

ELECTRICAL FUNDAMENTALS

OBJECTIVES: After studying Chapter 3, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Define electricity. • Explain the units of electrical measurement. • Discuss the relationship among volts, amperes, and ohms. • Explain how magnetism is used in automotive applications.

KEY TERMS: Ammeter 50 • Ampere 50 • Atom 46 • Bound electrons 48 • Conductors 48 • Conventional theory 50 • Coulomb 50 • Electrical potential 50 • Electricity 46 • Electrochemistry 52 • Electromotive force (EMF) 51 • Electron theory 50 • Free electrons 48 • Insulators 49 • Ion 47 • Neutral charge 46 • Ohmmeter 51 • Ohms 51 • Peltier effect 52 • Photoelectricity 52 • Piezoelectricity 52 • Positive temperature coefficient (PTC) 53 • Potentiometer 53 • Resistance 51 • Rheostat 53 • Semiconductor 49 • Static electricity 52 • Thermocouple 52 • Thermoelectricity 52 • Valence ring 48 • Volt 50 • Voltmeter 51 • Watt 51

INTRODUCTION

The electrical system is one of the most important systems in a vehicle today. Every year more and more components and systems use electricity. Those technicians who really know and understand automotive electrical and electronic systems will be in great demand.

Electricity may be difficult for some people to learn for the following reasons.

- It cannot be seen.
- Only the results of electricity can be seen.
- It has to be detected and measured.
- The test results have to be interpreted.

ELECTRICITY

BACKGROUND Our universe is composed of matter, which is *anything* that has mass and occupies space. All matter is made from slightly over 100 individual components called *elements*. The smallest particle that an element can be broken into and still retain the properties of that element is known as an **atom.** ● **SEE FIGURE 3–1.**

DEFINITION **Electricity** is the movement of electrons from one atom to another. The dense center of each atom is called the nucleus. The nucleus contains:

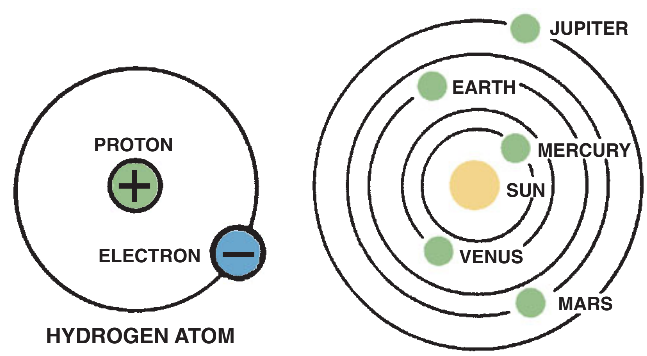


FIGURE 3–1 In an atom (left), electrons orbit protons in the nucleus just as planets orbit the sun in our solar system (right).

- *Protons*, which have a positive charge
- *Neutrons*, which are electrically neutral (have no charge)

Electrons, which have a negative charge, surround the nucleus in orbits. Each atom contains an equal number of electrons and protons. The physical aspect of all protons, electrons, and neutrons are the same for all atoms. It is the *number* of electrons and protons in the atom that determines the material and how electricity is conducted. Because the number of negative-charged electrons is balanced with the same number of positive-charged protons, an atom has a **neutral charge** (no charge).

NOTE: As an example of the relative sizes of the parts of an atom, consider that if an atom were magnified so that the nucleus were the size of the period at the end of this sentence, the whole atom would be bigger than a house.

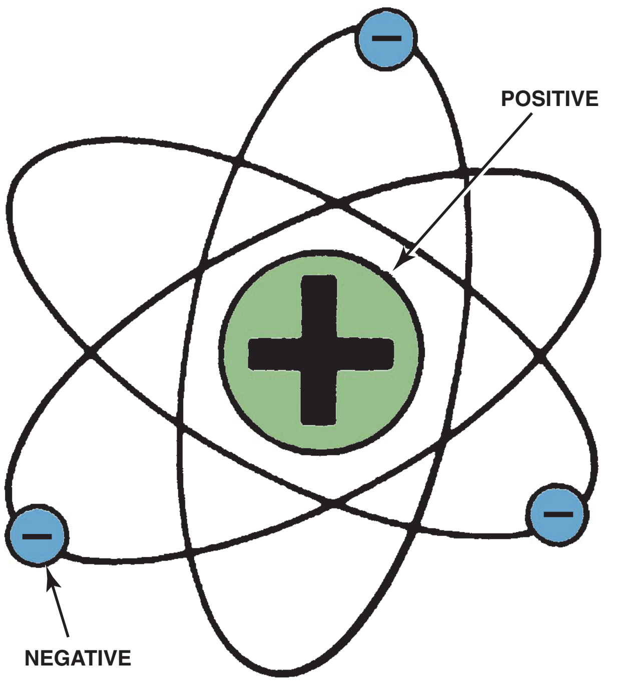


FIGURE 3–2 The nucleus of an atom has a positive (+) charge and the surrounding electrons have a negative (−) charge.

POSITIVE AND NEGATIVE CHARGES The parts of the atom have different charges. The orbiting electrons are negatively charged, while the protons are positively charged. Positive charges are indicated by the "plus" sign (+), and negative charges by the "minus" sign (−), as shown in ● **FIGURE 3–2.**

These same + and − signs are used to identify parts of an electrical circuit. Neutrons have no charge at all. They are neutral. In a normal, or balanced, atom, the number of negative particles equals the number of positive particles. That is, there are as many electrons as there are protons. ● **SEE FIGURE 3–3.**

MAGNETS AND ELECTRICAL CHARGES An ordinary magnet has two ends, or poles. One end is called the south pole, and the other is called the north pole. If two magnets are brought close to each other with like poles together (south to south or north to north), the magnets will push each other apart, because like poles repel each other. If the opposite poles of the magnets are brought close to each other, south to north, the magnets will snap together, because unlike poles attract each other.

The positive and negative charges within an atom are like the north and south poles of a magnet. Charges that are alike will repel each other, similar to the poles of a magnet. ● **SEE FIGURE 3–4.**

That is why the negative electrons continue to orbit around the positive protons. They are attracted and held by the opposite charge of the protons. The electrons keep moving in orbit because they repel each other.

IONS When an atom loses any electrons, it becomes unbalanced. It will have more protons than electrons, and therefore

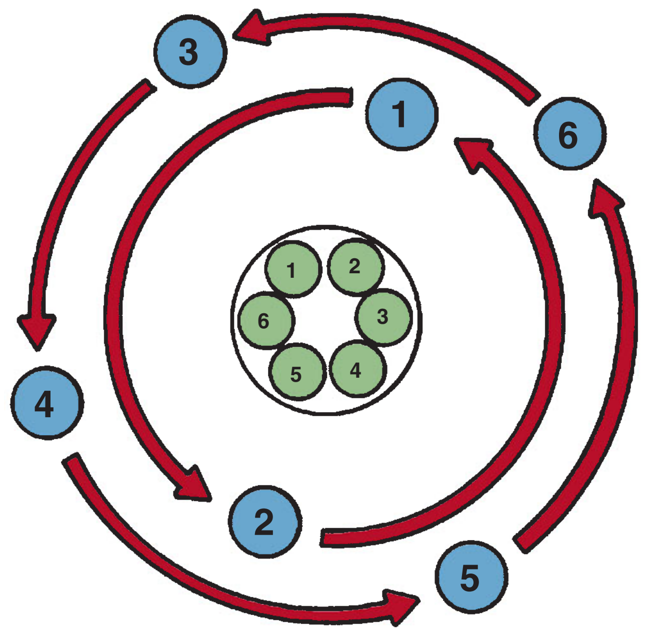


FIGURE 3–3 This figure shows a balanced atom. The number of electrons is the same as the number of protons in the nucleus.

FIGURE 3–4 Unlike charges attract and like charges repel.

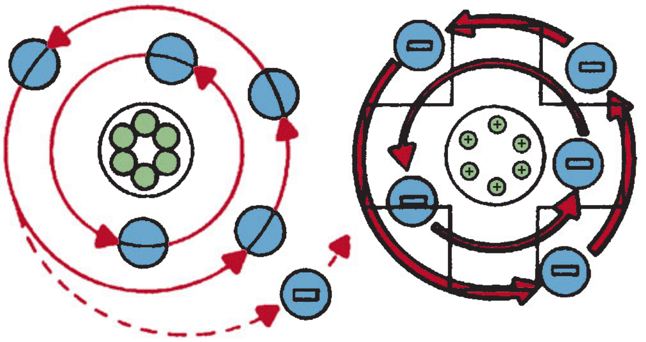


FIGURE 3–5 An unbalanced, positively charged atom (ion) will attract electrons from neighboring atoms.

will have a positive charge. If it gains more electrons than protons, the atom will be negatively charged. When an atom is not balanced, it becomes a charged particle called an **ion**. Ions try to regain their balance of equal protons and electrons by exchanging electrons with neighboring atoms. The flow of electrons during the "equalization" process is defined as the flow of electricity. ● **SEE FIGURE 3–5.**

ELECTRON SHELLS Electrons orbit around the nucleus in definite paths. These paths form shells, like concentric rings, around the nucleus. Only a specific number of electrons can orbit within each shell. If there are too many electrons for the

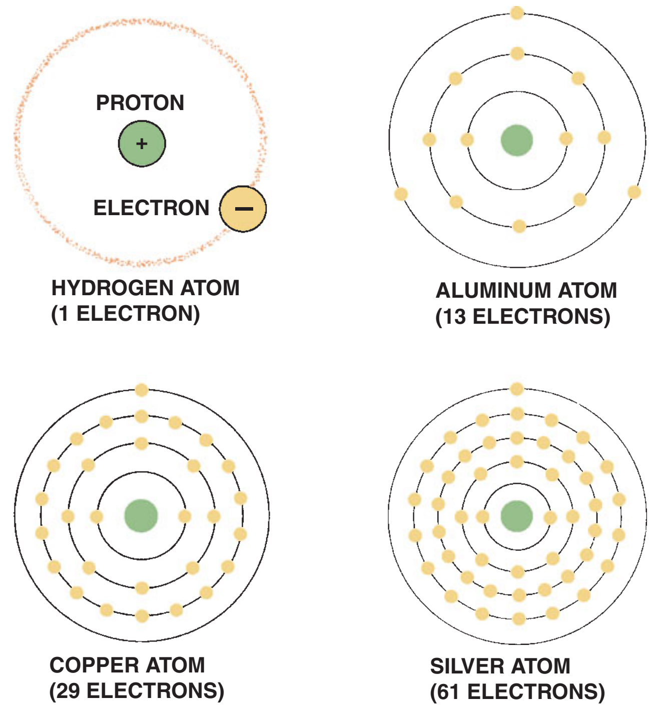


FIGURE 3–6 The hydrogen atom is the simplest atom, with only one proton, one neutron, and one electron. More complex elements contain higher numbers of protons, neutrons, and electrons.

first and closest shell to the nucleus, the others will orbit in additional shells until all electrons have an orbit within a shell. There can be as many as seven shells around a single nucleus. ● **SEE FIGURE 3–6.**

FREE AND BOUND ELECTRONS The outermost electron shell or ring, called the **valence ring**, is the most important part of understanding electricity. The number of electrons in this outer ring determines the valence of the atom, and indicates its capacity to combine with other atoms.

If the valence ring of an atom has three or fewer electrons in it, the ring has room for more. The electrons there are held very loosely, and it is easy for a drifting electron to join the valence ring and push another electron away. These loosely held electrons are called **free electrons.** When the valence ring has five or more electrons in it, it is fairly full. The electrons are held tightly, and it is hard for a drifting electron to push its way into the valence ring. These tightly held electrons are called **bound electrons**. ● **SEE FIGURES 3–7 AND 3–8.**

The movement of these drifting electrons is called current. Current can be small, with only a few electrons moving, or it can be large, with a tremendous number of electrons moving. Electric current is the controlled, directed movement of electrons from atom to atom within a conductor.

CONDUCTORS **Conductors** are materials with fewer than four electrons in their atom's outer orbit. ● **SEE FIGURE 3–9.**

Copper is an excellent conductor because it has only one electron in its outer orbit. This orbit is far enough away from the nucleus of the copper atom that the pull or force holding the outermost electron in orbit is relatively weak. ● **SEE FIGURE 3–10.**

Copper is the conductor most used in vehicles because the price of copper is reasonable compared to the relative cost of other conductors with similar properties. Examples of other commonly used conductors include:

- Silver
- Gold
- Aluminum
- Steel
- Cast iron

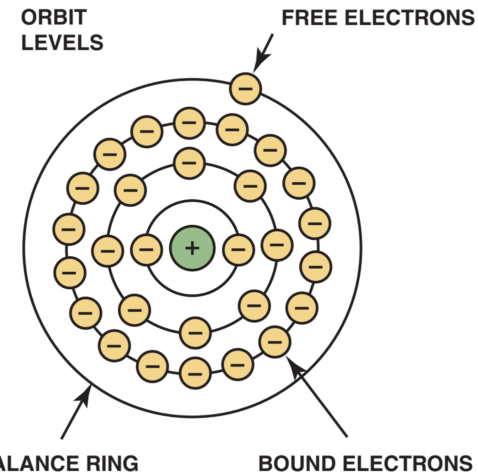


FIGURE 3–7 As the number of electrons increases, they occupy increasing energy levels that are farther from the center of the atom.

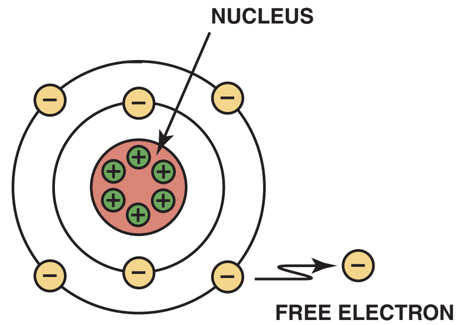


FIGURE 3–8 Electrons in the outer orbit, or shell, can often be drawn away from the atom and become free electrons.

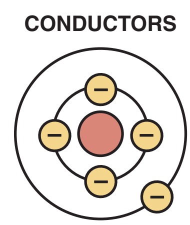


FIGURE 3–9 A conductor is any element that has one to three electrons in its outer orbit.

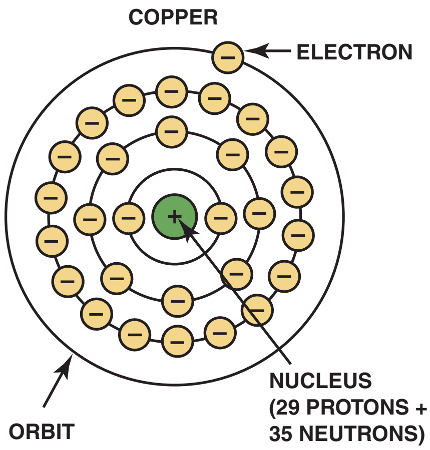


FIGURE 3–10 Copper is an excellent conductor of electricity because it has just one electron in its outer orbit, making it easy to be knocked out of its orbit and flow to other nearby atoms. This causes electron flow, which is the definition of electricity.

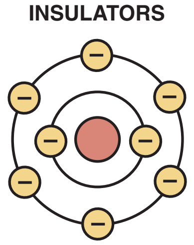


FIGURE 3–11 Insulators are elements with five to eight electrons in the outer orbit.

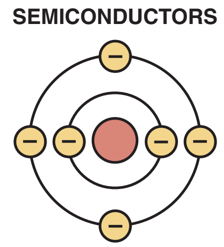


FIGURE 3–12 Semiconductor elements contain exactly four electrons in the outer orbit.

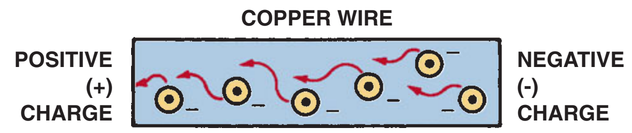


FIGURE 3–13 Current electricity is the movement of electrons through a conductor.

? FREQUENTLY ASKED QUESTION

Is Water a Conductor?

Pure water is an insulator; however, if anything is in the water, such as salt or dirt, then the water becomes conductive. Because it is difficult to keep it from becoming contaminated, water is usually thought of as being capable of conducting electricity, especially high-voltage household 110 or 220 volt outlets.

INSULATORS Some materials hold their electrons very tightly; therefore, electrons do not move through them very well. These materials are called insulators. **Insulators** are materials with more than four electrons in their atom's outer orbit. Because they have more than four electrons in their outer orbit, it becomes easier for these materials to acquire (gain) electrons than to release electrons. ● **SEE FIGURE 3–11.**

Examples of insulators include:

- Rubber
- Plastic
- Nylon
- Porcelain
- Ceramic
- Fiberglass

Examples of insulators include plastics, wood, glass, rubber, ceramics (spark plugs), and varnish for covering (insulating) copper wires in alternators and starters.

SEMICONDUCTORS Materials with exactly four electrons in their outer orbit are neither conductors nor insulators, but are called **semiconductors.** Semiconductors can be either an insulator or a conductor in different design applications. ● **SEE FIGURE 3–12.**

Examples of semiconductors include:

- Silicon
- Germanium
- Carbon

Semiconductors are used mostly in transistors, computers, and other electronic devices.

HOW ELECTRONS MOVE THROUGH A CONDUCTOR

CURRENT FLOW The following events occur if a source of power, such as a battery, is connected to the ends of a conductor—a positive charge (lack of electrons) is placed on one end of the conductor and a negative charge (excess of electrons) is placed on the opposite end of the conductor. For current to flow, there *must* be an imbalance of excess electrons at one end of the circuit and a deficiency of electrons at the opposite end of the circuit.

- The negative charge will repel the free electrons from the atoms of the conductor, whereas the positive charge on the opposite end of the conductor will attract electrons.
- As a result of this attraction of opposite charges and repulsion of like charges, electrons will flow through the conductor. ● **SEE FIGURE 3–13.**

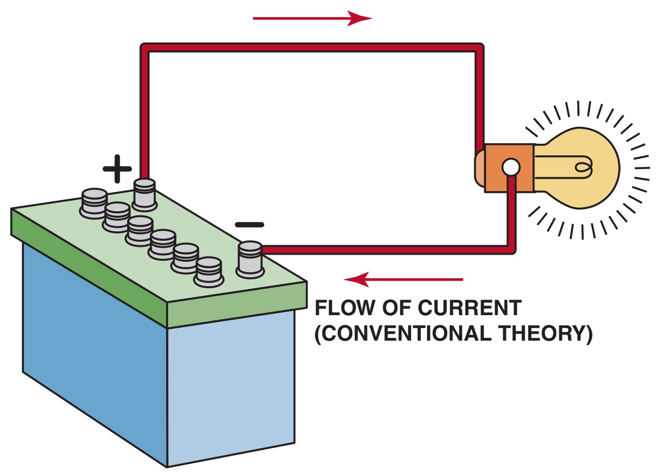


FIGURE 3–14 Conventional theory states that current flows through a circuit from positive (+) to negative (−). Automotive electricity uses the conventional theory in all electrical diagrams and schematics.

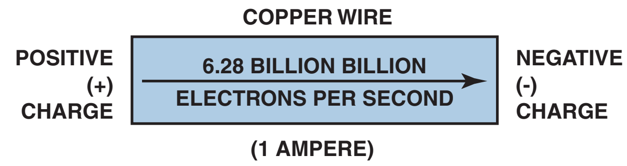


FIGURE 3–15 One ampere is the movement of 1 coulomb (6.28 billion billion electrons) past a point in 1 second.

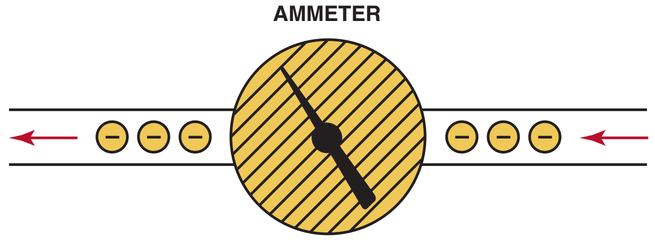


FIGURE 3–16 An ammeter is installed in the path of the electrons similar to a water meter used to measure the flow of water in gallons per minute. The ammeter displays current flow in amperes.

CONVENTIONAL THEORY VERSUS ELECTRON THEORY

- **Conventional theory.** It was once thought that electricity had only one charge and moved from positive to negative. This theory of the flow of electricity through a conductor is called the **conventional theory** of current flow. ● **SEE FIGURE 3–14.**
- **Electron theory.** The discovery of the electron and its negative charge led to the **electron theory,** which states that there is electron flow from negative to positive. Most automotive applications use the conventional theory. This book will use the conventional theory (positive to negative) unless stated otherwise.

UNITS OF ELECTRICITY

Electricity is measured using meters or other test equipment. The three fundamentals of electricity-related units include the ampere, volt, and ohm.

AMPERES The **ampere** is the unit used throughout the world to measure current flow. When 6.28 billion billion electrons (the name for this large number of electrons is a **coulomb**) move past a certain point in 1 second, this represents 1 ampere of current. ● **SEE FIGURE 3–15.**

The ampere is the electrical unit for the amount of electron flow, just as "gallons per minute" is the unit that can be used to measure the quantity of water flow. It is named for the French electrician, Andrè Marie Ampére (1775–1836). The conventional abbreviations and measurement for amperes are as follows:

1. The ampere is the unit of measurement for the amount of current flow.
2. *A* and *amps* are acceptable abbreviations for *amperes*.
3. The capital letter *I*, for *intensity*, is used in mathematical calculations to represent amperes.
4. Amperes do the actual work in the circuit. It is the actual movement of the electrons through a light bulb or motor that actually makes the electrical device work. Without amperage through a device it will not work at all.
5. Amperes are measured by an **ammeter** (not ampmeter). ● **SEE FIGURE 3–16.**

VOLTS The **volt** is the unit of measurement for electrical pressure. It is named for an Italian physicist, Alessandro Volta (1745–1827). The comparable unit using water pressure as an example would be pounds per square inch (psi). It is possible to have very high pressures (volts) and low water flow (amperes). It is also possible to have high water flow (amperes) and low pressures (volts). Voltage is also called **electrical potential**, because if there is voltage present in a conductor, there is a potential (possibility) for current flow. This electrical pressure is a result of the following:

- Excess electrons remain at one end of the wire or circuit.
- There is a lack of electrons at the other end of the wire or circuit.
- The natural effect is to equalize this imbalance, creating a pressure to allow the movement of electrons through a conductor.
- It is possible to have pressure (volts) without any flow (amperes). For example, a fully charged 12 volt battery sitting on a workbench has 12 volts of pressure potential, but because there is not a conductor (circuit) connected between the positive and negative posts of the battery, there is no flow (amperes). Current will only flow when there is pressure and a circuit for the electrons to flow in order to "equalize" to a balanced state.

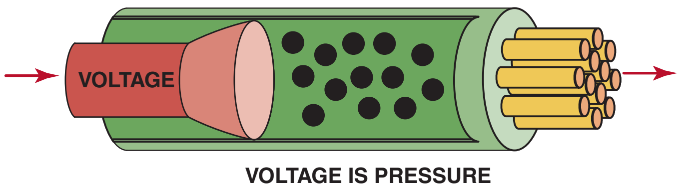


FIGURE 3–17 Voltage is the electrical pressure that causes the electrons to flow through a conductor.

FIGURE 3–18 This digital multimeter set to read DC volts is being used to test the voltage of a vehicle battery. Most multimeters can also measure resistance (ohms) and current flow (amperes).

Voltage does *not* flow through conductors, but voltage does cause current (in amperes) to flow through conductors. ● **SEE FIGURE 3–17.**

The conventional abbreviations and measurement for voltage are as follows:

1. The volt is the unit of measurement for the amount of electrical pressure.
2. **Electromotive force**, abbreviated **EMF,** is another way of indicating voltage.
3. *V* is the generally accepted abbreviation for *volts*.
4. The symbol used in calculations is *E*, for *electromotive force*.
5. Volts are measured by a **voltmeter.** ● **SEE FIGURE 3–18.**

OHMS **Resistance** to the flow of current through a conductor is measured in units called **ohms,** named after the German physicist, George Simon Ohm (1787–1854). The resistance to the flow of free electrons through a conductor results from the countless collisions the electrons cause within the atoms of the conductor. ● **SEE FIGURE 3–19.**

The conventional abbreviations and measurement for resistance are as follows:

1. The ohm is the unit of measurement for electrical resistance.
2. The symbol for ohms is Ω (Greek capital letter omega), the last letter of the Greek alphabet.

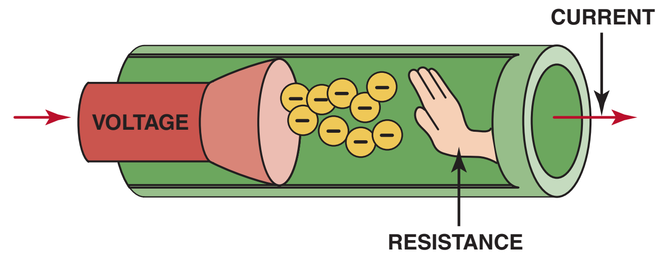


FIGURE 3–19 Resistance to the flow of electrons through a conductor is measured in ohms.

FIGURE 3–20 A display at the Henry Ford Museum in Dearborn, Michigan, which includes a hand-cranked generator and a series of light bulbs. This figure shows a young man attempting to light as many bulbs as possible. The crank gets harder to turn as more bulbs light because it requires more power to produce the necessary watts of electricity.

3. The symbol used in calculations is *R*, for *resistance*.
4. Ohms are measured by an **ohmmeter**.
5. Resistance to electron flow depends on the material used as a conductor.

WATTS A **watt** is the electrical unit for *power,* the capacity to do work. It is named after a Scottish inventor, James Watt (1736–1819). The symbol for power is *P*. Electrical power is calculated as amperes times volts:

$$P \text{ (power)} = I \text{ (amperes)} \times E \text{ (volts)}$$

The formula can also be used to calculate the amperage if the wattage and the voltage are known. For example, a 100 watt light bulb powered by 120 volts AC in the shop requires how many amperes?

A (amperes) = P (watts) divided by E (volts)

$A = 0.83$ amperes

● **SEE FIGURE 3–20.**

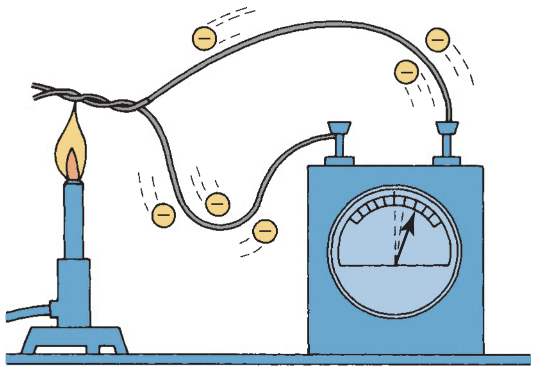


FIGURE 3–21 Electron flow is produced by heating the connection of two different metals.

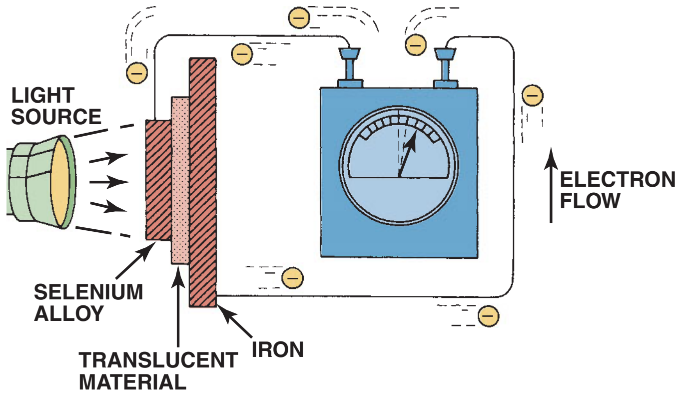


FIGURE 3–22 Electron flow is produced by light striking a light-sensitive material.

SOURCES OF ELECTRICITY

FRICTION When certain different materials are rubbed together, the friction causes electrons to be transformed from one to the other. Both materials become electrically charged. These charges are not in motion, but stay on the surface where they were deposited. Because the charges are stationary, or static, this type of voltage is called **static electricity.** Walking across a carpeted floor creates a buildup of a static charge in your body which is an insulator and then the charge is discharged when you touch a metal conductor. Vehicle tires rolling on pavement often create static electricity that interferes with radio reception.

HEAT When pieces of two different metals are joined together at both ends and one junction is heated, current passes through the metals. The current is very small, only millionths of an ampere, but this is enough to use in a temperature-measuring device called a **thermocouple.** ● **SEE FIGURE 3–21.**

Some engine temperature sensors operate in this manner. This form of voltage is called **thermoelectricity**.

Thermoelectricity was discovered and has been known for over a century. In 1823, a German physicist, Thomas Johann Seebeck, discovered that a voltage was developed in a loop containing two dissimilar metals, provided the two junctions were maintained at different temperatures. A decade later, a French scientist, Jean Charles Athanase Peltier, found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the **Peltier effect**. A Peltier effect device is often used in portable coolers to keep food items cool if the current flows in one direction and keep items warm if the current flows in reverse.

LIGHT In 1839, Edmond Becquerel noticed that by shining a beam of sunlight over two different liquids, he could develop an electric current. When certain metals are exposed to light, some of the light energy is transferred to the free electrons of the metal. This excess energy breaks the electrons loose from the surface of the metal. They can then be collected and made to flow in a conductor. ● **SEE FIGURE 3–22.**

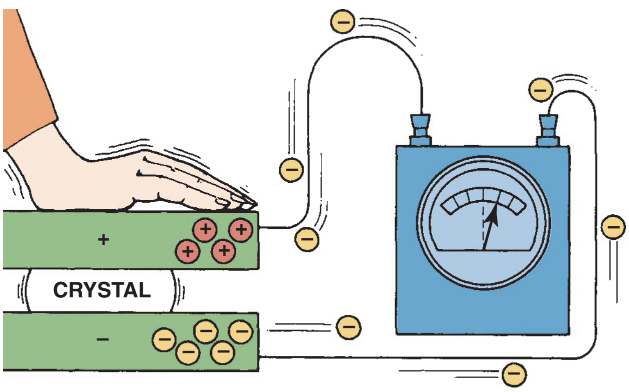


FIGURE 3–23 Electron flow is produced by pressure on certain crystals.

This **photoelectricity** is widely used in light-measuring devices such as photographic exposure meters and automatic headlamp dimmers.

PRESSURE The first experimental demonstration of a connection between the generation of a voltage due to pressure applied to a crystal was published in 1880 by Pierre and Jacques Curie. Their experiment consisted of voltage being produced when prepared crystals, such as quartz, topaz, and Rochelle salt, had a force applied. ● **SEE FIGURE 3–23.**

This current is used in crystal microphones, underwater hydrophones, and certain stethoscopes. The voltage created is called **piezoelectricity**. A gas grille igniter uses the principle of piezoelectricity to produce a spark, and engine knock sensor (KS) use piezoelectricity to create a voltage signal for use as an input as an engine computer input signal.

CHEMICAL Two different materials (usually metals) placed in a conducting and reactive chemical solution create a difference in potential, or voltage, between them. This principle is called **electrochemistry** and is the basis of the automotive battery.

? FREQUENTLY ASKED QUESTION

Why Is Gold Used if Copper Has Lower Resistance?

Copper is used for most automotive electrical components and wiring because it has low resistance and is reasonably priced. Gold is used in airbag connections and sensors because it does not corrode. Gold can be buried for hundreds of years and when dug up it is just as shiny as ever.

MAGNETISM Electricity can be produced if a conductor is moved through a magnetic field or a moving magnetic field is moved near a conductor. This is the principle of how many automotive devices work, including:

- Starter motor
- Alternator
- Ignition coils
- Solenoids and relays

CONDUCTORS AND RESISTANCE

All conductors have some resistance to current flow. The following are principles of conductors and their resistance.

- **If the conductor length is doubled, its resistance doubles.** This is the reason why battery cables are designed to be as short as possible.
- **If the conductor diameter is increased, its resistance is reduced.** This is the reason starter motor cables are larger in diameter than other wiring in the vehicle.
- **As the temperature increases, the resistance of the conductor also increases.** This is the reason for installing heat shields on some starter motors. The heat shield helps to protect the conductors (copper wiring inside the starter) from excessive engine heat and so reduces the resistance of starter circuits. Because a conductor increases in resistance with increased temperature, the conductor is called a **positive temperature coefficient (PTC)** resistor.
- **Materials used in the conductor have an impact on its resistance.** Silver has the lowest resistance of any conductor, but is expensive. Copper is the next lowest in resistance and is reasonably priced. ● **SEE CHART 3–1** for a comparison of materials.

1	Silver
2	Copper
3	Gold
4	Aluminum
5	Tungsten
6	Zinc
7	Brass (copper and zinc)
8	Platinum
9	Iron
10	Nickel
11	Tin
12	Steel
13	Lead

CHART 3–1

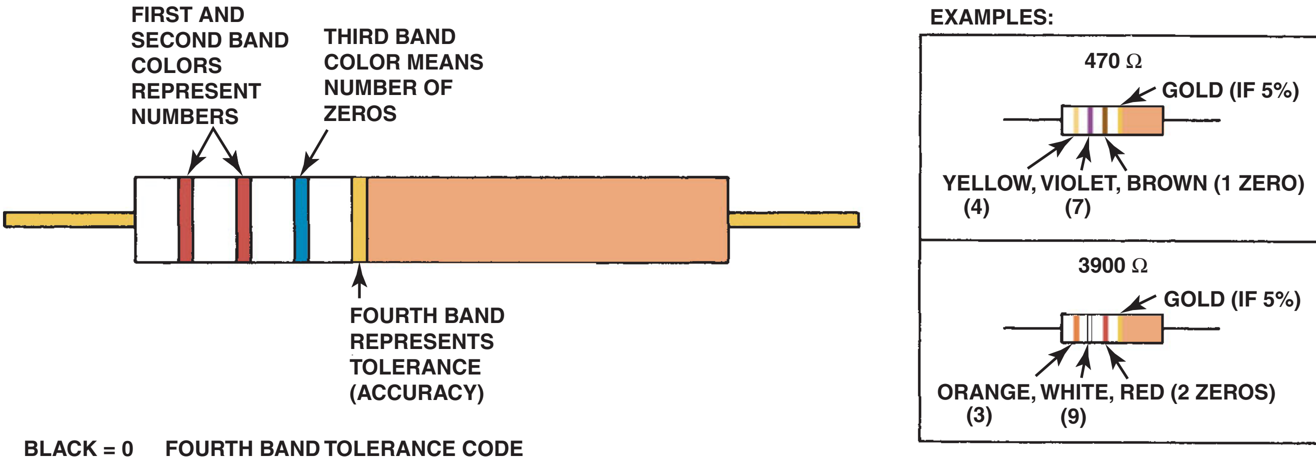
Conductor ratings (starting with the best).

RESISTORS

FIXED RESISTORS Resistance is the opposition to current flow. Resistors represent an electrical load, or resistance, to current flow. Most electrical and electronic devices use resistors of specific values to limit and control the flow of current. Resistors can be made from carbon or from other materials that restrict the flow of electricity and are available in various sizes and resistance values. Most resistors have a series of painted color bands around them. These color bands are coded to indicate the degree of resistance. ● **SEE FIGURES 3–24 AND 3–25.**

VARIABLE RESISTORS Two basic types of mechanically operated variable resistors are used in automotive applications.

- A **potentiometer** is a three-terminal variable resistor where a wiper contact provides a variable voltage output. ● **SEE FIGURE 3–26.** Potentiometers are most commonly used as throttle position (TP) sensors on computer-equipped engines. A potentiometer is also used to control audio volume, bass, treble, balance, and fade.
- Another type of mechanically operated variable resistor is the **rheostat.** A rheostat is a *two*-terminal unit in which all of the current flows through the movable arm. ● **SEE FIGURE 3–27.** A rheostat is commonly used for a dash light dimmer control.



BLACK = 0
BROWN = 1
RED = 2
ORANGE = 3
YELLOW = 4
GREEN = 5
BLUE = 6
VIOLET = 7
GRAY = 8
WHITE = 9

FOURTH BAND TOLERANCE CODE
NO FOURTH BAND = ±20%
SILVER = ±10%
* GOLD = ±5%
RED = ±2%
BROWN = ±1%

* GOLD IS THE MOST COMMONLY AVAILABLE RESISTOR TOLERANCE.

FIGURE 3–24 This figure shows a resistor color-code interpretation.

FIGURE 3–25 A typical carbon resistor.

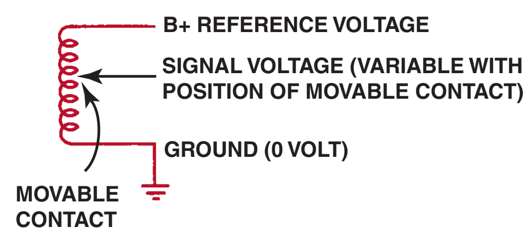


FIGURE 3–26 A three-wire variable resistor is called a potentiometer.

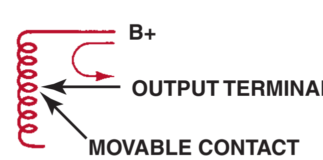


FIGURE 3–27 A two-wire variable resistor is called a rheostat.

SUMMARY

1. Electricity is the movement of electrons from one atom to another.
2. In order for current to flow in a circuit or wire, there must be an excess of electrons at one end and a deficiency of electrons at the other end.
3. Automotive electricity uses the conventional theory that electricity flows from positive to negative.
4. The ampere is the measure of the amount of current flow.
5. Voltage is the unit of electrical pressure.
6. The ohm is the unit of electrical resistance.
7. Sources of electricity include friction, heat, light, pressure, and chemical.

REVIEW QUESTIONS

1. What is electricity?
2. What are the ampere, volt, and ohm?
3. What are three examples of conductors and three examples of insulators?
4. What are the four sources of electricity?

CHAPTER QUIZ

1. An electrical conductor is an element with ________ electrons in its outer orbit.
   - **a.** Less than 2
   - **b.** Less than 4
   - **c.** Exactly 4
   - **d.** More than 4
2. Like charges ________.
   - **a.** Attract
   - **b.** Repel
   - **c.** Neutralize each other
   - **d.** Add
3. Carbon and silicon are examples of ________.
   - **a.** Semiconductors
   - **b.** Insulators
   - **c.** Conductors
   - **d.** Photoelectric materials
4. Which unit of electricity does the work in a circuit?
   - **a.** Volt
   - **b.** Ampere
   - **c.** Ohm
   - **d.** Coulomb
5. As temperature increases, ________.
   - **a.** The resistance of a conductor decreases
   - **b.** The resistance of a conductor increases
   - **c.** The resistance of a conductor remains the same
   - **d.** The voltage of the conductor decreases
6. The ________ is a unit of electrical pressure.
   - **a.** Coulomb
   - **b.** Volt
   - **c.** Ampere
   - **d.** Ohm
7. Technician A says that a two-wire variable resistor is called a rheostat. Technician B says that a three-wire variable resistor is called a potentiometer. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Creating electricity by exerting a force on a crystal is called ________.
   - **a.** Electrochemistry
   - **b.** Piezoelectricity
   - **c.** Thermoelectricity
   - **d.** Photoelectricity
9. The fact that a voltage can be created by exerting force on a crystal is used in which type of sensor?
   - **a.** Throttle position (TP)
   - **b.** Manifold absolute pressure (MAP)
   - **c.** Barometric pressure (BARO)
   - **d.** Knock sensor (KS)
10. A potentiometer, a three-wire variable resistance, is used in which type of sensor?
    - **a.** Throttle position (TP)
    - **b.** Manifold absolute pressure (MAP)
    - **c.** Barometric pressure (BARO)
    - **d.** Knock sensor (KS)

chapter 4

ELECTRICAL CIRCUITS AND OHM'S LAW

OBJECTIVES: After studying Chapter 4, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain Ohm's law. • Identify the parts of a complete circuit. • Explain Watt's law. • Describe the characteristics of an open, a short-to-ground, and a short-to-voltage.

KEY TERMS: Circuit 56 • Complete circuit 56 • Continuity 56 • Electrical load 56 • Grounded 58 • High resistance 58 • Load 56 • Ohm's law 59 • Open circuit 57 • Power path 56 • Power source 56 • Protection 56 • Return path (ground) 56 • Shorted 57 • Short-to-ground 58 • Short-to-voltage 57 • Watt 60 • Watt's law 60

CIRCUITS

DEFINITION A **circuit** is a complete path that electrons travel from a power source (such as a battery) through a **load** such as a light bulb and back to the power source. It is called a *circuit* because the current must start and finish at the same place (power source).

For *any* electrical circuit to work at all, it must be continuous from the battery (power), through all the wires and components, and back to the battery (ground). A circuit that is continuous throughout is said to have **continuity.**

PARTS OF A COMPLETE CIRCUIT Every **complete circuit** contains the following parts. ● **SEE FIGURE 4–1.**

1. A **power source,** such as a vehicle's battery
2. **Protection** from harmful overloads (excessive current flow) (Fuses, circuit breakers, and fusible links are examples of electrical circuit protection devices.)
3. The **power path** for the current to flow through from the power source to the resistance (This path from a power source to the load—a light bulb in this example—is usually an insulated copper wire.)
4. The **electrical load** or resistance which converts electrical energy into heat, light, or motion
5. A **return path (ground)** for the electrical current from the load back to the power source so that there is a *complete* circuit (This return, or ground, path is usually the metal body, frame, ground wires, and engine block of the vehicle. ● **SEE FIGURE 4–2.**)
6. Switches and controls that turn the circuit on and off (● **SEE FIGURE 4–3.**)

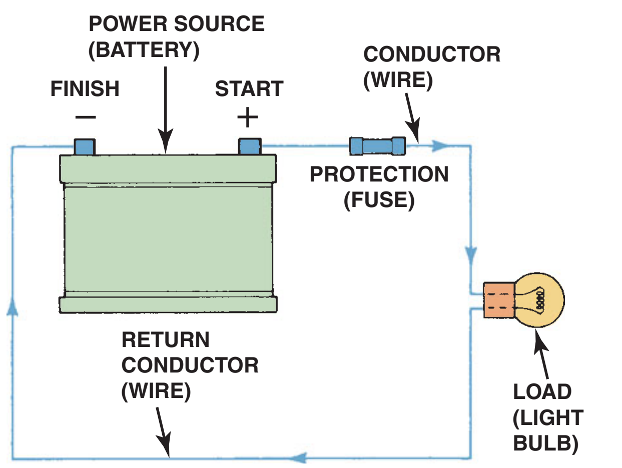


FIGURE 4–1 All complete circuits must have a power source, a power path, protection (fuse), an electrical load (light bulb in this case), and a return path back to the power source.

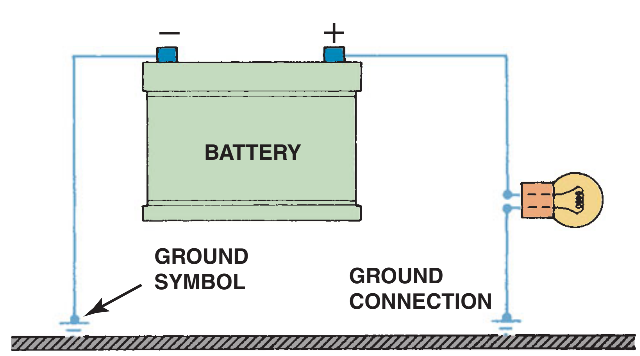


FIGURE 4–2 The return path back to the battery can be any electrical conductor, such as a copper wire or the metal frame or body of the vehicle.

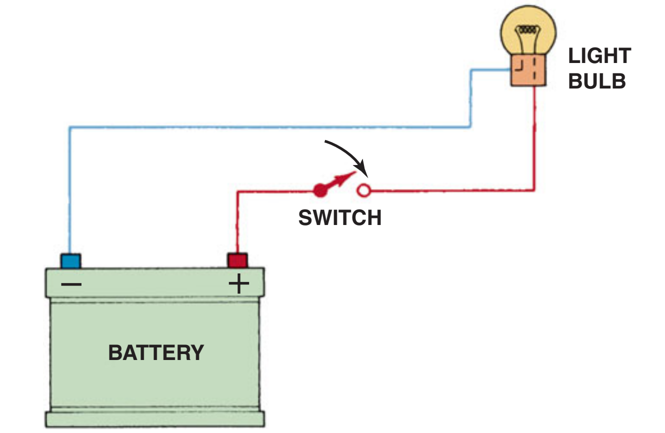


FIGURE 4–3 An electrical switch opens the circuit and no current flows. The switch could also be on the return (ground) path wire.

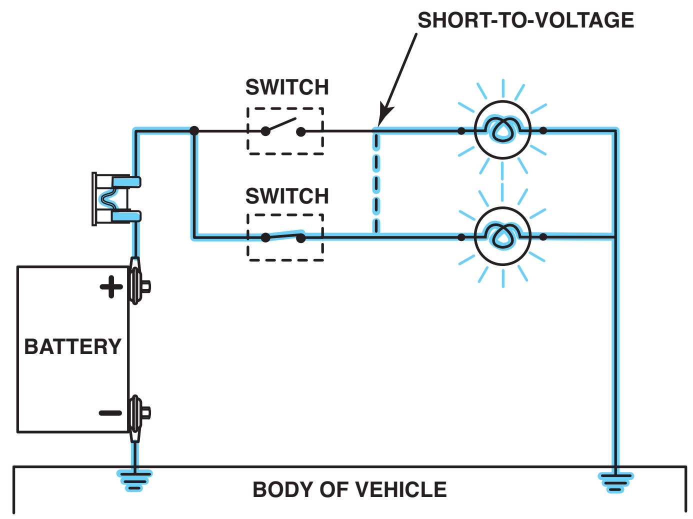


FIGURE 4–5 A short circuit permits electrical current to bypass some or all of the resistance in the circuit.

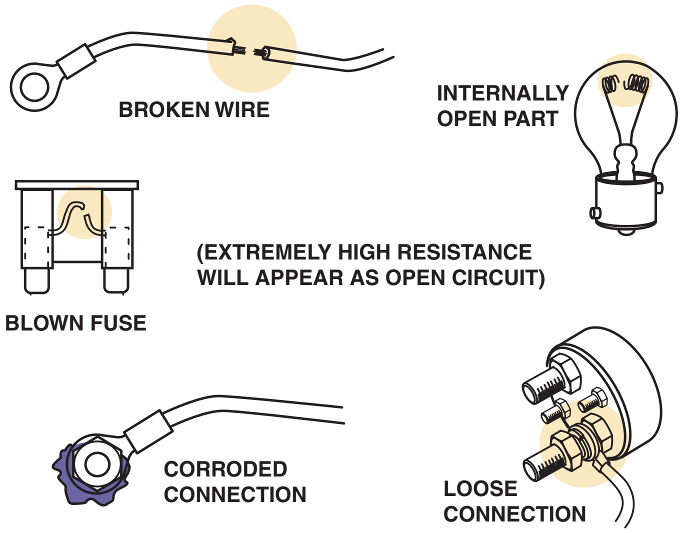


FIGURE 4–4 Examples of common causes of open circuits. Some of these causes are often difficult to find.

CIRCUIT FAULT TYPES

OPEN CIRCUITS An **open circuit** is any circuit that is *not* complete, or that lacks continuity, such as a broken wire. ● **SEE FIGURE 4–4.**

Open circuits have the following features:

1. *No current at all* will flow through an open circuit.
2. An open circuit may be created by a break in the circuit or by a switch that opens (turns off) the circuit and prevents the flow of current.
3. In any circuit containing a power load and ground, an opening anywhere in the circuit will cause the circuit not to work.

> **TECH TIP**
>
> **"Open" Is a Four-Letter Word**
>
> An open in a circuit breaks the path of current flow. The open can be any break in the power side, load, or ground side of a circuit. A switch is often used to close and open a circuit to turn it on and off. Just remember,
>
> Open = no current flow
> Closed = current flow
>
> Trying to locate an open circuit in a vehicle is often difficult and may cause the technician to use other four-letter words, such as "HELP"!

4. A light switch in a home and the headlight switch in a vehicle are examples of devices that open a circuit to control its operation.
5. A fuse will blow (open) when the current in the circuit exceeds the fuse rating. This stops the current flow to prevent any harm to the components or wiring as a result of the fault.

SHORT-TO-VOLTAGE *If a wire (conductor) or component is shorted to voltage*, it is commonly referred to as being **shorted.** A **short-to-voltage** occurs when the power side of one circuit is electrically connected to the power side of another circuit. ● **SEE FIGURE 4–5.**

A short circuit has the following features:

1. It is a complete circuit in which the current usually bypasses *some* or *all* of the resistance in the circuit.
2. It involves the power side of the circuit.
3. It involves a copper-to-copper connection (two power-side wires touching together).
4. It is also called a *short-to-voltage*.

REAL WORLD FIX

The Short-to-Voltage Story

A technician was working on a Chevrolet pickup truck with the following unusual electrical problems.

1. When the brake pedal was depressed, the dash light and the side marker lights would light.
2. The turn signals caused all lights to blink and the fuel gauge needle to bounce up and down.
3. When the brake lights were on, the front parking lights also came on.

The technician tested all fuses using a conventional test light and found them to be okay. All body-to-engine block ground wires were clean and tight. All bulbs were of the correct trade number as specified in the owner's manual.

NOTE: Using a single-filament bulb (such as a #1156) in the place of a dual-filament bulb (such as a #1157) could also cause many of these same problems.

Because most of the trouble occurred when the brake pedal was depressed, the technician decided to trace all the wires in the brake light circuit. The technician discovered the problem near the exhaust system. A small hole in the tailpipe (after the muffler) directed hot exhaust gases to the wiring harness containing all of the wires for circuits at the rear of the truck. The heat had melted the insulation and caused most of the wires to touch. Whenever one circuit was activated (such as when the brake pedal was applied), the current had a complete path to several other circuits. A fuse did not blow because there was enough resistance in the circuits being energized, so the current (in amperes) was too low to blow any fuses.

5. It usually affects more than one circuit. In this case if one circuit is electrically connected to another circuit, one of the circuits may operate when it is not supposed to because it is being supplied power from another circuit.
6. It *may* or *may not* blow a fuse. ● **SEE FIGURE 4–6.**

SHORT-TO-GROUND

A **short-to-ground** is a type of short circuit that occurs when the current bypasses part of the normal circuit and flows directly to ground. A short-to-ground has the following features.

1. Because the ground return circuit is metal (vehicle frame, engine, or body), it is often identified as having current flowing from copper to steel.
2. It occurs any place where a power path wire accidentally touches a return path wire or conductor. ● **SEE FIGURE 4–7.**

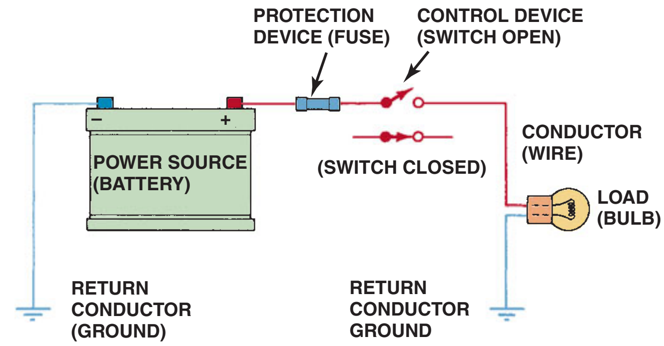


FIGURE 4–6 A fuse or circuit breaker opens the circuit to prevent possible overheating damage in the event of a short circuit.

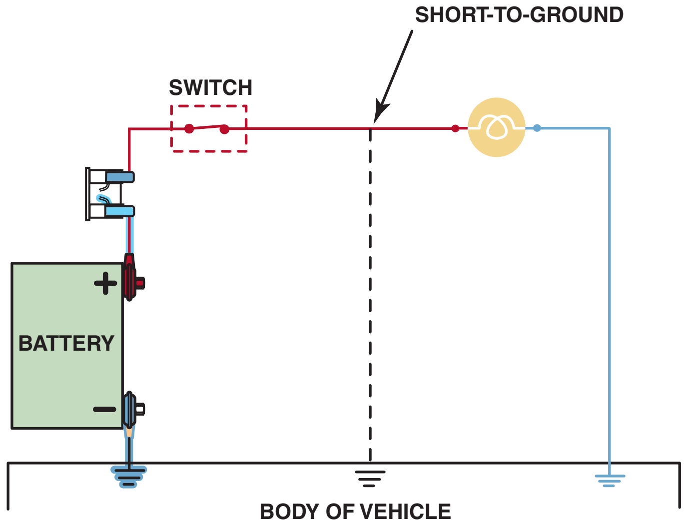


FIGURE 4–7 A short-to-ground affects the power side of the circuit. Current flows directly to the ground return, bypassing some or all of the electrical loads in the circuit. There is no current in the circuit past the short. A short-to ground will also cause the fuse to blow.

3. A defective component or circuit that is shorted to ground is commonly called **grounded.**
4. A short-to-ground almost always results in a blown fuse, damaged connectors, or melted wires.

HIGH RESISTANCE

High resistance can be caused by any of the following:

- Corroded connections or sockets
- Loose terminals in a connector
- Loose ground connections

If there is high resistance anywhere in a circuit, it may cause the following problems.

1. Slow operation of a motor-driven unit, such as the windshield wipers or blower motor
2. Dim lights
3. "Clicking" of relays or solenoids
4. No operation of a circuit or electrical component

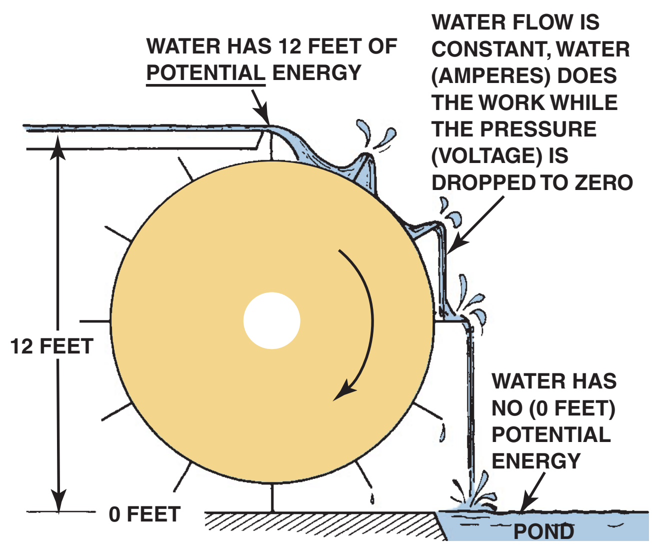


FIGURE 4–8 Electrical flow through a circuit is similar to water flowing over a waterwheel. The more the water (amperes in electricity), the greater the amount of work (waterwheel). The amount of water remains constant, yet the pressure (voltage in electricity) drops as the current flows through the circuit.

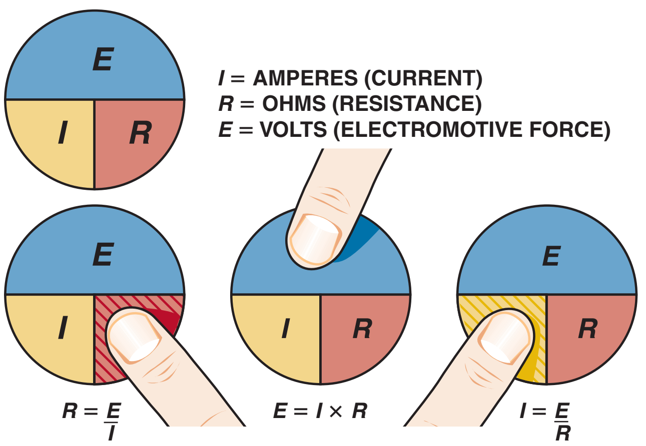


FIGURE 4–9 To calculate one unit of electricity when the other two are known, simply use your finger and cover the unit you do not know. For example, if both voltage (*E*) and resistance (*R*) are known, cover the letter *I* (amperes). Notice that the letter *E* is above the letter *R,* so divide the resistor's value into the voltage to determine the current in the circuit.

TECH TIP

Think of a Waterwheel

A beginner technician cleaned the positive terminal of the battery when the starter was cranking the engine slowly. When questioned by the shop foreman as to why only the positive post had been cleaned, the technician responded that the negative terminal was "only a ground." The foreman reminded the technician that the current, in amperes, is constant throughout a series circuit (such as the cranking motor circuit). If 200 amperes leave the positive post of the battery, then 200 amperes must return to the battery through the negative post.

The technician could not understand how electricity can do work (crank an engine), yet return the same amount of current, in amperes, as left the battery. The shop foreman explained that even though the current is constant throughout the circuit, the voltage (electrical pressure or potential) drops to zero in the circuit. To explain further, the shop foreman drew a waterwheel. ● **SEE FIGURE 4–8.**

As water drops from a higher level to a lower level, high potential energy (or voltage) is used to turn the waterwheel and results in low potential energy (or lower voltage). The same amount of water (or amperes) reaches the pond under the waterwheel as started the fall above the waterwheel. As current (amperes) flows through a conductor, it performs work in the circuit (turns the waterwheel) while its voltage (potential) drops.

OHM'S LAW

DEFINITION The German physicist, George Simon Ohm, established that electric pressure (EMF) in volts, electrical resistance in ohms, and the amount of current in amperes flowing through any circuit are all related. **Ohm's law** states:

It requires 1 volt to push 1 ampere through 1 ohm of resistance.

This means that if the voltage is doubled, then the number of amperes of current flowing through a circuit will also double if the resistance of the circuit remains the same.

FORMULAS Ohm's law can also be stated as a simple formula used to calculate one value of an electrical circuit if the other two are known. ● **SEE FIGURE 4–9.**

If, for example, the current (*I*) is unknown but the voltage (*E*) and resistance (*R*) are known, then Ohm's Law can be used to find the answer.

$$I = \frac{E}{R}$$

where

I = Current in amperes (A)

E = Electromotive force (EMF) in volts (V)

R = Resistance in ohms (Ω)

1. Ohm's law can determine the resistance if the volts and amperes are known: $R = \frac{E}{I}$
2. Ohm's law can determine the *voltage* if the resistance (ohms) and amperes are known: $E = I \times R$
3. Ohm's law can determine the amperes if the resistance and voltage are known: $I = \frac{E}{R}$

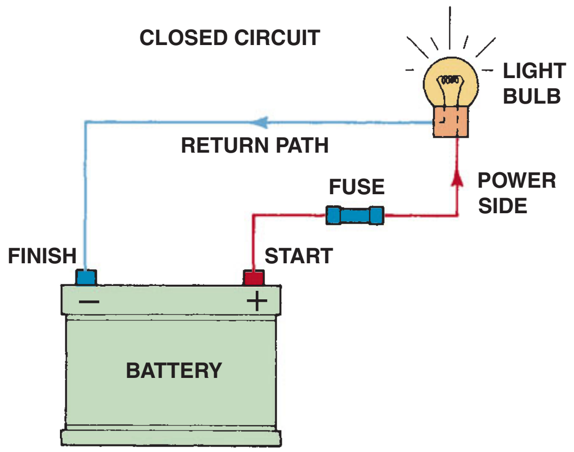


FIGURE 4–10 This closed circuit includes a power source, power-side wire, circuit protection (fuse), resistance (bulb), and return path wire. In this circuit, if the battery has 12 volts and the electrical load has 4 ohms, then the current through the circuit is 4 amperes.

VOLTAGE	RESISTANCE	AMPERAGE
Up	Down	Up
Up	Same	Up
Up	Up	Same
Same	Down	Up
Same	Same	Same
Same	Up	Down
Down	Up	Down
Down	Same	Down

CHART 4–1

Ohm's law relationship with the three units of electricity.

NOTE: Before applying Ohm's law, be sure that each unit of electricity is converted into base units. For example, 10 KΩ should be converted to 10,000 ohms and 10 mA should be converted into 0.010 A.

- **SEE CHART 4–1.**

OHM'S LAW APPLIED TO SIMPLE CIRCUITS If a battery with 12 volts is connected to a resistor of 4 ohms, as shown in **FIGURE 4–10,** how many amperes will flow through the circuit?

Using Ohm's law, we can calculate the number of amperes that will flow through the wires and the resistor. Remember, if two factors are known (volts and ohms in this example), the remaining factor (amperes) can be calculated using Ohm's law.

$$I = \frac{E}{R} = \frac{12\text{ V}}{4\,\Omega}\text{A}$$

The values for the voltage (12) and the resistance (4) were substituted for the variables *E* and *R*, and *I* is thus 3 amperes

$$\left(\frac{12}{4} = 3\right)$$

If we want to connect a resistor to a 12 volt battery, we now know that this simple circuit requires 3 amperes to operate. This may help us for two reasons.

1. We can now determine the wire diameter that we will need based on the number of amperes flowing through the circuit.
2. The correct fuse rating can be selected to protect the circuit.

WATT'S LAW

BACKGROUND James Watt (1736–1819), a Scottish inventor, first determined the power of a typical horse while measuring the amount of coal being lifted out of a mine. The power of one horse was determined to be 33,000 foot-pounds per minute. Electricity can also be expressed in a unit of power called a watt and the relationship is known as **Watt's law,** which states:

A watt is a unit of electrical power represented by a current of 1 ampere through a circuit with a potential difference of 1 volt.

FORMULAS A **watt** is a unit of electrical power represented by a current of 1 ampere through a circuit with a potential difference of 1 volt.

The symbol for a watt is the capital letter *W*. The formula for watts is:

$$W = I \times E$$

Another way to express this formula is to use the letter *P* to represent the unit of power. The formula then becomes:

$$P = I \times E$$

HINT: An easy way to remember this equation is that it spells "pie."

Engine power is commonly rated in watts or kilowatts (1,000 watts equal 1 kilowatt), because 1 horsepower is equal to 746 watts. For example, a 200 horsepower engine can be rated as having the power equal to 149,200 watts or 149.2 kilowatts (kW).

To calculate watts, both the current in amperes and the voltage in the circuit must be known. If any two of these factors are known, then the other remaining factor can be determined by the following equations:

$$P = I \times E \text{ (watts equal amperes times voltage)}$$

$$I = \frac{P}{E} \text{ (amperes equal watts divided by voltage)}$$

$$E = \frac{P}{I} \text{ (voltage equals watts divided by amperes)}$$

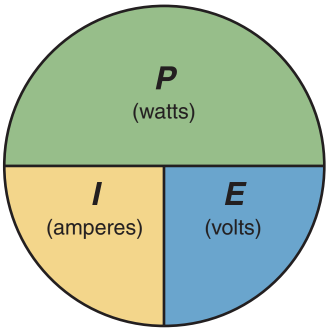


FIGURE 4–11 To calculate one unit when the other two are known, simply cover the unknown unit to see what unit needs to be divided or multiplied to arrive at the solution.

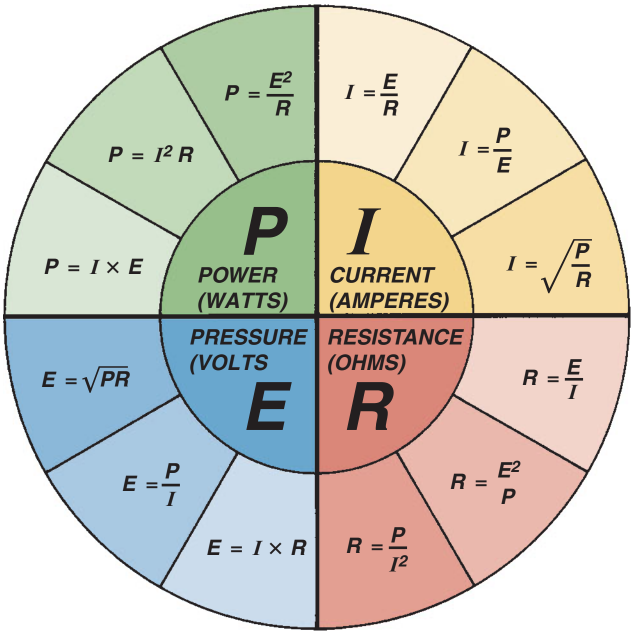


FIGURE 4–12 "Magic circle" of most formulas for problems involving Ohm's law. Each quarter of the "pie" has formulas used to solve for a particular unknown value: current (amperes), in the upper right segment; resistance (ohms), in the lower right; voltage (*E*), in the lower left; and power (watts), in the upper left.

TECH TIP

Wattage Increases by the Square of the Voltage

The brightness of a light bulb, such as an automotive headlight or courtesy light, depends on the number of watts available. The watt is the unit by which electrical power is measured. If the battery voltage drops, even slightly, the light becomes noticeably dimmer. The formula for calculating power (P) in watts is $P = I \times E$. This can also be expressed as Watts = Amps × Volts.

According to Ohm's law, $I = \frac{E}{R}$. Therefore, $\frac{E}{R}$ can be substituted for I in the previous formula resulting in $P = \frac{E}{R} \times E$ or $P = \frac{E^2}{R}$.

E^2 means E multiplied by itself. A small change in the voltage (E) has a big effect on the total brightness of the bulb. (Remember, household light bulbs are sold according to their wattage.) Therefore, if the voltage to an automotive bulb is reduced, such as by a poor electrical connection, the brightness of the bulb is *greatly* affected. A poor electrical ground causes a voltage drop. The voltage at the bulb is reduced and the bulb's brightness is reduced.

A Watt's circle can be drawn and used like the Ohm's law circle diagram. ● **SEE FIGURE 4–11.**

MAGIC CIRCLE The formulas for calculating any combination of electrical units are shown in ● **FIGURE 4–12.**

It is almost impossible to remember all of these formulas, so this one circle showing all of the formulas is nice to have available if needed.

SUMMARY

1. All complete electrical circuits have a power source (such as a battery), a circuit protection device (such as a fuse), a power-side wire or path, an electrical load, a ground return path, and a switch or a control device.
2. A short-to-voltage involves a copper-to-copper connection and usually affects more than one circuit.
3. A short-to-ground usually involves a power path conductor coming in contact with a return (ground) path conductor and usually causes the fuse to blow.
4. An open is a break in the circuit resulting in absolutely no current flow through the circuit.

REVIEW QUESTIONS

1. What is included in a complete electrical circuit?
2. What is the difference between a short-to-voltage and a short-to-ground?
3. What is the difference between an electrical open and a short?
4. What is Ohm's law?
5. What occurs to current flow (amperes) and wattage if the resistance of a circuit is increased because of a corroded connection?

CHAPTER QUIZ

1. If an insulated wire rubbed through a part of the insulation and the wire conductor touched the steel body of a vehicle, the type of failure would be called a(n) ________.
   a. Short-to-voltage **c.** Open
   b. Short-to-ground **d.** Chassis ground
2. If two insulated wires were to melt together where the copper conductors touched each other, the type of failure would be called a(n) ________.
   a. Short-to-voltage **c.** Open
   b. Short-to-ground **d.** Floating ground
3. If 12 volts are being applied to a resistance of 3 ohms, ________ amperes will flow.
   a. 12 **c.** 4
   b. 3 **d.** 36
4. How many watts are consumed by a light bulb if 1.2 amperes are measured when 12 volts are applied?
   a. 14.4 watts **c.** 10 watts
   b. 144 watts **d.** 0.10 watt
5. How many watts are consumed by a starter motor if it draws 150 amperes at 10 volts?
   a. 15 watts **c.** 1,500 watts
   b. 150 watts **d.** 15,000 watts
6. High resistance in an electrical circuit can cause ________.
   a. Dim lights
   b. Slow motor operation
   c. Clicking of relays or solenoids
   d. All of the above
7. If the voltage increases in a circuit, what happens to the current (amperes) if the resistance remains the same?
   a. Increases
   b. Decreases
   c. Remains the same
   d. Cannot be determined
8. If 200 amperes flow from the positive terminal of a battery and operate the starter motor, how many amperes will flow back to the negative terminal of the battery?
   a. Cannot be determined
   b. Zero
   c. One half (about 100 amperes)
   d. 200 amperes
9. What is the symbol for voltage used in calculations?
   a. *R* **c.** EMF
   b. *E* **d.** *I*
10. Which circuit failure is most likely to cause the fuse to blow?
    a. Open **c.** Short-to-voltage
    b. Short-to-ground **d.** High resistance

chapter 5

SERIES, PARALLEL, AND SERIES-PARALLEL CIRCUITS

OBJECTIVES: After studying Chapter 5, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area “A” (General Electrical/Electronic System Diagnosis). • Identify a series circuit. • Identify a parallel circuit. • Identify a series-parallel circuit. • Calculate the total resistance in a parallel circuit. • State Kirchhoff’s voltage law. • Calculate voltage drops in a series circuit. • Explain series and parallel circuit laws. • State Kirchhoff’s current law. • Identify where faults in a series-parallel circuit can be detected or determined.

KEY TERMS: Branches 67 • Combination circuit 71 • Compound circuit 71 • Kirchhoff’s current law 67 • Kirchhoff’s voltage law 64 • Leg 67 • Parallel circuit 67 • Series circuit 63 • Series-parallel circuits 71 • Shunt 67 • Total circuit resistance 68 • Voltage drop 65

SERIES CIRCUITS

A **series circuit** is a complete circuit that has more than one electrical load where all of the current has only one path to flow through all of the loads. Electrical components such as fuses and switches are generally not considered to be included in the determination of a series circuit. The circuit must be continuous or have continuity in order for current to flow through the circuit.

NOTE: Because an electrical load needs both a power and a ground to operate, a break (open) anywhere in a series circuit will cause the current in the circuit to stop.

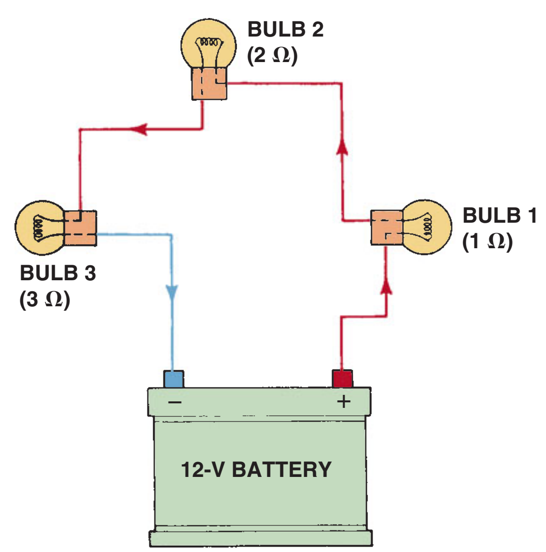


FIGURE 5–1 A series circuit with three bulbs. All current flows through all resistances (bulbs). The total resistance of the circuit is the sum of the total resistance of the bulbs, and the bulbs will light dimly because of the increased resistance and the reduction of current flow (amperes) through the circuit.

OHM’S LAW AND SERIES CIRCUITS

As explained earlier, a series circuit is a circuit containing more than one resistance in which all current must flow through all resistances in the circuit. Ohm’s law can be used to calculate the value of one unknown (voltage, resistance, or amperes) if the other two values are known.

Because *all* current flows through all resistances, the total resistance is the sum (addition) of all resistances. ● **SEE FIGURE 5–1.** The total resistance of the circuit shown here is 6 ohms (1 Ω + 2 Ω + 3 Ω). The formula for total resistance (R_T) for a series circuit is:

$$R_T = R_1 + R_2 + R_3 + \cdots$$

Using Ohm’s law to find the current flow, we have

$$I = E/R + 12\text{ V}/6\ \Omega + 2\text{ A}$$

Therefore, with a total resistance of 6 ohms using a 12-volt battery in the series circuit shown, 2 amperes of current will flow through the entire circuit. If the amount of resistance in a circuit is reduced, more current will flow.

In ● **FIGURE 5–2,** one resistance has been eliminated and now the total resistance is 3 ohms (1 Ω + 2 Ω). Using Ohm’s law to calculate current flow yields 4 amperes.

$$I = E/R = 12\text{ V}/3\ \Omega = 4\text{ A}$$

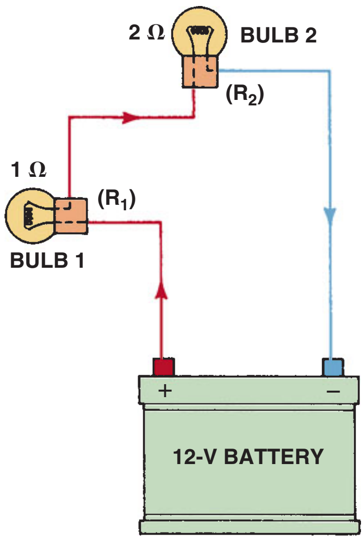


FIGURE 5–2 A series circuit with two bulbs.

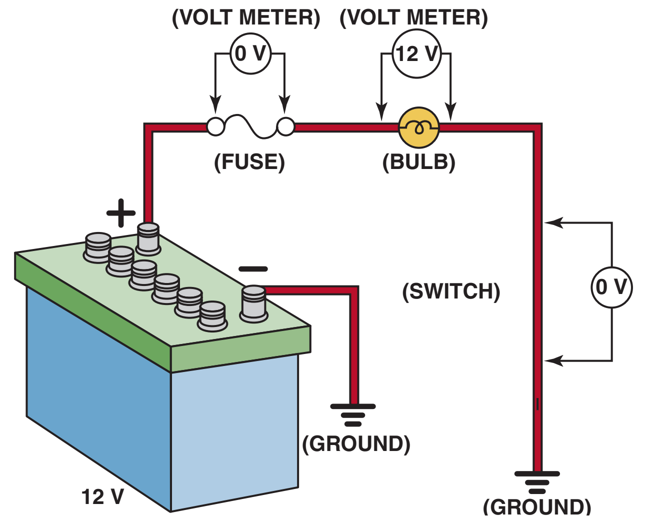


FIGURE 5–3 As current flows through a circuit, the voltage drops in proportion to the amount of resistance in the circuit. Most, if not all, of the resistance should occur across the load such as the bulb in this circuit. All of the other components and wiring should produce little, if any, voltage drop. If a wire or connection did cause a voltage drop, less voltage would be available to light the bulb and the bulb would be dimmer than normal.

TECH TIP

Farsighted Quality of Electricity

Electricity almost seems to act as if it "knows" what resistances are ahead on the long trip through a circuit. If the trip through the circuit has many high-resistance components, very few electrons (amperes) will choose to attempt to make the trip. If a circuit has little or no resistance (for example, a short circuit), then as many electrons (amperes) as possible attempt to flow through the complete circuit. If the flow exceeds the capacity of the fuse or the circuit breaker, then the circuit is opened and all current flow stops.

Notice that the current flow was doubled (4 amperes instead of 2 amperes) when the resistance was cut in half (from 6 ohms to 3 ohms).

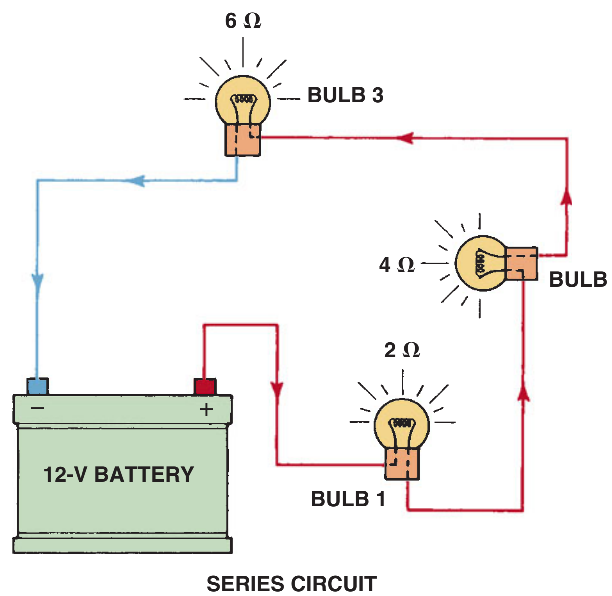


FIGURE 5–4 In a series circuit the voltage is dropped or lowered by each resistance in the circuit. The higher the resistance, the greater the drop in voltage.

KIRCHHOFF'S VOLTAGE LAW

The voltage that is applied through a series circuit drops with each resistor in a manner similar to that in which the strength of an athlete drops each time a strenuous physical feat is performed. The greater the resistance, the greater the drop in voltage.

A German physicist, Gustav Robert Kirchhoff (1824–1887), developed laws about electrical circuits. His second law, **Kirchhoff's voltage law,** concerns voltage drops. It states: *The voltage around any closed circuit is equal to the sum (total) of the voltage drops across the resistances.*

APPLYING KIRCHHOFF'S VOLTAGE LAW Kirchhoff states in his second law that the voltage will drop in proportion to the resistance and that the total of all voltage drops will equal the applied voltage. **SEE FIGURE 5–3.** Using **FIGURE 5–4,** the total resistance of the circuit can be determined by adding the individual resistances (2 Ω + 4 Ω + 6 Ω = 12 Ω). The current through the circuit is determined by using

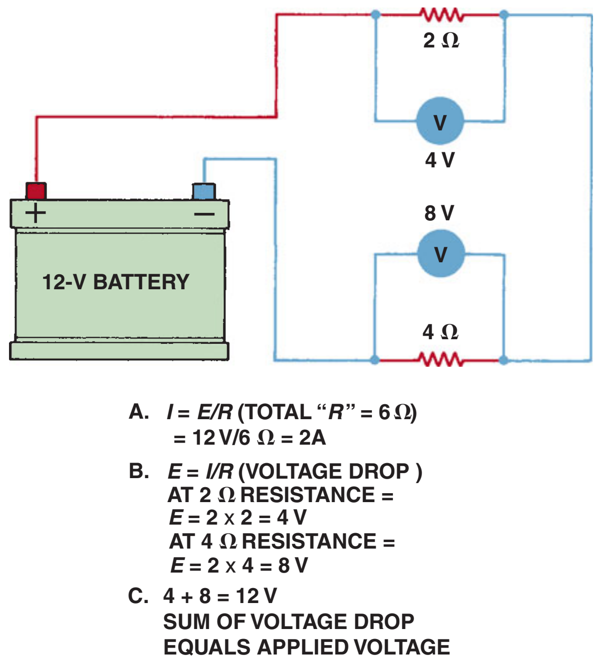


FIGURE 5–5 A voltmeter reads the differences of voltage between the test leads. The voltage read across a resistance is the voltage drop that occurs when current flows through a resistance. A voltage drop is also called an "*IR*" drop because it is calculated by multiplying the current (*I*) through the resistance (electrical load) by the value of the resistance (*R*).

Ohm's law, $I = E/R = 12\text{ V}/12\ \Omega = 1\text{ A}$. Therefore, in the circuit shown, the following values are known:

Resistance = 12 Ω

Voltage = 12 V

Current = 1 A

Everything is known *except* the voltage drop caused by each resistance. The **voltage drop** can be determined by using Ohm's law and calculating for voltage (*E*) using the value of each resistance individually:

$$E = I \times R$$

where

E = Voltage

I = Current in the circuit (remember, the current is constant in a series circuit; only the voltage varies)

R = Resistance of only one of the resistances

The voltage drops are as follows:

Voltage drop for bulb 1: $E = I \times R = 1\text{ A} \times 2\ \Omega = 2\text{ V}$

Voltage drop for bulb 2: $E = I \times R = 1\text{ A} \times 4\ \Omega = 4\text{ V}$

Voltage drop for bulb 3: $E = I \times R = 1\text{ A} \times 6\ \Omega = 6\text{ V}$

NOTE: Notice that the voltage drop is proportional to the resistance. In other words, the higher the resistance, the greater the voltage drop. A 6-ohm resistance dropped the voltage three times as much as the voltage drop created by the 2-ohm resistance.

? FREQUENTLY ASKED QUESTION

Why Check the Voltage Drop Instead of Measuring the Resistance?

Imagine a wire with all strands cut except for one. An ohmmeter can be used to check the resistance of this wire and the resistance would be low, indicating that the wire was okay. But this one small strand cannot properly carry the current (amperes) in the circuit. A voltage drop test is therefore a better test to determine the resistance in components for two reasons:

- An ohmmeter can only test a wire or component that has been disconnected from the circuit and is not carrying current. The resistance can, and does, change when current flows.
- A voltage drop test is a dynamic test because as the current flows through a component, the conductor increases in temperature, which in turn increases resistance. This means that a voltage drop test is testing the circuit during normal operation and is therefore the most accurate way of determining circuit conditions.

A voltage drop test is also easier to perform because the resistance does not have to be known, only that the unwanted loss of voltage in a circuit should be less than 3% or less than about 0.14 volts for any 12-volt circuit.

According to Kirchhoff, the sum (addition) of the voltage drops should equal the applied voltage (battery voltage):

$$\textbf{Total of voltage drops} = 2\text{ V} + 4\text{ V} + 6\text{ V} = 12\text{ V} = \textbf{Battery voltage}$$

This illustrates Kirchhoff's second (voltage) law. Another example is illustrated in ● **FIGURE 5–5.**

USE OF VOLTAGE DROPS Voltage drops, due to built-in resistance, are used in automotive electrical systems to drop the voltage in the following examples.

1. **Dash lights.** Most vehicles are equipped with a method of dimming the brightness of the dash lights by turning a variable resistor. This type of resistor can be changed and therefore varies the voltage to the dash light bulbs. A high voltage to the bulbs causes them to be bright, and a low voltage results in a dim light.
2. **Blower motor** (heater or air-conditioning fan). Speeds are usually controlled by a fan switch sending current through high-, medium-, or low-resistance wire resistors. The highest resistance will drop the voltage the most, causing the motor to run at the lowest speed. The highest speed of the motor will occur when *no* resistance is in the circuit and full battery voltage is switched to the blower motor.

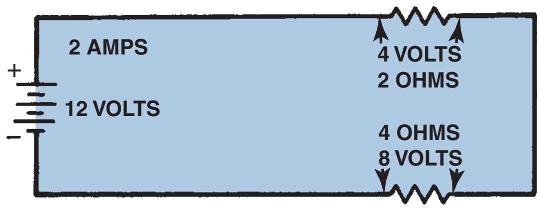


FIGURE 5–6 In this series circuit with a 2-ohm resistor and a 4-ohm resistor, current (2 amperes) is the same throughout even though the voltage drops across each resistor.

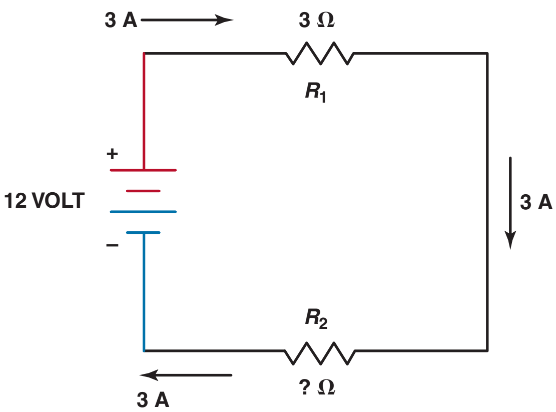


FIGURE 5–7 Example 1.

SERIES CIRCUIT LAWS

Law 1 The total resistance in a series circuit is the sum total of the individual resistances. The resistance values of each electrical load are simply added together.

Law 2 The current is constant throughout the entire circuit. ● **SEE FIGURE 5–6**. If 2 amperes of current leave the battery, 2 amperes of current return to the battery.

Law 3 Although the current (in amperes) is constant, the voltage drops across each resistance in the circuit. The voltage drop across each load is proportional to the value of the resistance compared to the total resistance. For example, if the resistance is one-half of the total resistance, the voltage drop across that resistance will be one-half of the applied voltage. The sum total of all individual voltage drops equals the applied source voltage.

SERIES CIRCUIT EXAMPLES

Each of the four examples includes solving for the following:

- Total resistance in the circuit
- Current flow (amperes) through the circuit
- Voltage drop across each resistance

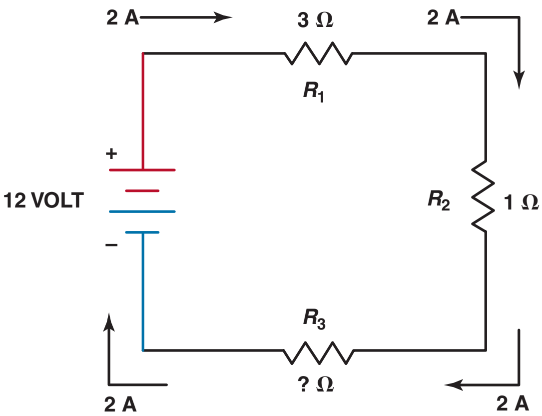


FIGURE 5–8 Example 2.

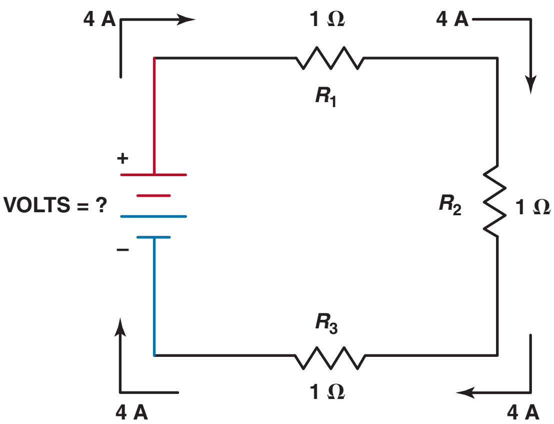


FIGURE 5–9 Example 3.

Example 1:

● **SEE FIGURE 5–7.**

The unknown in this problem is the value of R_2. The total resistance, however, can be calculated using Ohm's law.

$$R_{Total} = E/I = 12 \text{ volts}/3 \text{ A} = 4\ \Omega$$

Because R_1 is 3 ohms and the total resistance is 4 ohms, the value of R_2 is 1 ohm.

Example 2:

● **SEE FIGURE 5–8.**

The unknown in this problem is the value of R_3. The total resistance, however, can be calculated using Ohm's law.

$$R_{Total} = E/I = 12 \text{ volts}/2 \text{ A} = 6\ \Omega$$

The total resistance of R_1 (3 ohms) and R_2 (1 ohm) equals 4 ohms so that the value of R_3 is the difference between the total resistance (6 ohms) and the value of the known resistance (4 ohms).

$$6 - 4 = 2 \text{ ohms} = R_3$$

Example 3:

● **SEE FIGURE 5–9.**

The unknown value in this problem is the voltage of the battery. To solve for voltage, use Ohm's law ($E = I \times R$). The "R" in this problem refers to the total resistance (R_T). The total

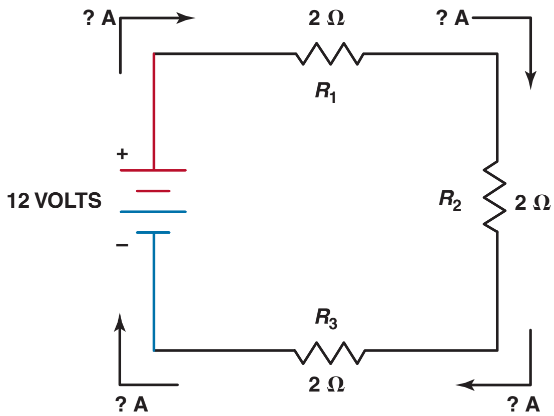


FIGURE 5–10 Example 4.

resistance of a series circuit is determined by adding the values of the individual resistors.

$$R_T = 1\ \Omega + 1\ \Omega + 1\ \Omega$$
$$R_T = 3\ \Omega$$

Placing the value for the total resistance (3 Ω) into the equation results in a battery voltage of 12 volts.

$$E = 4\ \text{A} \times 3\ \Omega$$
$$E = 12\ \text{volts}$$

Example 4:

● **SEE FIGURE 5–10.**

The unknown in this example is the current (amperes) in the circuit. To solve for current, use Ohm's law.

$$I = E/R = 12\ \text{volts}/6\ \text{ohms} = 2\ \text{A}$$

Notice that the total resistance in the circuit (6 ohms) was used in this example, which is the total of the three individual resistors (2 Ω + 2 Ω + 2 Ω = 6 Ω). The current through the circuit is two amperes.

PARALLEL CIRCUITS

A **parallel circuit** is a complete circuit that has more than one path for the current. The separate paths which split and meet at junction points are called **branches, legs,** or **shunts.** The current flow through each branch or leg varies depending on the resistance in that branch. A break or open in one leg or section of a parallel circuit does not stop the current flow through the remaining legs of the parallel circuit.

KIRCHHOFF'S CURRENT LAW

Kirchhoff's current law (his first law) states: *The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction.* This first law can be illustrated using

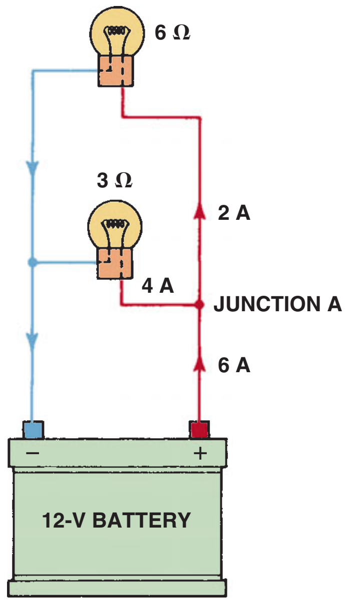


FIGURE 5–11 The amount of current flowing into junction point A equals the total amount of current flowing out of the junction.

Ohm's law, as seen in ● **FIGURE 5–11.** Kirchhoff's law states that the amount of current flowing into junction A will equal the current flowing out of junction A.

Because the 6-ohm leg requires 2 amperes and the 3-ohm resistance leg requires 4 amperes, it is necessary that the wire from the battery to junction A be capable of handling 6 amperes. Also notice that the sum of the current flowing *out* of a junction (2 + 4 = 6 A) is equal to the current flowing *into* the junction (6 A), proving Kirchhoff's current law.

PARALLEL CIRCUIT LAWS

Law 1 The total resistance of a parallel circuit is always less than that of the smallest-resistance leg. This occurs because not all of the current flows through each leg or branch. With many branches, more current can flow from the battery just as more vehicles can travel on a road with five lanes compared to a road with only one or two lanes.

Law 2 The voltage is the same for each leg of a parallel circuit.

Law 3 The sum of the individual currents in each leg will equal the total current. The amount of current flow through a parallel circuit may vary for each leg depending on the resistance of that leg. The current flowing through each leg results in the same voltage drop (from the power side to the ground side) as for every other leg of the circuit. ● **SEE FIGURE 5–12.**

NOTE: A parallel circuit drops the voltage from source voltage to zero (ground) across the resistance in each leg of the circuit.

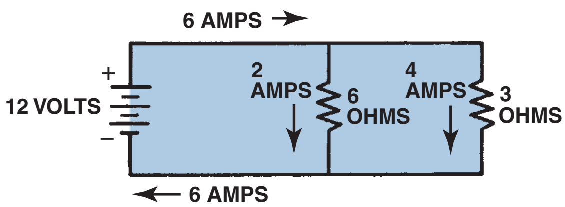


FIGURE 5–12 The current in a parallel circuit splits (divides) according to the resistance in each branch.

TECH TIP

The Path of Least Resistance

There is an old saying that electricity will always take the path of least resistance. This is true, especially if there is a fault such as in the secondary (high-voltage) section of the ignition system. If there is a path to ground that is lower than the path to the spark plug, the high-voltage spark will take the path of least resistance. In a parallel circuit where there is more than one path for the current to flow, most of the current will flow through the branch with the lower resistance. This does not mean that all of the current will flow through the lowest resistance, because the other path does provide a path to ground, and the amount of current flow through the other branches is determined by the resistance and the applied voltage according to Ohm's law.

Therefore, the only place where electricity takes the path of least resistance is in a series circuit where there are not other paths for the current to flow.

DETERMINING TOTAL RESISTANCE IN A PARALLEL CIRCUIT

There are five methods commonly used to determine total resistance in a parallel circuit.

NOTE: Determining the total *resistance* of a parallel circuit is very important in automotive service. Electronic fuel-injector and diesel engine glow plug circuits are two of the most commonly tested circuits where parallel circuit knowledge is required. Also, when installing extra lighting, the technician must determine the proper gauge wire and protection device.

METHOD 1 The total *current* (in amperes) can be calculated first by treating each leg of the parallel circuit as a simple circuit. ● **SEE FIGURE 5–13**. Each leg has its own power and ground (−), and therefore, the current through each leg is independent of the current through any other leg.

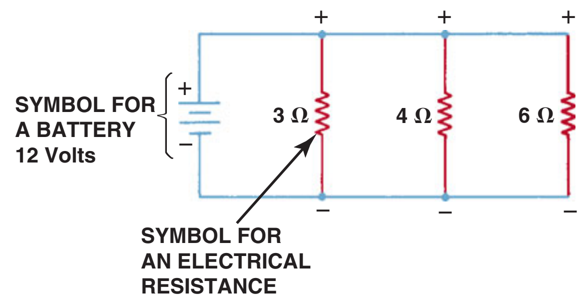


FIGURE 5–13 In a typical parallel circuit, each resistance has power and ground and each leg operates independently of the other legs of the circuit.

Current through the 3-Ω resistance =
$$I = E/R = 12\ \text{V}/3\ \Omega = 4\ \text{A}$$

Current through the 4-Ω resistance =
$$I = E/R = 12\ \text{V}/4\ \Omega = 3\ \text{A}$$

Current through the 6-Ω resistance =
$$I = E/R = 12\ \text{V}/6\ \Omega = 2\ \text{A}$$

The total current flowing from the battery is the sum total of the individual currents for each leg. Total current from the battery is, therefore, 9 amperes (4 A + 3 A + 2 A = 9 A).

If **total circuit resistance** (R_T) is needed, Ohm's law can be used to calculate it because voltage (E) and current (I) are now known.

$$R_T = E/I = 12\ \text{V}/9\ \text{A} = 1.33\ \Omega$$

Note that the total resistance (1.33 Ω) is smaller than that of the smallest-resistance leg of the parallel circuit. This characteristic of a parallel circuit holds true because not all current flows through all resistances as in a series circuit.

Because the current has alternative paths to ground through the various legs of a parallel circuit, as additional resistances (legs) are added to a parallel circuit, the total current from the battery (power source) *increases.*

Additional current can flow when resistances are added in parallel, because each leg of a parallel circuit has its own power and ground and the current flowing through each leg is strictly dependent on the resistance of *that* leg.

METHOD 2 If only two resistors are connected in parallel, the total resistance (R_T) can be found using the formula $R_T = (R_1 \times R_2) / (R_1 + R_2)$. For example, using the circuit in ● **FIGURE 5–14** and substituting 3 ohms for R_1 and 4 amperes for R_2, $R_T = (3 \times 4) / (3 + 4) = 12/7 = 1.7\ \Omega$. Note that the total resistance (1.7 Ω) is smaller than that of the smallest-resistance leg of the circuit.

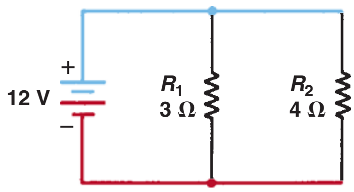


FIGURE 5–14 A schematic showing two resistors in parallel connected to a 12-volt battery.

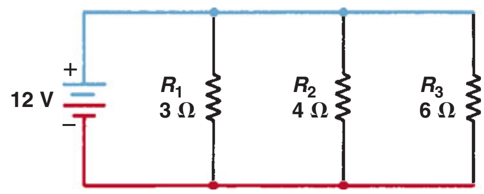


FIGURE 5–15 A parallel circuit with three resistors connected to a 12-volt battery.

NOTE: Which resistor is R_1 and which is R_2 is not important. The position in the formula makes no difference in the multiplication and addition of the resistor values.

This formula can be used for more than two resistances in parallel, but only two resistances can be calculated at a time. After solving for R_T for two resistors, use the value of R_T as R_1 and the additional resistance in parallel as R_2. Then solve for another R_T. Continue the process for all resistance legs of the parallel circuit. However, note that it might be easier to solve for R_T when there are more than two resistances in parallel by using Method 3 or 4.

METHOD 3 A formula that can be used to find the total resistance for any number of resistances in parallel is $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$

To solve for R_T for the three resistance legs in ● **FIGURE 5–15,** substitute the values of the resistances for R_1, R_2, and R_3: $1/R_T = 1/3 + 1/4 + 1/6$. The fractions cannot be added together unless they all have the same denominator. The lowest common denominator in this example is 12. Therefore, 1/3 becomes 4/12, 1/4 becomes 3/12, and 1/6 becomes 2/12. $1/R_T = 4/12 + 3/12 + 2/12$ or 9/12. Cross multiplying $R_T = 12/9 = 1.33\ \Omega$. Note that the result (1.33 Ω) is the same regardless of the method used (see Method 1). The most difficult part of using this method (besides using fractions) is determining the lowest common denominator, especially for circuits containing a wide range of ohmic values for the various legs. For an easier method using a calculator, see Method 4.

METHOD 4 This method uses an electronic calculator, commonly available at very low cost. Instead of determining the lowest common denominator as in Method 3, one can use the electronic calculator to convert the fractions to decimal equivalents. The

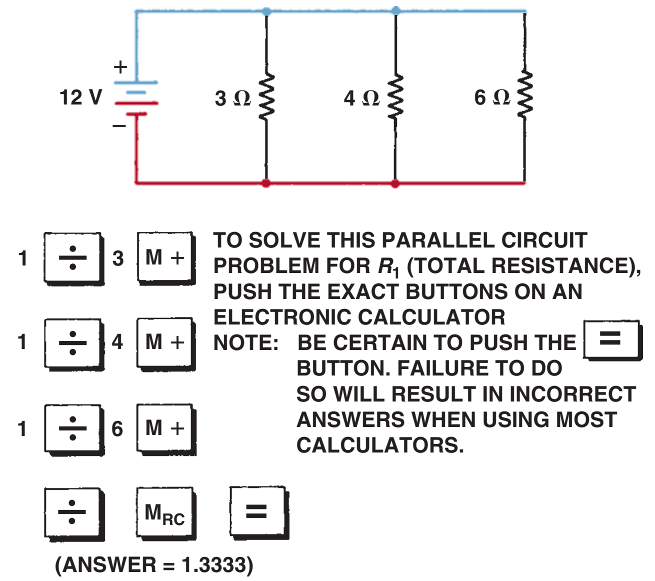


FIGURE 5–16 Using an electronic calculator to determine the total resistance of a parallel circuit.

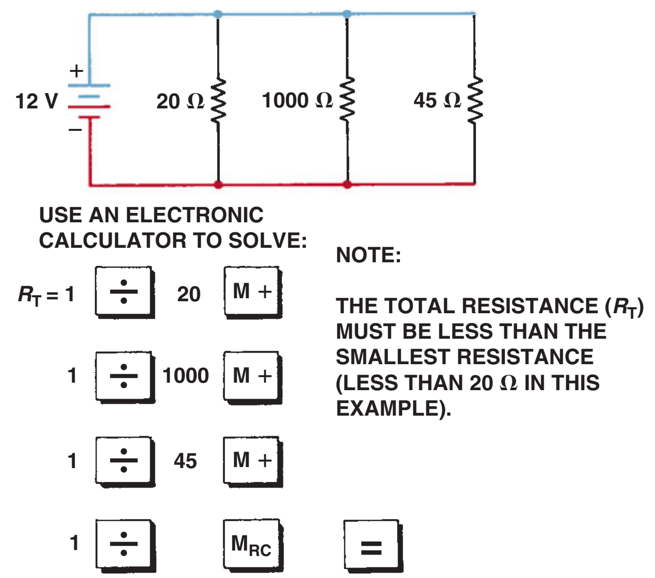


FIGURE 5–17 Another example of how to use an electronic calculator to determine the total resistance of a parallel circuit. The answer is 13.45 ohms. Notice that the effective resistance of this circuit is less than the resistance of the lowest branch (20 ohms).

memory buttons on most calculators can be used to keep a running total of the fractional values. Use ● **FIGURE 5–16** and calculate the total resistance (R_T) by pushing the indicated buttons on the calculator. Also ● **SEE FIGURE 5–17**.

NOTE: This method can be used to find the total resistance of *any number* of resistances in parallel.

The memory recall (MRC) and equals (=) buttons invert the answer to give the correct value for total

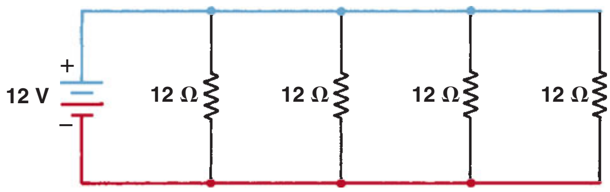


FIGURE 5–18 A parallel circuit containing four 12-ohm resistors. When a circuit has more than one resistor of equal value, the total resistance can be determined by simply dividing the value of the resistance (12 ohms in this example) by the number of equal-value resistors (4 in this example) to get 3 ohms.

resistance (1.33 Ω). The inverse (1/X or X^{-1}) button can be used with the sum (SUM) button on scientific calculators without using the memory button.

METHOD 5 This method can be easily used whenever two or more resistances connected in parallel are of the same value. ● **SEE FIGURE 5–18**. To calculate the total resistance (R_T) of equal-value resistors, divide the number of equal resistors into the value of the resistance. R_T = Value of equal resistance/Number of equal resistances = 12 Ω/4 = 3 Ω.

NOTE: Since most automotive and light-truck electrical circuits involve multiple use of the same resistance, this method is the most useful. For example, if six additional 12-ohm lights were added to a vehicle, the additional lights would represent just 2 ohms of resistance (12 Ω/6 lights = 2). Therefore, 6 amperes of additional current would be drawn by the additional lights ($I = E/R$ = 12 V/2 Ω = 6 A).

PARALLEL CIRCUIT EXAMPLES

Each of the four examples includes solving for the following:

- Total resistance
- Current flow (amperes) through each branch as well as total current flow
- Voltage drop across each resistance

Example 1:

● **SEE FIGURE 5–19.**

In this example, the voltage of the battery is unknown and the equation to be used is $E = I \times R$ where R represents the total resistance of the circuit. Using the equation for two resistors in parallel, the total resistance is 6 ohms.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{12 \times 12}{12 + 12} = \frac{144}{24} = 6\ \Omega$$

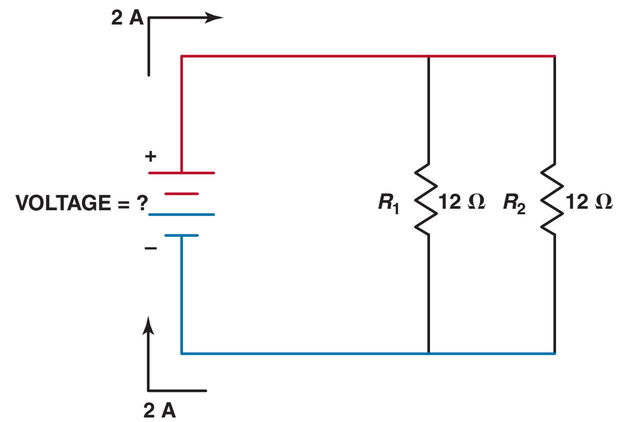


FIGURE 5–19 Example 1.

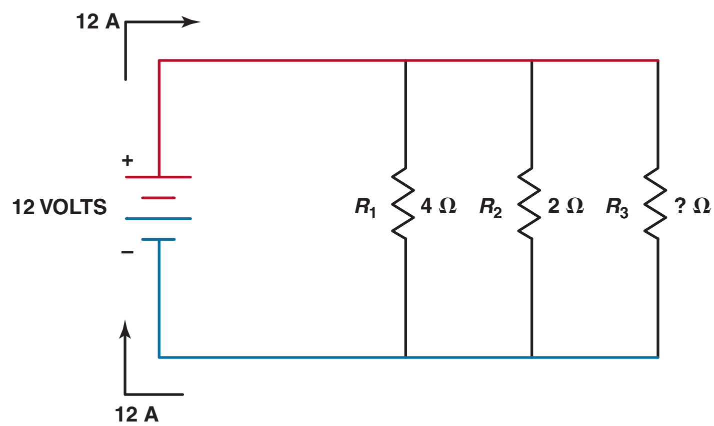


FIGURE 5–20 Example 2.

Placing the value of the total resistors into the equation results in a value for the battery voltage of 12 volts.

$$E = I \times R$$
$$E = 2\text{ A} \times 6\ \Omega$$
$$E = 12\text{ volts}$$

Example 2:

● **SEE FIGURE 5–20.**

In this example, the value of R_3 is unknown. Because the voltage (12 volts) and the current (12 A) are known, it is easier to solve for the unknown resistance by treating each branch or leg as a separate circuit. Using Kirchhoff's law, the total current equals the total current flow through each branch. The current flow through R_1 is 3 A ($I = E/R$ = 12 V/4 Ω = 3 A) and the current flow through R_2 is 6 A ($I = E/R$ = 12 V/2 Ω = 6 A). Therefore, the total current through the two known branches equals 9 A (3 A + 6 A = 9 A). Because there are 12 A leaving and returning to the battery, the current flow through R_3 must be 3 A (12 A − 9 A = 3 A). The resistance must therefore be 4 Ω because the current through the unknown resistance is 3 A ($I = E/R$ = 12 V/4 Ω = 3 A).

Example 3:

● **SEE FIGURE 5–21.**

In this example, the voltage of the battery is unknown. The equation to solve for voltage according to Ohm's law is:

$$E = I \times R$$

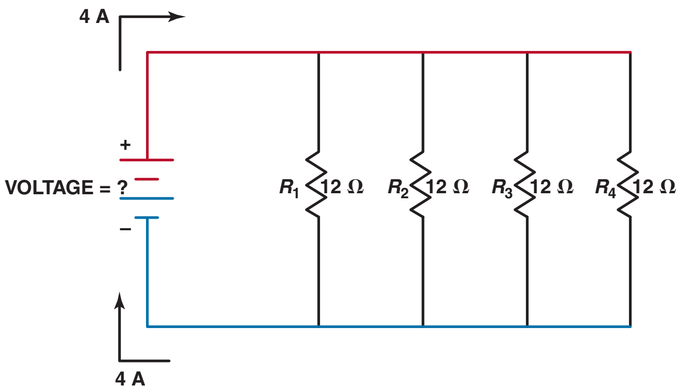


FIGURE 5–21 Example 3.

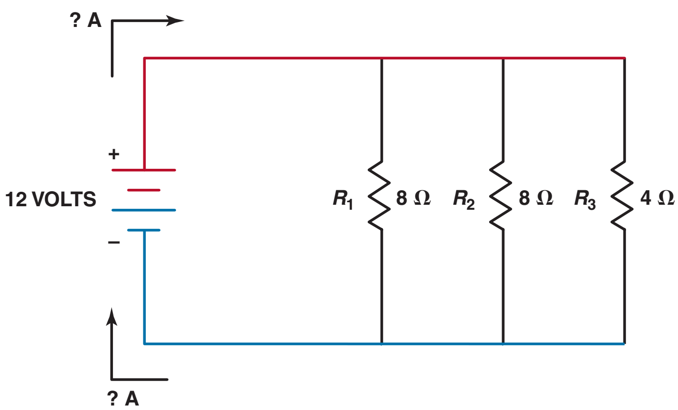


FIGURE 5–22 Example 4.

The *R* in this equation refers to the total resistance. Because there are four resistors of equal value, the total can be determined by the equation:

$$R_{Total} = \text{Value of Resistors/Number of Equal Resistors} = 12\ \Omega/4 = 3\ \Omega$$

Inserting the value of the total resistance of the parallel circuit (3 Ω) into Ohm's law results in a battery voltage of 12 V.

$$E = 4\text{ A} \times 3\ \Omega$$
$$E = 12\text{ V}$$

Example 4:

● **SEE FIGURE 5–22.**

The unknown is the amount of current in the circuit. The Ohm's law equation for determining current is:

$$I = E/R$$

The *R* represents the total resistance. Because there are two equal resistances (8 Ω), these two can be replaced by one resistance of 4 Ω (R_{Total} = Value/Number = 8 Ω/2 = 4 Ω).

The total resistance of this parallel circuit containing two 8-ohm resistors and one 4-ohm resistor is 2 ohms. (two 8 ohm resistors in parallel equals one four ohm. Then you have two four ohm resistors in parallel which equals 2 Ohms) The current flow from the battery is then calculated to be 6 A.

$$I = E/R = 12\text{ V}/2\ \Omega = 6\text{ A}$$

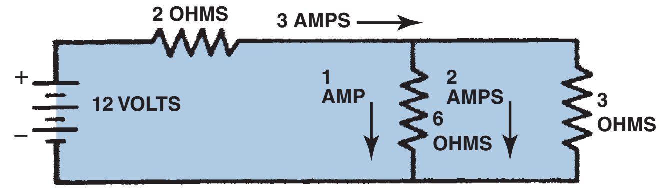


FIGURE 5–23 A series-parallel circuit.

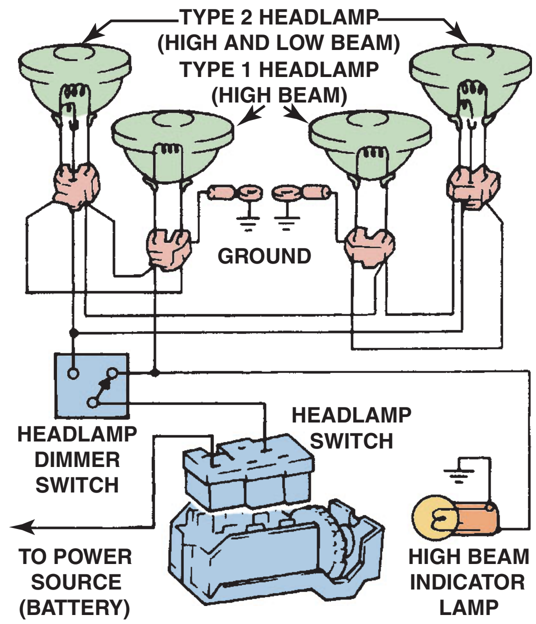


FIGURE 5–24 This complete headlight circuit with all bulbs and switches is a series-parallel circuit.

SERIES-PARALLEL CIRCUITS

Series-parallel circuits are a combination of series and parallel segments in one complex circuit. A series-parallel circuit is also called a **compound** or a **combination circuit.** Many automotive circuits include sections that are in parallel and in series.

A series-parallel circuit includes both parallel loads or resistances, plus additional loads or resistances that are electrically connected in series. There are two basic types of series-parallel circuits.

- A circuit where the load is in series with other loads in parallel. ● **SEE FIGURE 5–23.** An example of this type of series-parallel circuit is a dash light dimming circuit. The variable resistor is used to limit current flow to the dash light bulbs, which are wired in parallel.
- A circuit where a parallel circuit contains resistors or loads which are in series with one or more branches. A headlight and starter circuit is an example of this type of series-parallel circuit. A headlight switch is usually connected in series with a dimmer switch and in parallel with the dash light dimmer resistors. The headlights are also connected in parallel along with the taillights and side marker lights. ● **SEE FIGURE 5–24.**

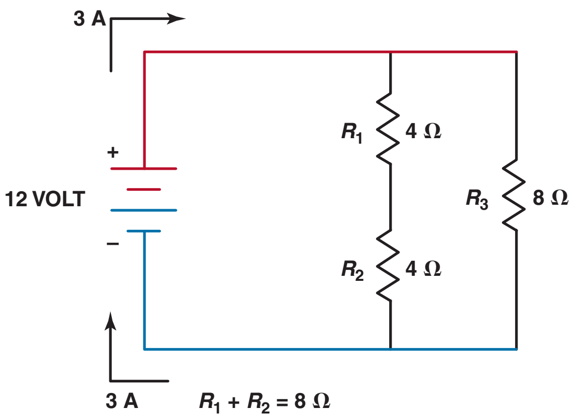


FIGURE 5–25 Solving a series-parallel circuit problem.

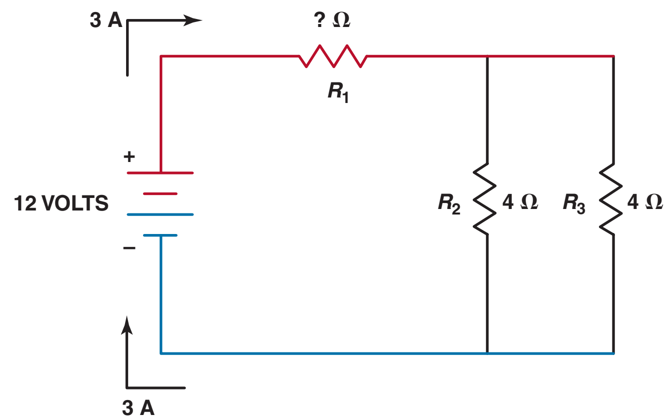


FIGURE 5–26 Example 1.

SERIES-PARALLEL CIRCUIT FAULTS If a conventional parallel circuit, such as a taillight circuit, had an electrical fault that increased the resistance in one branch of the circuit, then the amount of current flow through that one branch will be reduced. The added resistance, due to corrosion or other similar cause, would create a voltage drop. As a result of this drop in voltage, a lower voltage would be applied and the bulb in the taillight would be dimmer than normal. Because the brightness of the bulb depends on the voltage and current applied, the lower voltage and current would cause the bulb to be dimmer than normal. If, however, the added resistance occurred in a part of the circuit that fed both taillights, then both taillights would be dimmer than normal. In this case, the added resistance created a series-parallel circuit that was originally just a simple parallel circuit.

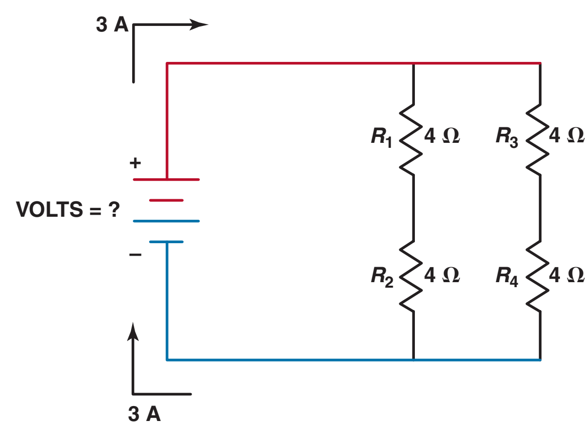


FIGURE 5–27 Example 2.

SOLVING SERIES-PARALLEL CIRCUIT PROBLEMS

The key to solving series-parallel circuit problems is to combine or simplify as much as possible. For example, if there are two loads or resistances in series within a parallel branch or leg, then the circuit can be made simpler if the two are first added together before attempting to solve the parallel section. ● **SEE FIGURE 5–25.**

SERIES-PARALLEL CIRCUIT EXAMPLES

Each of the four examples includes solving for the following.

- Total resistance
- Current flow (amperes) through each branch, as well as total current flow
- Voltage drop across each resistance

Example 1:

● **SEE FIGURE 5–26.**

The unknown resistor is in series with the other two resistances, which are connected in parallel. The Ohm's law equation to determine resistance is:

$$R = E/I = 12\ \text{V}/3\ \text{A} = 4\ \Omega$$

The total resistance of the circuit is therefore 4 ohms, and the value of the unknown can be determined by subtracting the value of the two resistors that are connected in parallel. The parallel branch resistance is 2 Ω.

$$R_T = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2\ \Omega$$

The value of the unknown resistance is therefore 2 Ω.

$$\text{Total } R = 4\ \Omega - 2\ \Omega = 2\ \Omega$$

Example 2:

● **SEE FIGURE 5–27.**

The unknown unit in this circuit is the voltage of the battery. The Ohm's law equation is:

$$E = I \times R$$

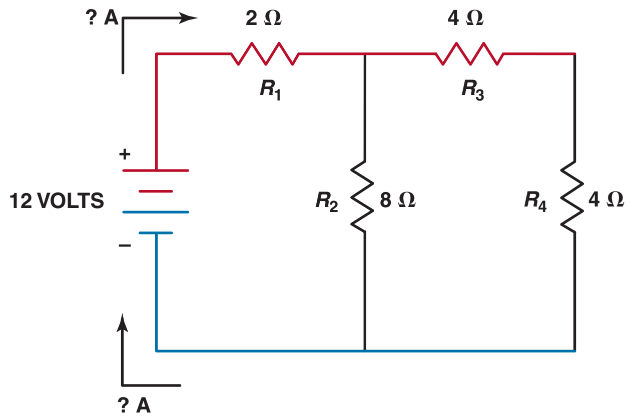


FIGURE 5–28 Example 3.

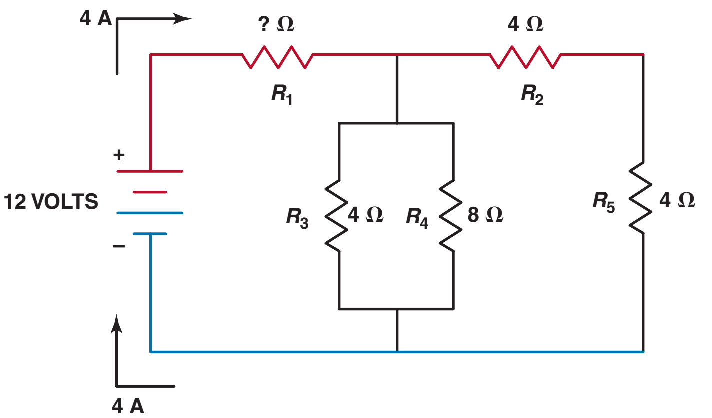


FIGURE 5–29 Example 4.

Before solving the problem, the total resistance must be determined. Because each branch contains two 4-ohm resistors in series, the value in each branch can be added to help simplify the circuit. By adding the resistors in each branch together, the parallel circuit now consists of two 8-ohm resistors.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\ \Omega$$

Inserting the value for the total resistance into the Ohm's law equation results in a value of 12 volts for the battery voltage.

$$E = I \times R$$
$$E = 3\text{ A} \times 4\ \Omega$$
$$E = 12\text{ volts}$$

Example 3:

SEE FIGURE 5–28.

In this example, the total current through the circuit is unknown. The Ohm's law equation to solve for it is:

$$I = E/R$$

The total resistance of the parallel circuit must be determined before the equation can be used to solve for current (amperes). To solve for total resistance, the circuit can first be simplified by adding R_3 and R_4 together because these two resistors are in series in the same branch of the parallel circuit. To simplify even more, the resulting parallel section of the circuit, now containing two 8-ohm resistors in parallel, can be replaced with one 4-ohm resistor.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\ \Omega$$

With the parallel branches now reduced to just one 4-ohm resistor, this can be added to the 2-ohm (R_1) resistor because it is in series, creating a total circuit resistance of 6 ohms. Now the current flow can be determined from Ohm's law:

$$I = E/R = 12\text{ V}/6\ \Omega = 2\text{ A}$$

Example 4:

SEE FIGURE 5–29.

In this example, the value of resistor R_1 is unknown. Using Ohm's law, the total resistance of the circuit is 3 ohms.

$$R = E/I = 12\text{ V}/4\text{ A} = 3\ \Omega$$

However, knowing the total resistance is not enough to determine the value of R_1. To simplify the circuit, R_2 and R_5 can combine to create a parallel branch resistance value of 8 ohms because they are in series. To simplify even further, the two 8-ohm branches can be reduced to one branch of 4 ohms.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\ \Omega$$

Now the circuit has been simplified to one resistor in series (R_1) with two branches with 4 ohms in each branch. These two branches can be reduced to the equal of one 2-ohm resistor.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2\ \Omega$$

Now the circuit includes just one 2-ohm resistor plus the unknown R_1. Because the total resistance is 3 ohms, the value of R_1 must be 1 ohm.

$$3\ \Omega - 2\ \Omega = 1\ \Omega$$

SUMMARY

1. Series circuits:
   - a. In a simple series circuit, the current remains constant throughout, but the voltage drops as current flows through the resistances of the circuit.
   - b. The voltage drop across each resistance or load is directly proportional to the value of the resistance compared to the total resistance in the circuit.
   - c. The sum (total) of the voltage drops equals the applied voltage (Kirchhoff's voltage law).
   - d. An open or a break anywhere in a series circuit stops all current from flowing.
2. Parallel circuits:
   - a. A parallel circuit, such as is used for all automotive lighting, has the same voltage available to each resistance (bulb).
   - b. The total resistance of a parallel circuit is always lower than the smallest resistance.
   - c. The separate paths that split and meet at junction points are called branches, legs, or shunts.
   - d. Kirchhoff's current law states: "The current flowing into a junction of an electrical circuit is equal to current flowing out of that junction."
3. Series-parallel circuits:
   - a. A series-parallel circuit is also called a compound circuit or a combination circuit.
   - b. A series-parallel circuit is a combination of a series and a parallel circuit, which does not include fuses or switches.
   - c. A fault in a series portion of the circuit would affect the operation if the series part was in the power or the ground side of the parallel portion of the circuit.
   - d. A fault in one leg of a series-parallel circuit will affect just the component(s) in that one leg.

REVIEW QUESTIONS

1. What is Kirchhoff's voltage law?
2. What would current (amperes) do if the voltage were doubled in a circuit?
3. What would current (amperes) do if the resistance in the circuit were doubled?
4. What is the formula for voltage drop?
5. Why is the total resistance of a parallel circuit less than the smallest resistance?
6. Why are parallel circuits (instead of series circuits) used in most automotive applications?
7. What does Kirchhoff's current law state?
8. What would be the effect of an open circuit in one leg of a parallel portion of a series-parallel circuit?
9. What would be the effect of an open circuit in a series portion of a series-parallel circuit?

CHAPTER QUIZ

1. The amperage in a series circuit is _____________.
   - a. The same anywhere in the circuit
   - b. Varies in the circuit due to the different resistances
   - c. High at the beginning of the circuit and decreases as the current flows through the resistance
   - d. Always less returning to the battery than leaving the battery
2. The sum of the voltage drops in a series circuit equals the _____________.
   - a. Amperage
   - b. Resistance
   - c. Source voltage
   - d. Wattage
3. If the resistance and the voltage are known, what is the formula for finding the current (amperes)?
   - a. $E = I \times R$
   - b. $I = E \times R$
   - c. $R = E \times I$
   - d. $I = E/R$
4. A series circuit has three resistors of 4 ohms each. The voltage drop across each resistor is 4 volts. Technician A says that the source voltage is 12 volts. Technician B says that the total resistance is 18 ohms. Which technician is correct?
   - a. Technician A only
   - b. Technician B only
   - c. Both Technicians A and B
   - d. Neither Technician A nor B
5. If a 12-volt battery is connected to a series circuit with three resistors of 2 ohms, 4 ohms, and 6 ohms, how much current will flow through the circuit?
   - a. 1 amp
   - b. 2 amp
   - c. 3 amp
   - d. 4 amp

6. A series circuit has two 10-ohm bulbs. A third bulb is added in series. Technician A says that the three bulbs will be dimmer than when only two bulbs were in the circuit. Technician B says that the current in the circuit will increase. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Technician A says that the sum of the voltage drops in a series circuit should equal the source voltage. Technician B says that the current (amperes) varies depending on the value of the resistance in a series circuit. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Two bulbs are connected in parallel to a 12-volt battery. One bulb has a resistance of 6 ohms and the other bulb has a resistance of 2 ohms. Technician A says that only the 2-ohm bulb will light because all of the current will flow through the path with the least resistance and no current will flow through the 6-ohm bulb. Technician B says that the 6-ohm bulb will be dimmer than the 2-ohm bulb. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Calculate the total resistance and current in a parallel circuit with three resistors of 4 Ω, 8 Ω, and 16 Ω, using any one of the five methods (calculator suggested). What is the total resistance and current?
   - **a.** 27 ohms (0.4 ampere)
   - **b.** 14 ohms (0.8 ampere)
   - **c.** 4 ohms (3.0 amperes)
   - **d.** 2.3 ohms (5.3 amperes)
10. A vehicle has four parking lights all connected in parallel and one of the bulbs burns out. Technician A says that this could cause the parking light circuit fuse to blow (open). Technician B says that it would decrease the current in the circuit. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

chapter 6

CIRCUIT TESTERS AND DIGITAL METERS

OBJECTIVES: After studying Chapter 6, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Discuss how to safely use a fused jumper wire, a test light, and a logic probe. • Explain how to set up and use a digital meter to read voltage, resistance, and current. • Explain meter terms and readings. • Interpret meter readings and compare to factory specifications. • Discuss how to properly and safely use meters.

KEY TERMS: AC/DC clamp-on DMM 83 • Continuity light 77 • DMM 78 • DVOM 78 • High-impedance test meter 78 • IEC 88 • Inductive ammeter 82 • Kilo (k) 84 • LED test light 77 • Logic probe 78 • Mega (M) 84 • Meter accuracy 87 • Meter resolution 86 • Milli (m) 84 • OL 80 • RMS 86 • Test light 77

FUSED JUMPER WIRE

DEFINITION A fused jumper wire is used to check a circuit by bypassing the switch or to provide a power or ground to a component. A fused jumper wire, also called a test lead, can be purchased or made by the service technician. ● **SEE FIGURE 6–1.**

It should include the following features.

- **Fused.** A typical fused jumper wire has a blade-type fuse that can be easily replaced. A 10 ampere fuse (red color) is often the value used.
- **Alligator clip ends.** Alligator clips on the ends allow the fused jumper wire to be clipped to a ground or power source while the other end is attached to the power side or ground side of the unit being tested.
- **Good-quality insulated wire.** Most purchased jumper wire is about 14 gauge stranded copper wire with a flexible rubberized insulation to allow it to move easily even in cold weather.

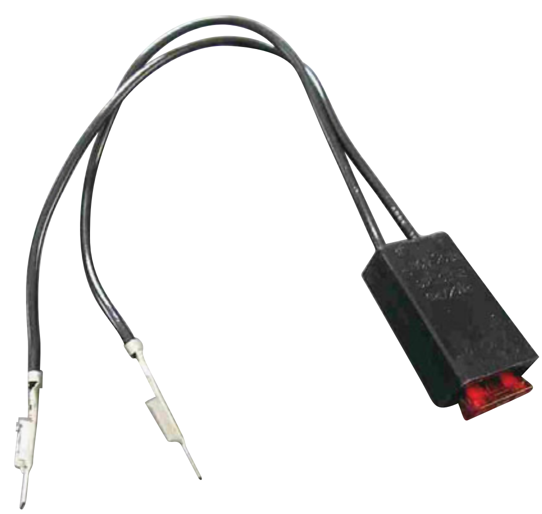


FIGURE 6–1 A technician-made fused jumper lead, which is equipped with a red 10 ampere fuse. This fused jumper wire uses terminals for testing circuits at a connector instead of alligator clips.

USES OF A FUSED JUMPER WIRE A fused jumper wire can be used to help diagnose a component or circuit by performing the following procedures.

- **Supply power or ground.** If a component, such as a horn, does not work, a fused jumper wire can be used to supply a temporary power and/or ground. Start by unplugging the electrical connector from the device and connect a fused jumper lead to the power terminal. Another fused jumper wire may be needed to provide the ground. If the unit works, the problem is in the power side or ground side circuit.

CAUTION: Never use a fused jumper wire to bypass any resistance or load in the circuit. The increased current flow could damage the wiring and could blow the fuse on the jumper lead.

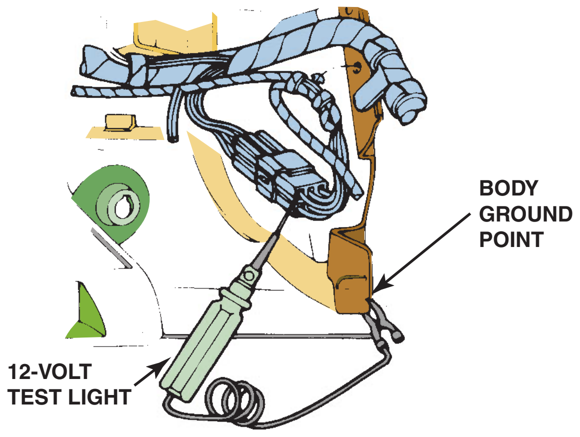


FIGURE 6–2 A 12 volt test light is attached to a good ground while probing for power.

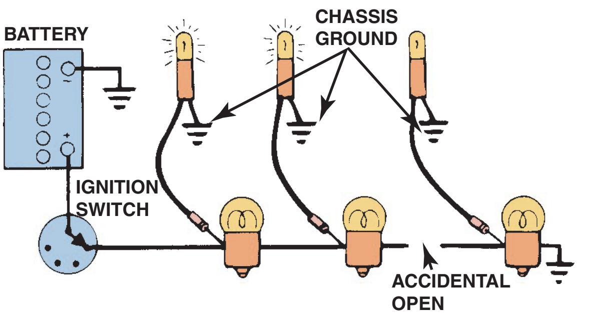


FIGURE 6–3 A test light can be used to locate an open in a circuit. Note that the test light is grounded at a different location than the circuit itself.

TEST LIGHTS

NONPOWERED TEST LIGHT A 12 volt test light is one of the simplest testers that can be used to detect electricity. A **test light** is simply a light bulb with a probe and a ground wire attached. ● **SEE FIGURE 6–2.**

It is used to detect battery voltage potential at various test points. Battery voltage cannot be seen or felt, and can be detected only with test equipment.

The ground clip is connected to a clean ground on either the negative terminal of the battery or a clean metal part of the body and the probe touched to terminals or components. If the test light comes on, this indicates that voltage is available. ● **SEE FIGURE 6–3.**

A purchased test light could be labeled a "12 volt test light." Do not purchase a test light designed for household current (110 or 220 volts), as it will not light with 12 to 14 volts.

USES OF A 12 VOLT TEST LIGHT A 12 volt test light can be used to check the following:

- **Electrical power.** If the test light lights, then there is power available. It will not, however, indicate the voltage level or if there is enough current available to operate an electrical load. This indicates only that there is enough voltage and current to light the test light (about 0.25 A).
- **Grounds.** A test light can be used to check for grounds by attaching the clip of the test light to the positive terminal of the battery or any 12 volt electrical terminal. The tip of the test light can then be used to touch the ground wire. If there is a ground connection, the test light will light.

CONTINUITY TEST LIGHTS A **continuity light** is similar to a test light but includes a battery for self-power. A continuity light illuminates whenever it is connected to both ends of a wire that has continuity or is not broken. ● **SEE FIGURE 6–4.**

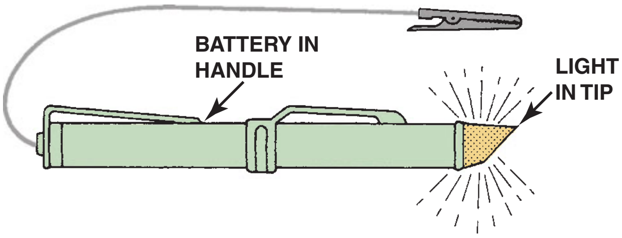


FIGURE 6–4 A continuity light should not be used on computer circuits because the applied voltage can damage delicate electronic components or circuits.

CAUTION: The use of a self-powered (continuity) test light is not recommended on any electronic circuit, because a continuity light contains a battery and applies voltage; therefore, it may harm delicate electronic components.

HIGH-IMPEDANCE TEST LIGHT A high-impedance test light has a high internal resistance and therefore draws very low current in order to light. High-impedance test lights are safe to use on computer circuits because they will not affect the circuit current in the same way as conventional 12 volt test lights when connected to a circuit. There are two types of high-impedance test lights.

- Some test lights use an electronic circuit to limit the current flow, to avoid causing damage to electronic devices.
- An **LED test light** uses a light-emitting diode (LED) instead of a standard automotive bulb for a visual indication of voltage. An LED test light requires only about 25 milliamperes (0.025 ampere) to light; therefore, it can be used on electronic circuits as well as on standard circuits.

● **SEE FIGURE 6–5** for construction details for a homemade LED test light.

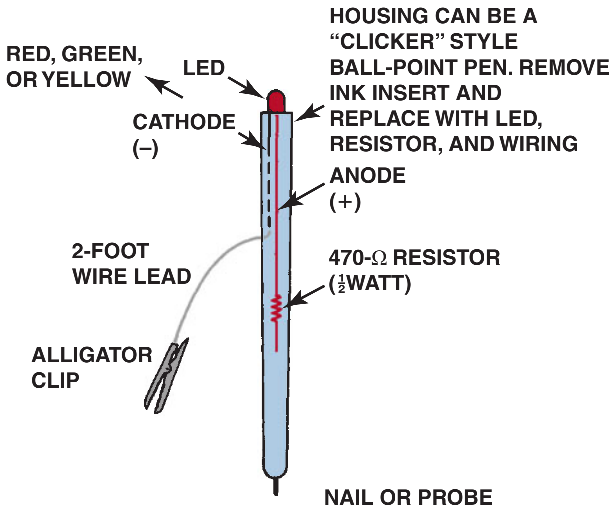


FIGURE 6–5 An LED test light can be easily made using low cost components and an old ink pen. With the 470 ohm resistor in series with the LED, this tester only draws 0.025 ampere (25 milliamperes) from the circuit being tested. This low current draw helps assure the technician that the circuit or component being tested will not be damaged by excessive current flow.

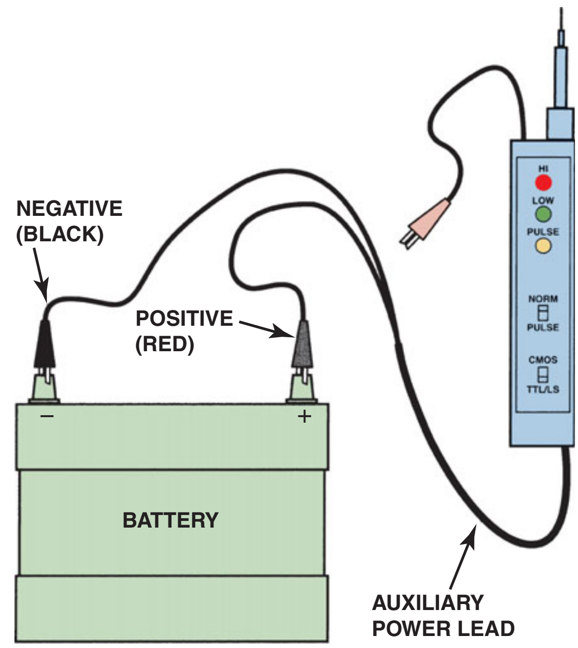


FIGURE 6–6 A logic probe connected to the vehicle battery. When the tip probe is connected to a circuit, it can check for power, ground, or a pulse.

LOGIC PROBE

PURPOSE AND FUNCTION A **logic probe** is an electronic device that lights up a red (usually) LED if the probe is touched to battery voltage. If the probe is touched to ground, a green (usually) LED lights. **SEE FIGURE 6–6.**

A logic probe can "sense" the difference between high- and low-voltage levels, which explains the name *logic.*

- A typical logic probe can also light another light (often amber color) when a change in voltage levels occurs.
- Some logic probes will flash the red light when a pulsing voltage signal is detected.
- Some will flash the green light when a pulsing ground signal is detected.

This feature is helpful when checking for a variable voltage output from a computer or ignition sensor.

USING A LOGIC PROBE A logic probe must first be connected to a power and ground source such as the vehicle battery. This connection powers the probe and gives it a reference low (ground).

Most logic probes also make a distinctive sound for each high- and low-voltage level. This makes troubleshooting easier when probing connectors or component terminals. A sound (usually a beep) is heard when the probe tip is touched to a changing voltage source. The changing voltage also usually lights the pulse light on the logic probe. Therefore, the probe can be used to check components such as:

- Pickup coils
- Hall-effect sensors
- Magnetic sensors

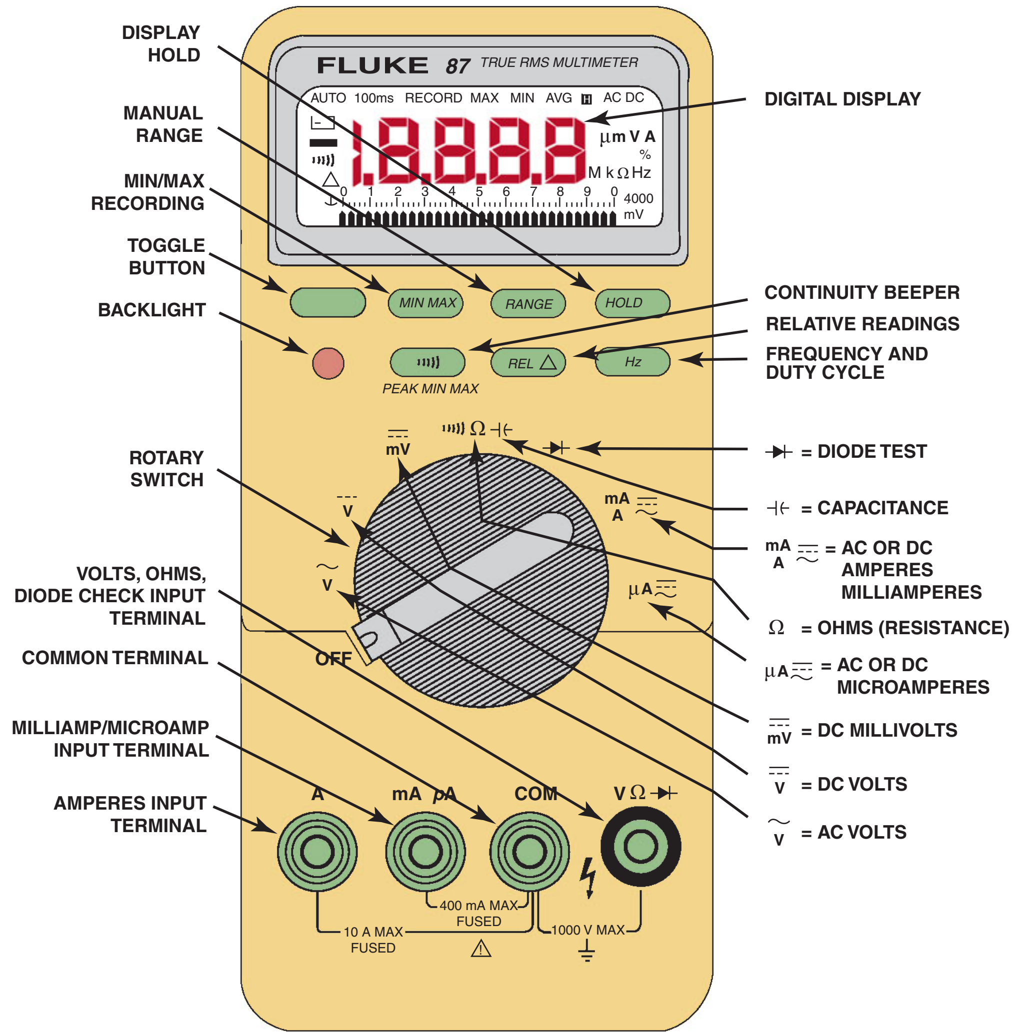
DIGITAL MULTIMETERS

TERMINOLOGY **Digital multimeter (DMM)** and **digital volt-ohm-mmeter (DVOM)** are terms commonly used for electronic **high-impedance test meters.** *High impedance* means that the electronic internal resistance of the meter is high enough to prevent excessive current draw from any circuit being tested. Most meters today have a minimum of 10 million ohms (10 megohms) of resistance. This high internal resistance between the meter leads is present only when measuring volts. The high resistance in the meter itself reduces the amount of current flowing through the meter when it is being used to measure voltage, leading to more accurate test results because the meter does not change the load on the circuit. High-impedance meters are required for measuring computer circuits.

CAUTION: Analog (needle-type) meters are almost always lower than 10 megohms and should not be used to measure any computer or electronic circuit. Connecting an analog meter to a computer circuit could damage the computer or other electronic modules.

A high-impedance meter can be used to measure any automotive circuit within the ranges of the meter. **SEE FIGURE 6–7.**

FIGURE 6–7 Typical digital multimeter. The black meter lead always is placed in the COM terminal. The red meter test lead should be in the volt-ohm terminal except when measuring current in amperes.



The common abbreviations for the units that many meters can measure are often confusing. ● **SEE CHART 6–1** for the most commonly used symbols and their meanings.

SYMBOL	MEANING
AC	Alternating current or voltage
DC	Direct current or voltage
V	Volts
mV	Millivolts (1/1,000 volts)
A	Ampere (amps), current
mA	Milliampere (1/1,000 amps)
%	Percent (for duty cycle readings only)
Ω	Ohms, resistance
kΩ	Kilohm (1,000 ohms), resistance
MΩ	Megohm (1,000,000 ohms), resistance
Hz	Hertz (cycles per second), frequency
kHz	Kilohertz (1,000 cycles/sec.), frequency
Ms	Milliseconds (1/1,000 sec.) for pulse width measurements

CHART 6–1

Common symbols and abbreviations used on digital meters.

MEASURING VOLTAGE A voltmeter measures the *pressure* or potential of electricity in units of volts. A voltmeter is connected to a circuit in parallel. Voltage can be measured by selecting either AC or DC volts.

- **DC volts (DCV).** This setting is the most common for automotive use. Use this setting to measure battery voltage and voltage to all lighting and accessory circuits.
- **AC volts (ACV).** This setting is used to check for unwanted AC voltage from alternators and some sensors.
- **Range.** The range is automatically set for most meters but can be manually ranged if needed.
  ● **SEE FIGURES 6–8 AND 6–9.**

MEASURING RESISTANCE An ohmmeter measures the resistance in ohms of a component or circuit section when no current is flowing through the circuit. An ohmmeter contains a battery (or other power source) and is connected in series with the component

FIGURE 6–8 Typical digital multimeter (DMM) set to read DC volts.

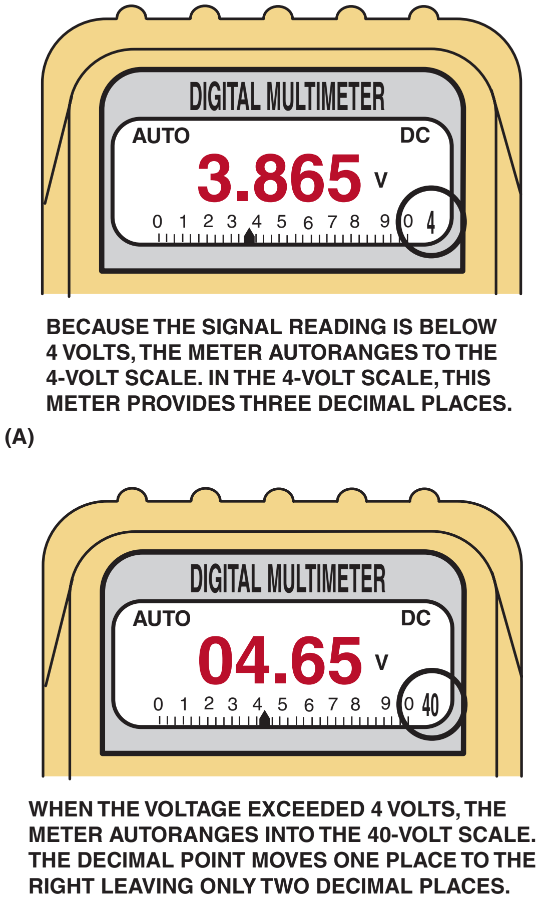


FIGURE 6–9 A typical autoranging digital multimeter automatically selects the proper scale to read the voltage being tested. The scale selected is usually displayed on the meter face. (a) Note that the display indicates "4," meaning that this range can read up to 4 volts. (b) The range is now set to the 40 volt scale, meaning that the meter can read up to 40 volts on the scale. Any reading above this level will cause the meter to reset to a higher scale. If not set on autoranging, the meter display would indicate OL if a reading exceeds the limit of the scale selected.

FIGURE 6–10 Using a digital multimeter set to read ohms (Ω) to test this light bulb. The meter reads the resistance of the filament.

or wire being measured. When the leads are connected to a component, current flows through the test leads and the difference in voltage (voltage drop) between the leads is measured as resistance. Note the following facts about using an ohmmeter.

- Zero ohms on the scale means that there is no resistance between the test leads, thus indicating continuity or a continuous path for the current to flow in a closed circuit.
- Infinity means no connection, as in an open circuit.
- Ohmmeters have no required polarity even though red and black test leads are used for resistance measurement.

CAUTION: The circuit must be electrically open with no current flowing when using an ohmmeter. If current is flowing when an ohmmeter is connected, the reading will be incorrect and the meter can be destroyed.

Different meters have different ways of indicating infinity resistance, or a reading higher than the scale allows. Examples of an over limit display include:

- **OL,** meaning **over limit** or overload
- Flashing or solid number 1
- Flashing or solid number 3 on the left side of the display
- Flashing or solid number 4 on the display.

Check the meter instructions for the exact display used to indicate an open circuit or over range reading. **SEE FIGURES 6–10 AND 6–11.**

To summarize, open and zero readings are as follows:

0.00 Ω = Zero resistance (component or circuit has continuity)

OL = An open circuit or reading is higher than the scale selected (no current flows)

MEASURING AMPERES An ammeter measures the flow of *current* through a complete circuit in units of amperes. The ammeter has to be installed in the circuit (in series) so that it can measure all the current flow in that circuit, just as a water flow meter would measure the amount of water flow (cubic feet per minute, for example). **SEE FIGURE 6–12.**

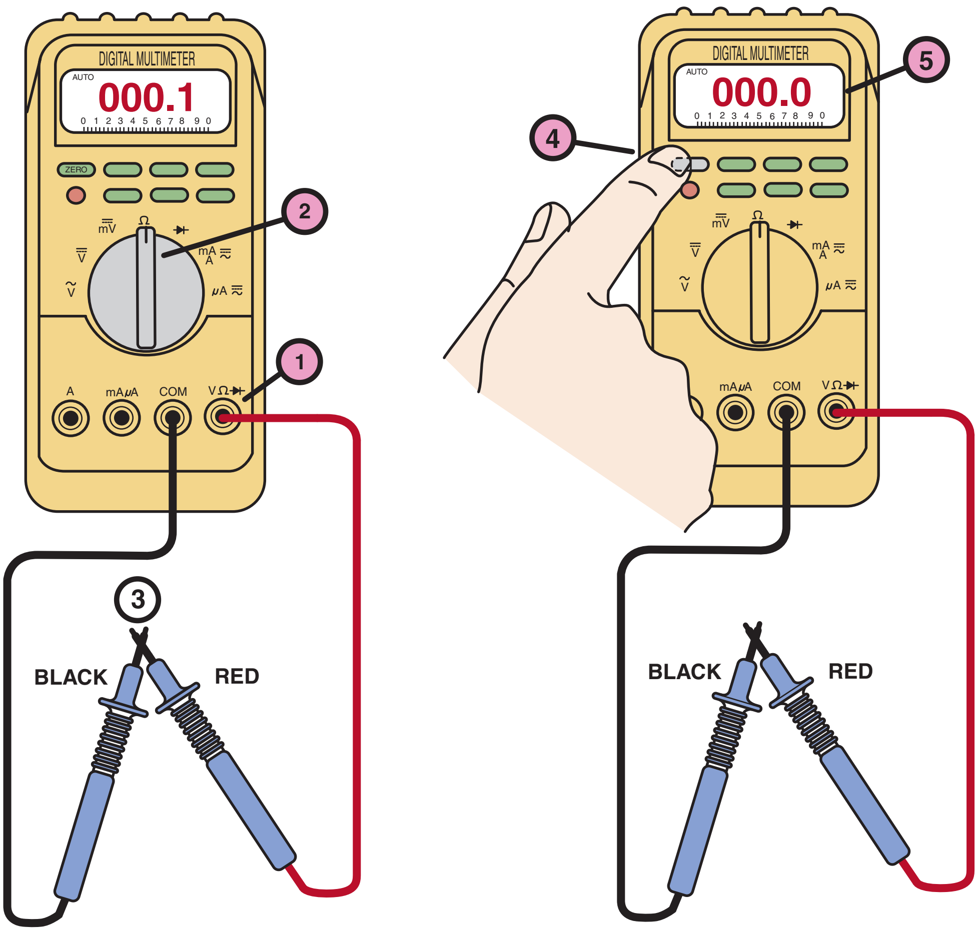


FIGURE 6–11 Many digital multimeters can have the display indicate zero to compensate for test lead resistance. (1) Connect leads in the V Ω and COM meter terminals. (2) Select the Ω scale. (3) Touch the two meter leads together. (4) Push the "zero" or "relative" button on the meter. (5) The meter display will now indicate zero ohms of resistance.

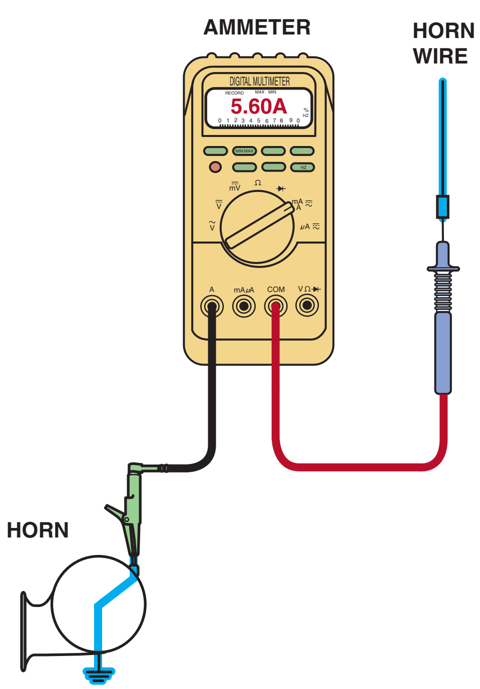


FIGURE 6–12 Measuring the current flow required by a horn requires that the ammeter be connected to the circuit in series and the horn button be depressed by an assistant.

FREQUENTLY ASKED QUESTION

How Much Voltage Does an Ohmmeter Apply?

Most digital meters that are set to measure ohms (resistance) apply 0.3 to 1 volt to the component being measured. The voltage comes from the meter itself to measure the resistance. Two things are important to remember about an ohmmeter.

1. The component or circuit must be disconnected from any electrical circuit while the resistance is being measured.
2. Because the meter itself applies a voltage (even though it is relatively low), a meter set to measure ohms can damage electronic circuits. Computer or electronic chips can be easily damaged if subjected to only a few milliamperes of current, similar to the amount an ohmmeter applies when a resistance measurement is being performed.

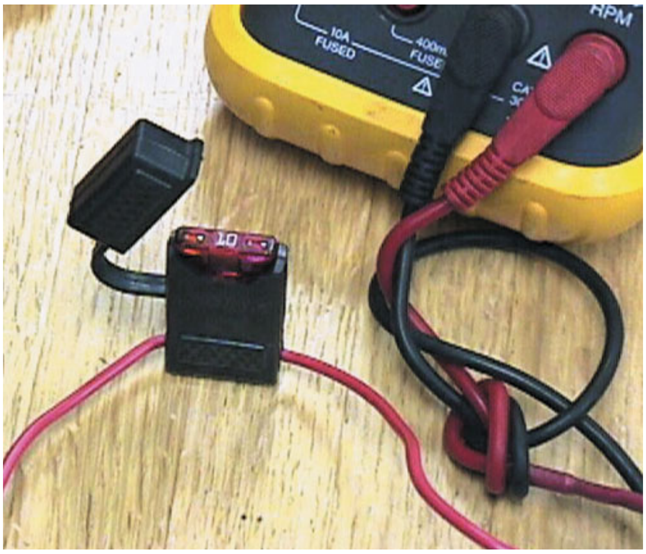


FIGURE 6–13 Note the blade-type fuse holder soldered in series with one of the meter leads. A 10 ampere fuse helps protect the internal meter fuse (if equipped) and the meter itself from damage that may result from excessive current flow if accidentally used incorrectly.

TECH TIP

Fuse Your Meter Leads!

Most digital meters include an ammeter capability. When reading amperes, the leads of the meter must be changed from volts or ohms (V or Ω) to amperes (A), milliamperes (mA), or microamperes (μA).

A common problem may then occur the next time voltage is measured. Although the technician may switch the selector to read volts, often the leads are not switched back to the volt or ohm position. Because the ammeter lead position results in zero ohms of resistance to current flow through the meter, the meter or the fuse inside the meter will be destroyed if the meter is connected to a battery. Many meter fuses are expensive and difficult to find.

To avoid this problem, simply solder an inline 10 ampere blade-fuse holder into one meter lead. ● **SEE FIGURE 6–13**.

Do not think that this technique is for beginners only. Experienced technicians often get in a hurry and forget to switch the lead. A blade fuse is faster, easier, and less expensive to replace than a meter fuse or the meter itself. Also, if the soldering is done properly, the addition of an inline fuse holder and fuse does not increase the resistance of the meter leads. All meter leads have some resistance. If the meter is measuring very low resistance, touch the two leads together and read the resistance (usually no more than 0.2 ohm). Simply subtract the resistance of the leads from the resistance of the component being measured.

FIGURE 6–14 An inductive ammeter clamp is used with all starting and charging testers to measure the current flow through the battery cables.

FREQUENTLY ASKED QUESTION

What Does "CE" Mean on Many Meters?

The "CE" means that the meter meets the newest European Standards and the letters CE stands for a French term for "Conformite' Europeenne" meaning European Conformity in French.

CAUTION: An ammeter must be installed in series with the circuit to measure the current flow in the circuit. If a meter set to read amperes is connected in parallel, such as across a battery, the meter or the leads may be destroyed, or the fuse will blow, by the current available across the battery. Some digital multimeters (DMMs) beep if the unit selection does not match the test lead connection on the meter. However, in a noisy shop, this beep sound may be inaudible.

Digital meters require that the meter leads be moved to the ammeter terminals. Most digital meters have an ampere scale that can accommodate a maximum of 10 amperes. See the Tech Tip, "Fuse Your Meter Leads!"

INDUCTIVE AMMETERS

OPERATION **Inductive ammeters** do not make physical contact with the circuit. They measure the strength of the magnetic field surrounding the wire carrying the current, and use a Hall-effect sensor to measure current. The Hall-effect sensor detects the strength of the magnetic field that surrounds the wire carrying an electrical current. ● **SEE FIGURE 6–14.**

FIGURE 6–15 A typical mini clamp-on-type digital multimeter. This meter is capable of measuring alternating current (AC) and direct current (DC) without requiring that the circuit be disconnected to install the meter in series. The jaws are simply placed over the wire and current flow through the circuit is displayed.

This means that the meter probe surrounds the wire(s) carrying the current and measures the strength of the magnetic field that surrounds any conductor carrying a current.

AC/DC CLAMP-ON DIGITAL MULTIMETERS An **AC/DC clamp-on digital multimeter (DMM)** is a useful meter for automotive diagnostic work. ● **SEE FIGURE 6–15.**

The major advantage of the clamp-on-type meter is that there is no need to break the circuit to measure current (amperes). Simply clamp the jaws of the meter around the power lead(s) or ground lead(s) of the component being measured and read the display. Most clamp-on meters can also measure alternating current, which is helpful in the diagnosis of an alternator problem. Volts, ohms, frequency, and temperature can also be measured with the typical clamp-on DMM, but use conventional meter leads. The inductive clamp is only used to measure amperes.

DIODE CHECK, PULSE WIDTH, AND FREQUENCY

DIODE CHECK Diode check is a meter function that can be used to check diodes including light-emitting diodes (LEDs).

The meter is able to text diodes by way of the following:

- The meter applies roughly a 3 volt DC signal to the text leads.
- The voltage is high enough to cause a diode to work and the meter will display:
  1. 0.4 to 0.7 volt when testing silicon diodes such as found in alternators
  2. 1.5 to 2.3 volts when testing LEDs such as found in some lighting applications

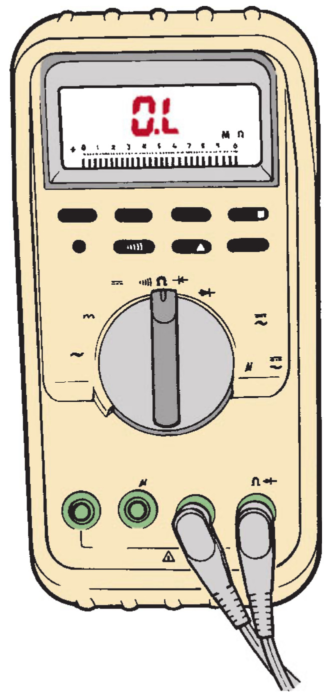


FIGURE 6–16 Typical digital multimeter showing OL (over limit) on the readout with the ohms (Ω) unit selected. This usually means that the unit being measured is open (infinity resistance) and has no continuity.

TECH TIP

Over Limit Display Does Not Mean the Meter Is Reading "Nothing"

The meaning of the over limit display on a digital meter often confuses beginning technicians. When asked what the meter is reading when an over limit (OL) is displayed on the meter face, the response is often, "Nothing." Many meters indicate *over limit* or *over load,* which simply means that the reading is over the maximum that can be displayed for the selected range. For example, the meter will display OL if 12 volts are being measured but the meter has been set to read a maximum of 4 volts.

Autoranging meters adjust the range to match what is being measured. Here OL means a value higher than the meter can read (unlikely on the voltage scale for automobile usage), or infinity when measuring resistance (ohms). Therefore, OL means infinity when measuring resistance or an open circuit is being indicated. The meter will read 00.0 if the resistance is zero, so "nothing" in this case indicates continuity (zero resistance), whereas OL indicates infinity resistance. Therefore, when talking with another technician about a meter reading, make sure you know exactly what the reading on the face of the meter means. Also be sure that you are connecting the meter leads correctly. ● **SEE FIGURE 6–16**.

PULSE WIDTH Pulse width is the amount of time in a percentage that a signal is on compared to being off.

- 100% pulse width indicates that a device is being commanded on all of the time.
- 50% pulse width indicates that a device is being commanded on half of the time.
- 25% pulse width indicates that a device is being commanded on just 25% of the time.

Pulse width is used to measure the on time for fuel injectors and other computer-controlled solenoid and devices.

FREQUENCY Frequency is a measure of how many times per second a signal changes. Frequency is measured in a unit called hertz, formerly termed "cycles per second."

Frequency measurements are used when checking the following:

- Mass airflow (MAF) sensors for proper operation
- Ignition primary pulse signals when diagnosing a no-start condition
- Checking a wheel speed sensor

ELECTRICAL UNIT PREFIXES

DEFINITIONS Electrical units are measured in numbers such as 12 volts, 150 amperes, and 470 ohms. Large units over 1,000 may be expressed in kilo units. **Kilo (k)** means 1,000. ● **SEE FIGURE 6–17.**

4,700 ohms = 4.7 kilohms (kΩ)

If the value is over 1 million (1,000,000), then the prefix **mega (M)** is often used. For example:

1,100,000 volts = 1.1 megavolts (MV)

4,700,000 ohms = 4.7 megohms (MΩ)

Sometimes a circuit conducts so little current that a smaller unit of measure is required. Small units of measure expressed in 1/1,000 are prefixed by **milli (m).** To summarize:

mega (M) = 1,000,000 (decimal point six places to the right = 1,000,000)

kilo (k) = 1,000 (decimal point three places to the right = 1,000)

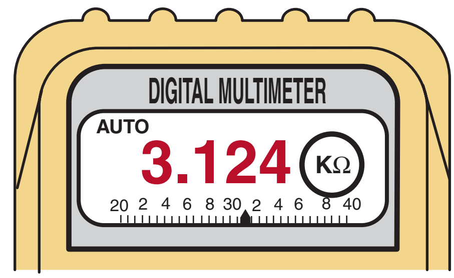
milli (m) = 1/1,000 (decimal point three places to the left = 0.001)

HINT: Lowercase *m* equals a small unit (milli), whereas a capital *M* represents a large unit (mega).

● **SEE CHART 6–2.**

PREFIXES The prefixes can be confusing because most digital meters can express values in more than one unit, especially if the meter is autoranging. For example, an ammeter reading may show 36.7 mA on autoranging. When the scale is changed to amperes ("A" in the window of the display), the number displayed will be 0.037 A. Note that the resolution of the value is reduced.

HINT: Always check the face of the meter display for the unit being measured. To best understand what is being displayed on the face of a digital meter, select a manual scale and move the selector until *whole units appear,* such as "A" for amperes instead of "mA" for milliamperes.



THE SYMBOL ON THE RIGHT SIDE OF THE DISPLAY INDICATES WHAT RANGE THE METER HAS BEEN SET TO READ.

Ω = OHMS

IF THE ONLY SYMBOL ON THE DISPLAY IS THE OHMS SYMBOL, THE READING ON THE DISPLAY IS EXACTLY THE RESISTANCE IN OHMS.

KΩ = KILOHMS = OHMS TIMES 1000

A "K" IN FRONT OF THE OHMS SYMBOL MEANS "KILOHMS"; THE READING ON THE DISPLAY IS IN KILOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1000 TO GET THE RESISTANCE IN OHMS.

MΩ = MEGOHMS = OHMS TIMES 1,000,000

A "M" IN FRONT OF THE OHMS SYMBOL MEANS "MEGOHMS"; THE READING ON THE DISPLAY IS IN MEGOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1,000,000 TO GET THE RESISTANCE IN OHMS.

FIGURE 6–17 Always look at the meter display when a measurement is being made, especially if using an autoranging meter.

TO/ FROM	MEGA	KILO	BASE	MILLI
Mega	0 places	3 places to the right	6 places to the right	9 places to the right
Kilo	3 places to the left	0 places	3 places to the right	6 places to the right
Base	6 places to the left	3 places to the left	0 places	3 places to the right
Milli	9 places to the left	6 places to the left	3 places to the left	0 places

CHART 6–2

A conversion chart showing the decimal point location for the various prefixes.

TECH TIP

Think of Money

Digital meter displays can often be confusing. The display for a battery measured as 12 1/2 volts would be 12.50 V, just as $12.50 is 12 dollars and 50 cents. A 1/2 volt reading on a digital meter will be displayed as 0.50 V, just as $0.50 is half of a dollar.

It is more confusing when low values are displayed. For example, if a voltage reading is 0.063 volt, an autoranging meter will display 63 millivolts (63 mV), or 63/1,000 of a volt, or $63 of $1,000. (It takes 1,000 mV to equal 1 volt.) Think of millivolts as one-tenth of a cent, with 1 volt being $1.00. Therefore, 630 millivolts are equal to $0.63 of $1.00 (630 tenths of a cent, or 63 cents).

To avoid confusion, try to manually range the meter to read base units (whole volts). If the meter is ranged to base unit volts, 63 millivolts would be displayed as 0.063 or maybe just 0.06, depending on the display capabilities of the meter.

HOW TO READ DIGITAL METERS

STEPS TO FOLLOW Getting to know and use a digital meter takes time and practice. The first step is to read, understand, and follow all safety and operational instructions that come with the meter. Use of the meter usually involves the following steps.

STEP 1 **Select the proper unit of electricity for what is being measured.** This unit could be volts, ohms (resistance), or amperes (amount of current flow). If the meter is not autoranging, select the proper scale for the anticipated reading. For example, if a 12 volt battery is being measured, select a meter reading range that is higher than the voltage but not too high. A 20 or 30 volt range will accurately show the voltage of a 12 volt battery. If a 1,000 volt scale is selected, a 12 volt reading may not be accurate.

STEP 2 **Place the meter leads into the proper input terminals.**

- The black lead is inserted into the common (COM) terminal. This meter lead usually stays in this location for all meter functions.
- The red lead is inserted into the volt, ohm, or diode check terminal usually labeled "VΩ" when voltage, resistance, or diodes are being measured.
- When current flow in amperes is being measured, most digital meters require that the red test lead be inserted in the ammeter terminal, usually labeled "A" or "mA."

CAUTION: If the meter leads are inserted into ammeter terminals, even though the selector is set to volts, the meter may be damaged or an internal fuse may blow if the test leads touch both terminals of a battery.

STEP 3 **Measure the component being tested.** Carefully note the decimal point and the unit on the face of the meter.

- **Meter lead connections.** If the meter leads are connected to a battery backwards (red to the battery negative, for example), the display will still show the correct reading, but a negative sign (−) will be displayed in front of the number. The correct polarity is not important when measuring resistance (ohms) except where indicated, such as measuring a diode.
- **Autorange.** Many meters automatically default to the autorange position and the meter will display the value in the most readable scale. The meter can be manually ranged to select other levels or to lock in a scale for a value that is constantly changing.

  If a 12 volt battery is measured with an autoranging meter, the correct reading of 12.0 is given. "AUTO" and "V" should show on the face of the meter. For example, if a meter is manually set to the 2 kilohm scale, the highest that the meter will read is 2,000 ohms. If the reading is over 2,000 ohms, the meter will display OL. ● **SEE CHART 6–3.**

STEP 4 **Interpret the reading.** This is especially difficult on autoranging meters, where the meter itself selects the proper scale. The following are two examples of different readings.

Example 1: A voltage drop is being measured. The specifications indicate a maximum voltage drop of 0.2 volt. The meter reads "AUTO" and "43.6 mV." This reading means that the voltage drop is 0.0436 volt, or 43.6 mV, which is far lower than the 0.2 volt (200 millivolts). Because the number showing on the meter face is much larger than the specifications, many beginner technicians are led to believe that the voltage drop is excessive.

NOTE: Pay attention to the units displayed on the meter face and convert to whole units.

Example 2: A spark plug wire is being measured. The reading should be less than 10,000 ohms for each foot in length if the wire is okay. The wire being tested is 3 ft long (maximum allowable resistance is 30,000 ohms). The meter reads "AUTO" and "14.85 kΩ." This reading is equivalent to 14,850 ohms.

NOTE: When converting from kilohms to ohms, make the decimal point a comma.

Because this reading is well below the specified maximum allowable, the spark plug wire is okay.

VOLTAGE BEING MEASURED	0.01 V (10 MV)	0.150 V (150 MV)	1.5 V	10.0 V	12.0 V	120 V
Scale Selected	Voltmeter will display:					
200 mV	10.0	150.0	OL	OL	OL	OL
2 V	0.100	0.150	1.500	OL	OL	OL
20 V	0.1	1.50	1.50	10.00	12.00	OL
200 V	00.0	01.5	01.5	10.0	12.0	120.0
2 kV	00.00	00.00	000.1	00.10	00.12	0.120
Autorange	10.0 mV	15.0 mV	1.50	10.0	12.0	120.0

RESISTANCE BEING MEASURED	10 OHMS	100 OHMS	470 OHMS	1 KILOHM	220 KILOHMS	1 MEGOHM
Scale Selected	Ohmmeter will display:					
400 ohms	10.0	100.0	OL	OL	OL	OL
4 kilohms	010	100	0.470 k	1000	OL	OL
40 kilohms	00.0	0.10 k	0.47 k	1.00 k	OL	OL
400 kilohms	000.0	00.1 k	00.5 k	0.10 k	220.0 k	OL
4 megohms	00.00	0.01 M	0.05 M	00.1 M	0.22 M	1.0 M
Autorange	10.0	100.0	470.0	1.00 k	220 k	1.00 M

CURRENT BEING MEASURED	50 MA	150 MA	1.0 A	7.5 A	15.0 A	25.0 A
Scale Selected	Ammeter will display:					
40 mA	OL	OL	OL	OL	OL	OL
400 mA	50.0	150	OL	OL	OL	OL
4 A	0.05	0.00	1.00	OL	OL	OL
40 A	0.00	0.000	01.0	7.5	15.0	25.0
Autorange	50.0 mA	150.0 mA	1.00	7.5	15.0	25.0

CHART 6–3

Sample meter readings using manually set and autoranging selection on the digital meter control.

RMS VERSUS AVERAGE Alternating current voltage waveforms can be true sinusoidal or nonsinusoidal. A true sine wave pattern measurement will be the same for both **root-mean-square (RMS)** and average reading meters. RMS and averaging are two methods used to measure the true effective rating of a signal that is constantly changing. ● **SEE FIGURE 6–18.**

Only true RMS meters are accurate when measuring nonsinusoidal AC waveforms, which are seldom used in automotive applications.

RESOLUTION, DIGITS, AND COUNTS **Meter resolution** refers to how small or fine a measurement the meter can make. By knowing the resolution of a DMM you can determine whether the meter could measure down to only 1 volt or down to 1 millivolt (1/1,000 of a volt).

You would not buy a ruler marked in 1 in. segments (or centimeters) if you had to measure down to 1/4 in. (or 1 mm). A thermometer that only measured in whole degrees is not of

TECH TIP

Purchase a Digital Meter That Will Work for Automotive Use

Try to purchase a digital meter that is capable of reading the following:

- DC volts
- AC volts
- DC amperes (up to 10 A or more is helpful)
- Ohms (Ω) up to 40 MΩ (40 million ohms)
- Diode check

Additional features for advanced automotive diagnosis include:

- Frequency (hertz, abbreviated Hz)
- Temperature probe (°F and/or °C)
- Pulse width (millisecond, abbreviated ms)
- Duty cycle (%)

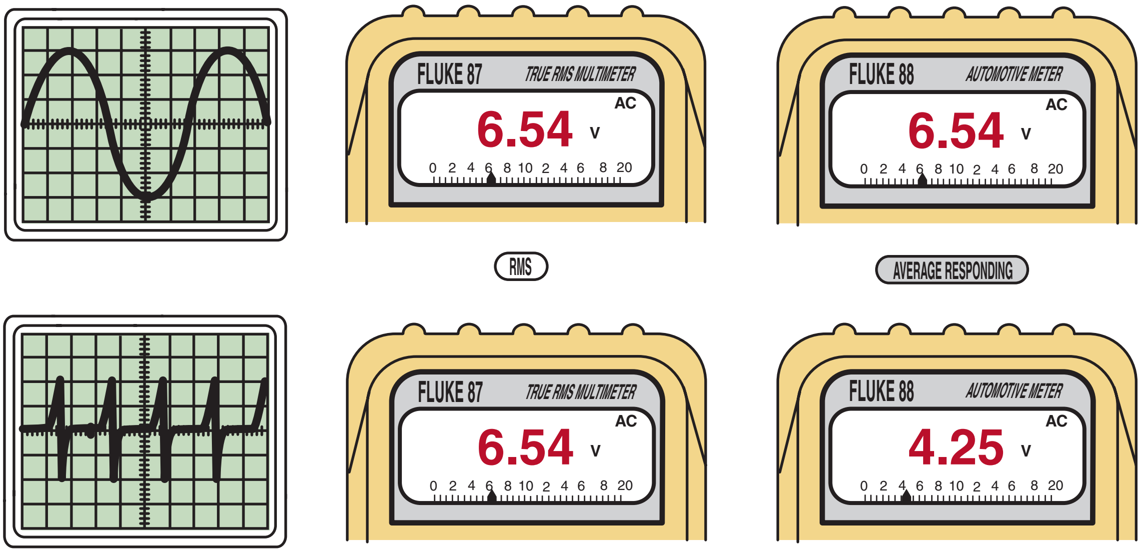


FIGURE 6–18 When reading AC voltage signals, a true RMS meter (such as a Fluke 87) provides a different reading than an average responding meter (such as a Fluke 88). The only place this difference is important is when a reading is to be compared with a specification.

FIGURE 6–19 This meter display shows 052.2 AC volts. Notice that the zero beside the 5 indicates that the meter can read over 100 volts AC with a resolution of 0.1 volt.

much use when your normal temperature is 98.6°F. You need a thermometer with 0.1° *resolution.*

The terms *digits* and *counts* are used to describe a meter's resolution. DMMs are grouped by the number of counts or digits they display.

- A 3 1/2-digit meter can display three full digits ranging from 0 to 9, and one "half" digit that displays only a 1 or is left blank. A 3 1/2-digit meter will display up to 1,999 counts of resolution.
- A 4 1/2-digit meter can display up to 19,000 counts of resolution. It is more precise to describe a meter by counts of resolution than by 3 1/2 or 4 1/2 digits. Some 3 1/2-digit meters have enhanced resolution of up to 3,200 or 4,000 counts.

Meters with more counts offer better resolution for certain measurements. For example, a 1,999 count meter will not be able to measure down to a tenth of a volt when measuring 200 volts or more. SEE FIGURE 6–19.

However, a 3,200 count meter will display a tenth of a volt up to 320 volts. Digits displayed to the far right of the display may at times flicker or constantly change. This is called *digit rattle* and represents a changing voltage being measured on the ground (COM terminal of the meter lead). High-quality meters are designed to reject this unwanted voltage.

ACCURACY **Meter accuracy** is the largest allowable error that will occur under specific operating conditions. In other words, it is an indication of how close the DMM's displayed measurement is to the actual value of the signal being measured.

Accuracy for a DMM is usually expressed as a percent of reading. An accuracy of ±1% of reading means that for a displayed reading of 100.0 V, the actual value of the voltage could be anywhere between 99.0 V and 101.0 V. Thus, the lower the percent of accuracy is, the better.

- Unacceptable = 1.00%
- Okay = 0.50% (1/2%)
- Good = 0.25% (1/4%)
- Excellent = 0.10% (1/10%)

FIGURE 6–20 Be sure to only use a meter that is CAT III rated when taking electrical voltage measurements on a hybrid vehicle.

FIGURE 6–21 Always use meter leads that are CAT III rated on a meter that is also CAT III rated, to maintain the protection needed when working on hybrid vehicles.

For example, if a battery had 12.6 volts, a meter could read between the following, based on its accuracy.

±0.1%	high = 12.61
	low = 12.59
±0.25%	high = 12.63
	low = 12.57
±0.50%	high = 12.66
	low = 12.54
±1.00%	high = 12.73
	low = 12.47

Before you purchase a meter, check the accuracy. Accuracy is usually indicated on the specifications sheet for the meter.

SAFETY TIP

Meter Usage on Hybrid Electric Vehicles

Many hybrid electric vehicles use system voltage as high as 650 volts DC. Be sure to follow all vehicle manufacturer's testing procedures; and if a voltage measurement is needed, be sure to use a meter and test leads that are designed to insulate against high voltages. The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meter and meter leads. These categories are ratings for overvoltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category, the greater the protection against voltage spikes caused by high-energy circuits. Under each category there are various energy and voltage ratings.

CAT I	Typically a CAT I meter is used for low-energy voltage measurements such as at wall outlets in the home. Meters with a CAT I rating are usually rated at 300 to 800 volts.
CAT II	This higher rated meter would be typically used for checking higher energy level voltages at the fuse panel in the home. Meters with a CAT II rating are usually rated at 300 to 600 volts.
CAT III	This minimum rated meter should be used for hybrid vehicles. The CAT III category is designed for high-energy levels and voltage measurements at the service pole at the transformer. Meters with this rating are usually rated at 600 to 1,000 volts.
CAT IV	CAT IV meters are for clamp-on meters only. If a clamp-on meter also has meter leads for voltage measurements, that part of the meter will be rated as CAT III.

NOTE: Always use the highest CAT rating meter, especially when working with hybrid vehicles. A CAT III, 600 volt meter is safer than a CAT II, 1,000 volt meter because of the energy level of the CAT ratings.

Therefore, for best personal protection, use only meters and meter leads that are CAT III or CAT IV rated when measuring voltage on a hybrid vehicle. ● **SEE FIGURES 6–20 AND 6–21**.

1 For most electrical measurements, the black meter lead is inserted in the terminal labeled COM and the red meter lead is inserted into the terminal labeled V.

2 To use a digital meter, turn the power switch and select the unit of electricity to be measured. In this case, the rotary switch is turned to select DC volts. (V symbol with the straight line above)

3 For most automotive electrical use, such as for measuring battery voltage, select DC volts.

4 Connect the red meter lead to the positive (+) terminal of a battery and the black meter lead to the negative (−) terminal of a battery. The meter reads the voltage difference between the leads.

5 This jump start battery unit measures 13.151 volts with the meter set on autoranging on the DC voltage scale.

6 Another meter (Fluke 87 III) displays four digits when measuring the voltage of the battery jump start unit.

CONTINUED ▶

7 To measure resistance turn the rotary dial to the ohm (Ω) symbol. With the meter leads separated, the meter display reads OL (over limit).

8 The meter can read your own body resistance if you grasp the meter lead terminals with your fingers. The reading on the display indicates 196.35 kΩ.

9 When measuring anything; be sure to read the symbol on the meter face. In this case, the meter is reading 291.10 kΩ.

10 A meter set on ohms can be used to check the resistance of a light bulb filament. In this case, the meter reads 3.15 ohms. If the bulb were bad (filament open), the meter would display OL.

11 A digital meter set to read ohms should measure 0.00 as shown when the meter leads are touched together.

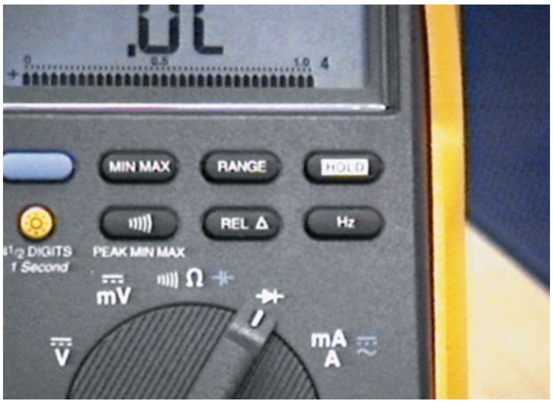
12 The large letter V means volts and the wavy symbol over the V means that the meter measures alternating current (AC) voltage if this position is selected.

13 The next symbol is a V with a dotted and a straight line overhead. This symbol stands for direct current (DC) volts. This position is most used for automotive service.

14 The symbol mV indicates millivolts or 1/1000 of a volt (0.001). The solid and dashed line above the mV means DC mV.

15 The rotary switch is turned to Ω (ohms) unit of resistance measure. The symbol to the left of the Ω symbol is the beeper or continuity indicator.

16 Notice that AUTO is in the upper left and the MΩ is in the lower right. This MΩ means megaohms or that the meter is set to read in millions of ohms.



17 The symbol shown is the symbol of a diode. In this position, the meter applies a voltage to a diode and the meter reads the voltage drop across the junction of a diode.

18 One of the most useful features of this meter is the MIN/MAX feature. By pushing the MIN/MAX button, the meter will be able to display the highest (MAX) and the lowest (MIN) reading.

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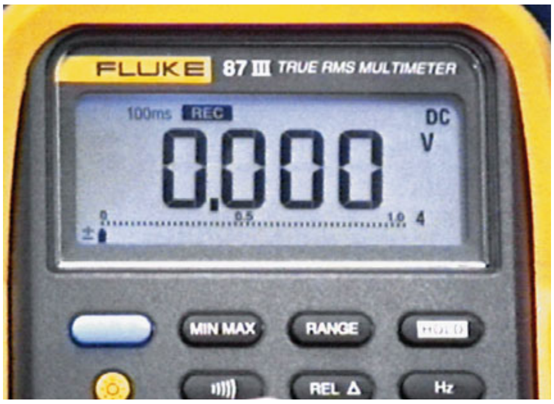


19 Pushing the MIN/MAX button puts the meter into record mode. Note the 100 mS and “REC” on the display. In this position, the meter is capturing any voltage change that lasts 100 mS (0.1 sec) or longer.

20 To increase the range of the meter touch the range button. Now the meter is set to read voltage up to 40 volts DC.

21 Pushing the range button one more time changes the meter scale to the 400-voltage range. Notice that the decimal point has moved to the right.

22 Pushing the range button again changes the meter to the 4000-volt range. This range is not suitable to use in automotive applications.

23 By pushing and holding the range button, the meter will reset to autorange. Autorange is the preferred setting for most automotive measurements except when using MIN/MAX record mode.

SUMMARY

1. Circuit testers include test lights and fused jumper leads.
2. Digital multimeter (DMM) and digital volt-ohm-meter (DVOM) are terms commonly used for electronic high-impedance test meters.
3. Use of a high-impedance digital meter is required on any computer-related circuit or component.
4. Ammeters measure current and must be connected in series in the circuit.
5. Voltmeters measure voltage and are connected in parallel.
6. Ohmmeters measure resistance of a component and must be connected in parallel, with the circuit or component disconnected from power.
7. Logic probes can indicate the presence of power, ground, or pulsed signals.

REVIEW QUESTIONS

1. Why should high-impedance meters be used when measuring voltage on computer-controlled circuits?
2. How is an ammeter connected to an electrical circuit?
3. Why must an ohmmeter be connected to a disconnected circuit or component?

CHAPTER QUIZ

1. Inductive ammeters work because of what principle?
   - **a.** Magic
   - **b.** Electrostatic electricity
   - **c.** A magnetic field surrounds any wire carrying a current
   - **d.** Voltage drop as it flows through a conductor
2. A meter used to measure amperes is called a(n) ________.
   - **a.** Amp meter
   - **b.** Ampmeter
   - **c.** Ammeter
   - **d.** Coulomb meter
3. A voltmeter should be connected to the circuit being tested ________.
   - **a.** In series
   - **b.** In parallel
   - **c.** Only when no power is flowing
   - **d.** Both a and c
4. An ohmmeter should be connected to the circuit or component being tested ________.
   - **a.** With current flowing in the circuit or through the component
   - **b.** When connected to the battery of the vehicle to power the meter
   - **c.** Only when no power is flowing (electrically open circuit)
   - **d.** Both b and c
5. A high-impedance meter ________.
   - **a.** Measures a high amount of current flow
   - **b.** Measures a high amount of resistance
   - **c.** Can measure a high voltage
   - **d.** Has a high internal resistance
6. A meter is set to read DC volts on the 4 volt scale. The meter leads are connected at a 12 volt battery. The display will read ________.
   - **a.** 0.00
   - **b.** OL
   - **c.** 12 V
   - **d.** 0.012 V
7. What could happen if the meter leads were connected to the positive and negative terminals of the battery while the meter and leads were set to read amperes?
   - **a.** Could blow an internal fuse or damage the meter
   - **b.** Would read volts instead of amperes
   - **c.** Would display OL
   - **d.** Would display 0.00
8. The highest amount of resistance that can be read by the meter set to the 2 kΩ scale is ________.
   - **a.** 2,000 ohms
   - **b.** 200 ohms
   - **c.** 200 kΩ (200,000 ohms)
   - **d.** 20,000,000 ohms
9. If a digital meter face shows 0.93 when set to read kΩ, the reading means ________.
   - **a.** 93 ohms
   - **b.** 930 ohms
   - **c.** 9,300 ohms
   - **d.** 93,000 ohms
10. A reading of 432 shows on the face of the meter set to the millivolt scale. The reading means ________.
    - **a.** 0.432 volt
    - **b.** 4.32 volts
    - **c.** 43.2 volts
    - **d.** 4,320 volts

chapter 7

OSCILLOSCOPES AND GRAPHING MULTIMETERS

OBJECTIVES: After studying Chapter 7, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Use a digital storage oscilloscope to measure voltage signals. • Interpret meter and scope readings and determine if the values are within factory specifications. • Explain time base and volts per division settings.

KEY TERMS: AC coupling 96 • BNC connector 99 • Cathode ray tube (CRT) 94 • Channel 97 • DC coupling 96 • Digital storage oscilloscope (DSO) 94 • Division 95 • Duty cycle 97 • External trigger 98 • Frequency 97 • GMM 100 • Graticule 94 • Hertz 97 • Oscilloscope (scope) 94 • Pulse train 96 • Pulse width 97 • PWM 97 • Time base 95 • Trigger level 98 • Trigger slope 98

TYPES OF OSCILLOSCOPES

TERMINOLOGY An **oscilloscope** (usually called a **scope**) is a visual voltmeter with a timer that shows when a voltage changes. Following are several types of oscilloscopes.

- An *analog scope* uses a **cathode ray tube (CRT)** similar to a television screen to display voltage patterns. The scope screen displays the electrical signal constantly.
- A *digital scope* commonly uses a liquid crystal display (LCD), but a CRT may also be used on some digital scopes. A digital scope takes samples of the signals that can be stopped or stored and is therefore called a **digital storage oscilloscope,** or **DSO.**
- A digital scope does not capture each change in voltage but instead captures voltage levels over time and stores them as dots. Each dot is a voltage level. Then the scope displays the waveforms using the thousands of dots (each representing a voltage level) and then electrically connects the dots to create a waveform.
- A DSO can be connected to a sensor output signal wire and can record over a long period of time the voltage signals. Then it can be replayed and a technician can see if any faults were detected. This feature makes a DSO the perfect tool to help diagnose intermittent problems.
- A digital storage scope, however, can sometimes miss faults called *glitches* that may occur between samples captured by the scope. This is why a DSO with a high "sampling rate" is preferred. Sampling rate means that a scope is cable of capturing voltage changes that occur over a very short period of time. Some digital storage scopes have a capture rate of 25 million (25,000,000) samples per second. This means that the scope can capture a glitch (fault) that lasts just 40 nano (0.00000040) seconds long.
- A scope has been called "a voltmeter with a clock."
  - The voltmeter part means that a scope can capture and display changing voltage levels.
  - The clock part means that the scope can display these changes in voltage levels within a specific time period; and with a DSO it can be replayed so that any faults can be seen and studied.

OSCILLOSCOPE DISPLAY GRID A typical scope face usually has eight or ten grids vertically (up and down) and ten grids horizontally (left to right). The transparent scale (grid), used for reference measurements, is called a **graticule**. This arrangement is commonly 8 × 10 or 10 × 10 divisions. ● **SEE FIGURE 7–1.**

NOTE: These numbers originally referred to the metric dimensions of the graticule in centimeters. Therefore, an 8 × 10 display would be 8 cm (80 mm or 3.14 in.) high and 10 cm (100 mm or 3.90 in.) wide.

- Voltage is displayed on a scope starting with zero volts at the bottom and higher voltage being displayed vertically.
- The scope illustrates time left to right. The pattern starts on the left and sweeps across the screen from left to right.

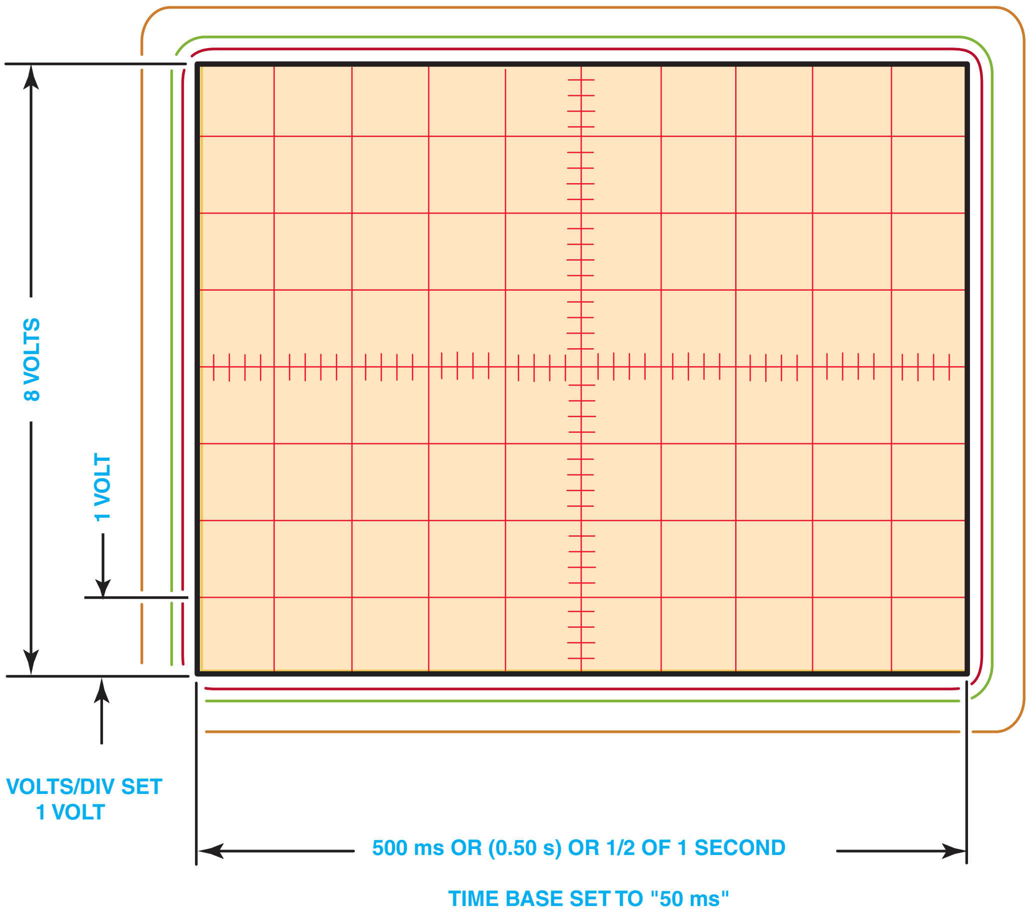


FIGURE 7–1 A scope display allows technicians to take measurements of voltage patterns. In this example, each vertical division is 1 volt and each horizontal division is set to represent 50 milliseconds.

SCOPE SETUP AND ADJUSTMENTS

SETTING THE TIME BASE Most scopes use 10 graticules from left to right on the display. Setting the **time base** means setting how much time will be displayed in each block called a **division**. For example, if the scope is set to read 2 seconds per division (referred to as *s/div*), then the total displayed would be 20 seconds (2 × 10 divisions = 20 sec.). The time base should be set to an amount of time that allows two to four events to be displayed. Milliseconds (0.001 sec.) are commonly used in scopes when adjusting the time base. Sample time is milliseconds per division (indicated as *ms/div*) and total time. ● **SEE CHART 7–1.**

NOTE: Increasing the time base reduces the number of samples per second.

The horizontal scale is divided into 10 divisions (sometimes called *grats*). If each division represents 1 second of time, then the total time period displayed on the screen will be 10 seconds. The time per division is selected so that several events of the waveform are displayed. Time per division settings can vary greatly in automotive use, including:

- MAP/MAF sensors: 2 ms/div (20 ms total)
- Network (CAN) communications network: 2 ms/div (20 ms total)
- Throttle position (TP) sensor: 100 ms per division (1 sec. total)
- Fuel injector: 2 ms/div (20 ms total)
- Oxygen sensor: 1 sec. per division (10 sec. total)

MILLISECONDS PER DIVISION (MS/DIV)	TOTAL TIME DISPLAYED
1 ms	10 ms (0.010 sec.)
10 ms	100 ms (0.100 sec.)
50 ms	500 ms (0.500 sec.)
100 ms	1 sec. (1.000 sec.)
500 ms	5 sec. (5.0 sec.)
1,000 ms	10 sec. (10.0 sec.)

CHART 7–1

The time base is milliseconds (ms) and total time of an event that can be displayed.

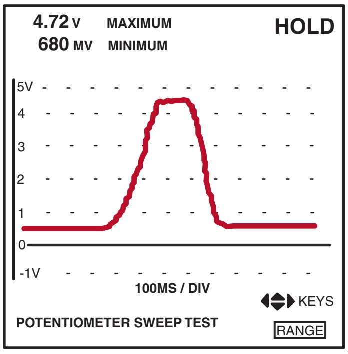


FIGURE 7–2 The display on a digital storage oscilloscope (DSO) displays the entire waveform of a throttle position (TP) sensor from idle to wide-open throttle and then returns to idle. The display also indicates the maximum reading (4.72 V) and the minimum (680 mV or 0.68 V). The display does not show anything until the throttle is opened, because the scope has been set up to only start displaying a waveform after a certain voltage level has been reached. This voltage is called the trigger or trigger point.

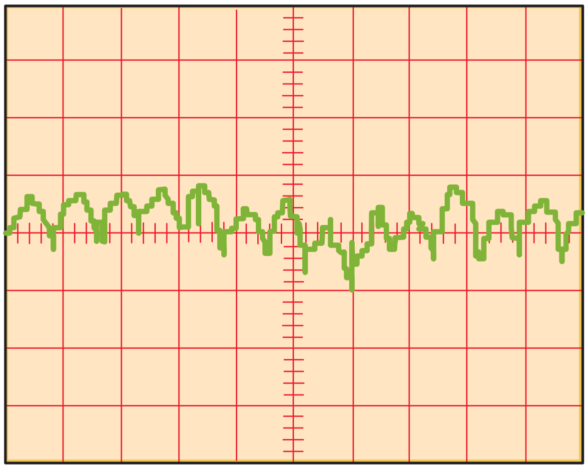


FIGURE 7–3 Ripple voltage is created from the AC voltage from an alternator. Some AC ripple voltage is normal but if the AC portion exceeds 0.5 volt, then a bad diode is the most likely cause. Excessive AC ripple can cause many electrical and electronic devices to work incorrectly.

- Primary ignition: 10 ms/div (100 ms total)
- Secondary ignition: 10 ms/div (100 ms total)
- Voltage measurements: 5 ms/div (50 ms total)

The total time displayed on the screen allows comparisons to see if the waveform is consistent or is changing. Multiple waveforms shown on the display at the same time also allow for measurements to be seen more easily. ● **SEE FIGURE 7–2** for an example of a throttle position sensor waveform created by measuring the voltage output as the throttle was depressed and then released.

VOLTS PER DIVISION The volts per division, abbreviated *V/div*, should be set so that the entire anticipated waveform can be viewed. Examples include:

Throttle position (TP) sensor: 1 V/div (8 V total)

Battery, starting and charging: 2 V/div (16 V total)

Oxygen sensor: 200 mV/div (1.6 V total)

Notice from the examples that the total voltage to be displayed exceeds the voltage range of the component being tested. This ensures that all the waveform will be displayed. It also allows for some unexpected voltage readings. For example, an oxygen sensor should read between 0 V and 1 V (1,000 mV). By setting the V/div to 200 mV, up to 1.6 V (1,600 mV) will be displayed.

DC AND AC COUPLING

DC COUPLING **DC coupling** is the most used position on a scope because it allows the scope to display both alternating current (AC) voltage signals and direct current (DC) voltage signals present in the circuit. The AC part of the signal will ride on top of the DC component. For example, if the engine is running and the charging voltage is 14.4 volts DC, this will be displayed as a horizontal line on the screen. Any AC ripple voltage leaking past the alternator diodes will be displayed as an AC signal on top of the horizontal DC voltage line. Therefore, both components of the signal can be observed at the same time.

AC COUPLING When the **AC coupling** position is selected, a capacitor is placed into the meter lead circuit, which effectively blocks all DC voltage signals but allows the AC portion of the signal to pass and be displayed. AC coupling can be used to show output signal waveforms from sensors such as:

- Distributor pickup coils
- Magnetic wheel speed sensors
- Magnetic crankshaft position sensors
- Magnetic camshaft position sensors
- Magnetic vehicle speed sensors
- The AC ripple from an alternator. ● **SEE FIGURE 7–3**.

NOTE: Check the instructions from the scope manufacturer for the recommended settings to use. Sometimes it is necessary to switch from DC coupling to AC coupling or from AC coupling to DC coupling to properly see some waveforms.

PULSE TRAINS

DEFINITION Scopes can show all voltage signals. Among the most commonly found in automotive applications is a DC voltage that varies up and down and does not go below zero like an AC voltage. A DC voltage that turns on and off in a series of pulses is called a **pulse train**. Pulse trains differ from an AC

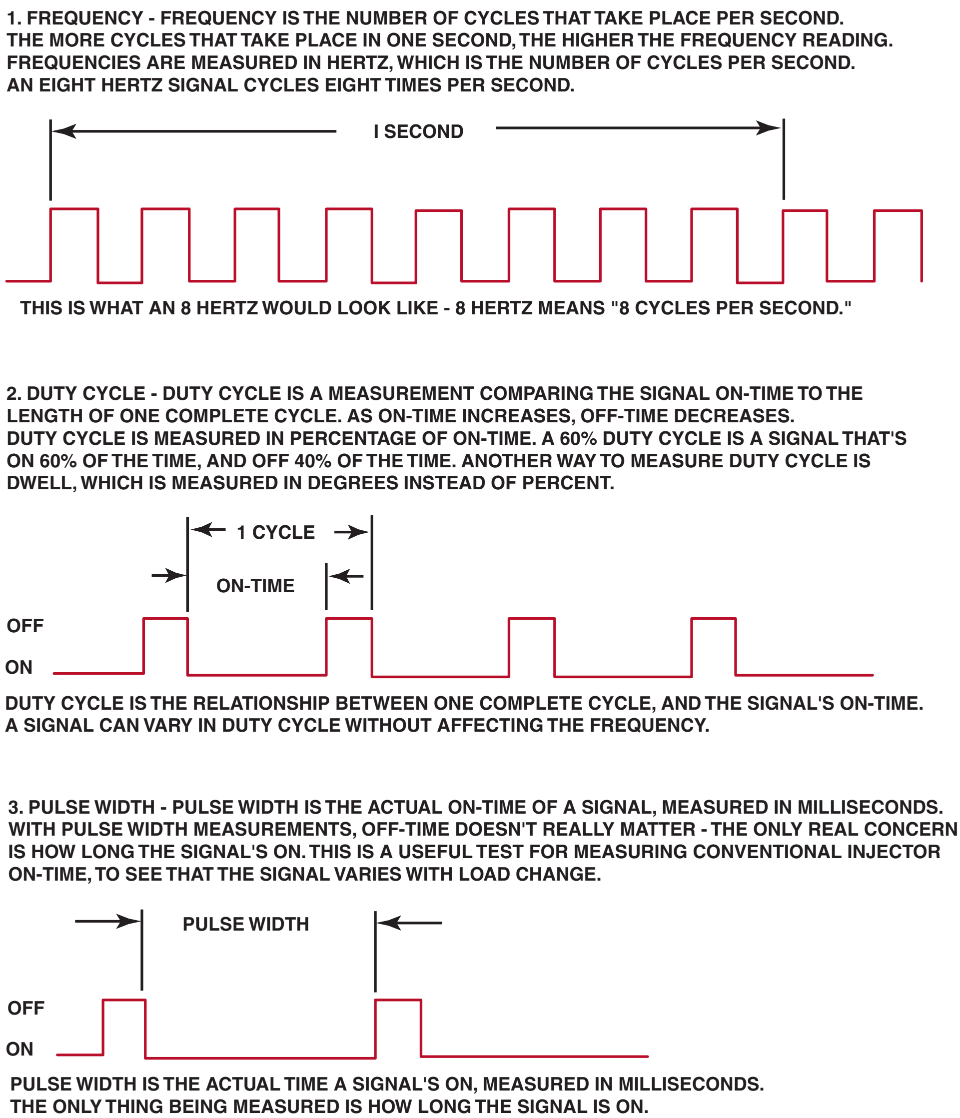


FIGURE 7–4 A pulse train is any electrical signal that turns on and off, or goes high and low in a series of pulses. Ignition module and fuel-injector pulses are examples of a pulse train signal.

signal in that they do not go below zero. An alternating voltage goes above and below zero voltage. Pulse train signals can vary in several ways. ● **SEE FIGURE 7–4.**

FREQUENCY **Frequency** is the number of cycles per second measured in **hertz.** The engine revolutions per minute (RPM) signal is an example of a signal that can occur at various frequencies. At low engine speed, the ignition pulses occur fewer times per second (lower frequency) than when the engine is operated at higher engine speeds (RPM).

DUTY CYCLE **Duty cycle** refers to the percentage of on-time of the signal during one complete cycle. As on-time increases, the amount of time the signal is off decreases and is usually measured in percentage. Duty cycle is also called **pulse-width modulation (PWM)** and can be measured in degrees. ● **SEE FIGURE 7–5.**

PULSE WIDTH The **pulse width** is a measure of the actual on-time measured in milliseconds. Fuel injectors are usually controlled by varying the pulse width. ● **SEE FIGURE 7–6.**

NUMBER OF CHANNELS

DEFINITION Scopes are available that allow the viewing of more than one sensor or event at the same time on the display. The number of events, which require leads for each, is called a **channel**. A channel is an input to a scope. Commonly available scopes include:

- **Single channel.** A single channel scope is capable of displaying only one sensor signal waveform at a time.
- **Two channel.** A two-channel scope can display the waveform from two separate sensors or components at the

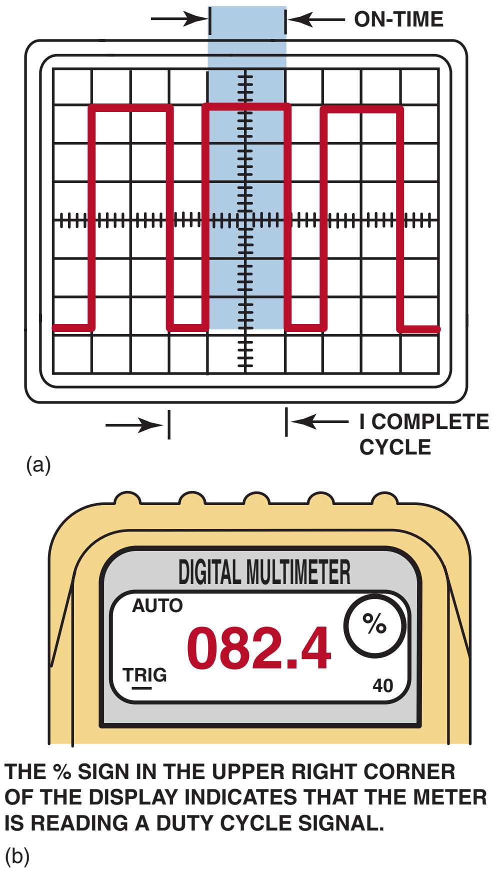


FIGURE 7–5 (a) A scope representation of a complete cycle showing both on-time and off-time. (b) A meter display indicating the on-time duty cycle in a percentage (%). Note the trigger and negative (−) symbol. This indicates that the meter started to record the percentage of on-time when the voltage dropped (start of on-time).

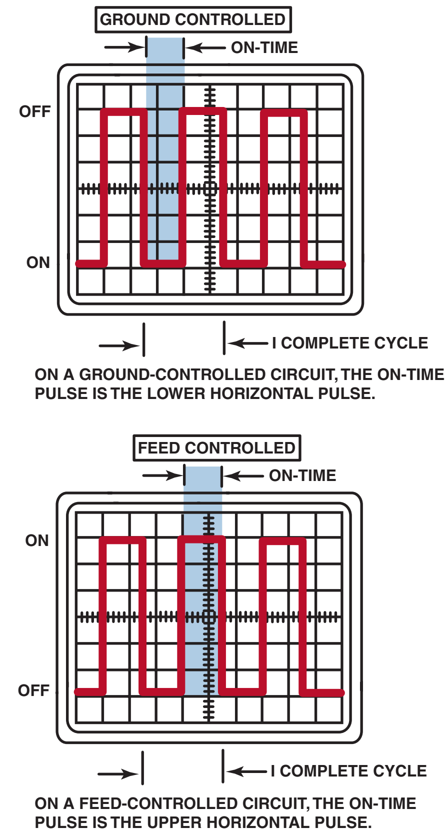


FIGURE 7–6 Most automotive computer systems control the device by opening and closing the ground to the component.

same time. This feature is very helpful when testing the camshaft and crankshaft position sensors on an engine to see if they are properly timed. ● **SEE FIGURE 7–7.**

- **Four channel.** A four-channel scope allows the technician to view up to four different sensors or actuators on one display.

NOTE: Often the capture speed of the signals is slowed when using more than one channel.

TRIGGERS

EXTERNAL TRIGGER An **external trigger** is when the waveform starts when a signal is received from another external source rather than from the signal pickup lead. A common example of an external trigger comes from the probe clamp around the cylinder #1 spark plug wire to trigger the start of an ignition pattern.

TRIGGER LEVEL **Trigger level** is the voltage that must be detected by the scope before the pattern will be displayed. A scope will only start displaying a voltage signal when it is triggered or is told to start. The trigger level must be set to start the display. If the pattern starts at 1 volt, then the trace will begin displaying on the left side of the screen *after* the trace has reached 1 volt.

TRIGGER SLOPE The **trigger slope** is the voltage direction that a waveform must have in order to start the display. Most often, the trigger to start a waveform display is taken from the signal itself. Besides trigger voltage level, most scopes can be adjusted to trigger only when the voltage rises past the trigger-level voltage. This is called a *positive slope*. When the voltage falling past the higher level activates the trigger, this is called a *negative slope*.

The scope display indicates both a positive and a negative slope symbol. For example, if a waveform such as a magnetic sensor used for crankshaft position or wheel speed starts moving upward, a positive slope should be selected. If a negative slope is selected, the waveform will not start showing until the voltage reaches the trigger level in a downward direction. A negative slope should be used when a fuel-injector circuit is being analyzed. In this circuit, the computer provides the ground and the voltage level drops when the computer commands the injector on. Sometimes the technician needs to change from negative to positive or positive to negative trigger if a waveform is not being shown correctly. ● **SEE FIGURE 7–8.**

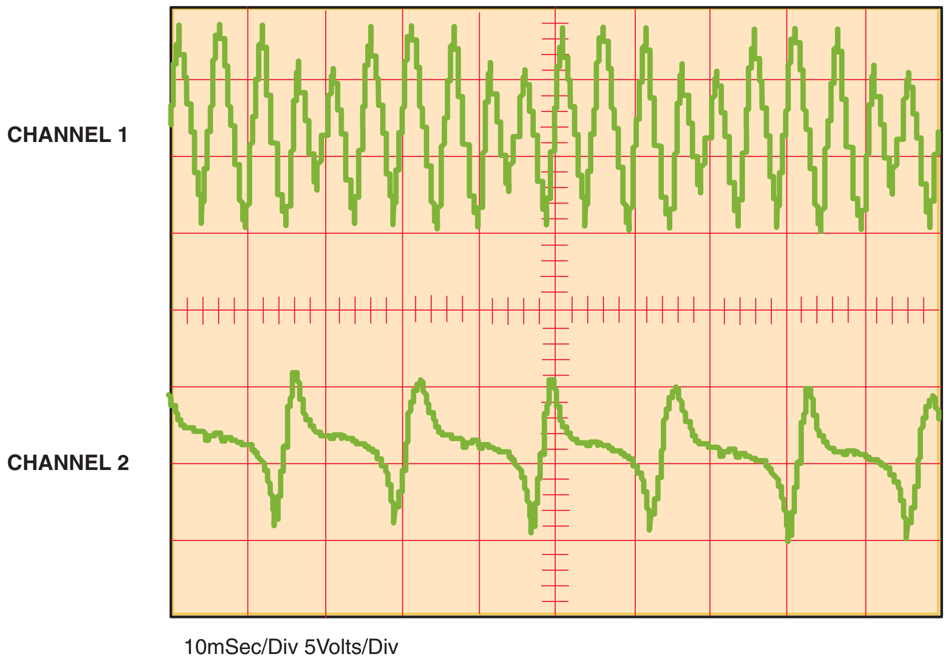


FIGURE 7–7 A two-channel scope being used to compare two signals on the same vehicle.

FIGURE 7–8 (a) A symbol for a positive trigger—a trigger occurs at a rising (positive) edge of the signal (waveform). (b) A symbol for a negative trigger—a trigger occurs at a falling (negative) edge of the signal (waveform).

USING A SCOPE

USING SCOPE LEADS Most scopes, both analog and digital, normally use the same test leads. These leads usually attach to the scope through a **BNC connector**, a miniature standard coaxial cable connector. BNC is an international standard that is used in the electronics industry. If using a BNC connector, be sure to connect one lead to a good clean, metal engine ground. The probe of the scope lead attaches to the circuit or component being tested. Many scopes use one ground lead and then each channel has it own signal pickup lead.

MEASURING BATTERY VOLTAGE WITH A SCOPE One of the easiest things to measure and observe on a scope is battery voltage. A lower voltage can be observed on the scope display as the engine is started and a higher voltage should be displayed after the engine starts. ● **SEE FIGURE 7–9.**

An analog scope displays rapidly and cannot be set to show or freeze a display. Therefore, even though an analog

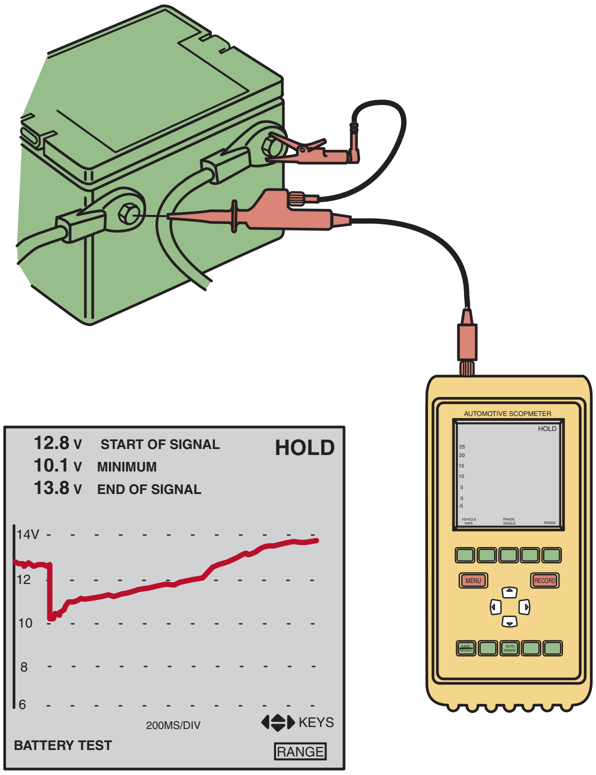


FIGURE 7–9 Constant battery voltage is represented by a flat horizontal line. In this example, the engine was started and the battery voltage dropped to about 10 V as shown on the left side of the scope display. When the engine started, the alternator started to charge the battery and the voltage is shown as climbing.

FIGURE 7–10 A typical graphing multimeter that can be used as a digital meter, plus it can display the voltage levels on the display screen.

scope shows all voltage signals, it is easy to miss a momentary glitch on an analog scope.

CAUTION: Check the instructions for the scope being used before attempting to scope household AC circuits. Some scopes, such as the Snap-On MODIS, are not designed to measure high-voltage AC circuits.

GRAPHING MULTIMETER

A **graphing multimeter**, abbreviated **GMM**, is a cross between a digital meter and a digital storage oscilloscope. A graphing multimeter displays the voltage levels at two places:

- On a display screen
- In a digital readout

It is usually not capable of capturing very short duration faults or glitches that would likely be captured with a digital storage oscilloscope. ● **SEE FIGURE 7–10.**

GRAPHING SCAN TOOLS

Many scan tools are capable of displaying the voltage levels captured by the scan tool through the data link connector (DLC) on a screen. This feature is helpful where seeing changes in voltage levels is difficult to detect by looking at numbers that are constantly changing. Read and follow the instructions for the scan tool being used.

SUMMARY

1. Analog oscilloscopes use a cathode ray tube to display voltage patterns.
2. The waveforms shown on an analog oscilloscope cannot be stored for later viewing.
3. A digital storage oscilloscope (DSO) creates an image or waveform on the display by connecting thousands of dots captured by the scope leads.
4. An oscilloscope display grid is called a graticule. Each of the 8 × 10 or 10 × 10 dividing boxes is called a division.
5. Setting the time base means establishing the amount of time each division represents.
6. Setting the volts per division allows the technician to view either the entire waveform or just part of it.
7. DC coupling and AC coupling are two selections that can be made to observe different types of waveforms.
8. A graphing multimeter is not capable of capturing short duration faults but can display usable waveforms.
9. Oscilloscopes display voltage over time. A DSO can capture and store a waveform for viewing later.

REVIEW QUESTIONS

1. What are the differences between an analog and a digital oscilloscope?
2. What is the difference between DC coupling and AC coupling?
3. Why are DC signals that change called pulse trains?
4. What is the difference between an oscilloscope and a graphing multimeter?

CHAPTER QUIZ

1. Technician A says an analog scope can store the waveform for viewing later. Technician B says that the trigger level has to be set on most scopes to be able to view a changing waveform. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. An oscilloscope display is called a ________.
   - **a.** Grid
   - **b.** Graticule
   - **c.** Division
   - **d.** Box
3. A signal showing the voltage of a battery displayed on a digital storage oscilloscope (DSO) is being discussed. Technician A says that the display will show one horizontal line above the zero line. Technician B says that the display will show a line sloping upward from zero to the battery voltage level. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Setting the time base to 50 ms per division will allow the technician to view a waveform how long in duration?
   - **a.** 50 ms
   - **b.** 200 ms
   - **c.** 400 ms
   - **d.** 500 ms
5. A throttle position sensor waveform is going to be observed. At what setting should the volts per division be set to see the entire waveform from 0 to 5 volts?
   - **a.** 0.5 V/division
   - **b.** 1.0 V/division
   - **c.** 2.0 V/division
   - **d.** 5.0 V/division
6. Two technicians are discussing the DC coupling setting on a DSO. Technician A says that the position allows both the DC and AC signals of the waveform to be displayed. Technician B says that this setting allows just the DC part of the waveform to be displayed. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Voltage signals (waveforms) that do not go below zero are called ________.
   - **a.** AC signals
   - **b.** Pulse trains
   - **c.** Pulse width
   - **d.** DC coupled signals
8. Cycles per second are expressed in ________.
   - **a.** Hertz
   - **b.** Duty cycle
   - **c.** Pulse width
   - **d.** Slope
9. Oscilloscopes use what type of lead connector?
   - **a.** Banana plugs
   - **b.** Double banana plugs
   - **c.** Single conductor plugs
   - **d.** BNC
10. A digital meter that can show waveforms is called a ________.
    - **a.** DVOM
    - **b.** DMM
    - **c.** GMM
    - **d.** DSO

chapter 8

AUTOMOTIVE WIRING AND WIRE REPAIR

OBJECTIVES: After studying Chapter 8, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the wire gauge number system. • Describe how fusible links and fuses protect circuits and wiring. • Discuss electrical terminals and connectors • Describe how to solder • Discuss circuit breakers and PTC electronic circuit protection devices. • Explain the types of electrical conduit • List the steps for performing a proper wire repair.

KEY TERMS: Adhesive-lined heat shrink tubing 112 • American wire gauge (AWG) 102 • Auto link 106 • Battery cables 104 • Braided ground straps 104 • Circuit breakers 107 • Cold solder joint 112 • Connector 110 • CPA 110 • Crimp-and-seal connectors 112 • Fuse link 106 • Fuses 105 • Fusible link 108 • Heat shrink tubing 112 • Jumper cables 104 • Lock tang 110 • Metric wire gauge 103 • Pacific fuse element 106 • Primary wire 103 • PTC circuit protectors 108 • Rosin-core solder 111 • Skin effect 104 • Terminal 110 • Twisted pair 104

AUTOMOTIVE WIRING

DEFINITION AND TERMINOLOGY Most automotive wire is made from strands of copper covered by plastic insulation. Copper is an excellent conductor of electricity that is reasonably priced and very flexible. However, solid copper wire can break when moved repeatedly; therefore, most copper wiring is constructed of multiple small strands that allow for repeated bending and moving without breaking. Solid copper wire is generally used for components such as starter armature and alternator stator windings that do not bend or move during normal operation. Copper is the best electrical conductor besides silver, which is a great deal more expensive. The conductivity of various metals is rated. ● **SEE CHART 8–1.**

1.	Silver
2.	Copper
3.	Gold
4.	Aluminum
5.	Tungsten
6.	Zinc
7.	Brass (copper and zinc)
8.	Platinum
9.	Iron
10.	Nickel
11.	Tin
12.	Steel
13.	Lead

CHART 8–1

The list of relative conductivity of metals, showing silver to be the best.

AMERICAN WIRE GAUGE Wiring is sized and purchased according to gauge size as assigned by the **American wire gauge (AWG)** system. AWG numbers can be confusing because as the gauge number *increases,* the size of the conductor wire *decreases*. Therefore, a 14 gauge wire is smaller than a 10 gauge wire. The *greater* the amount of current (in amperes) that is flowing through a wire, the *larger the diameter (smaller gauge number)* that will be required. ● **SEE CHART 8–2,** which compares the AWG number to the actual wire diameter in inches. The diameter refers to the diameter of the metal conductor and does not include the insulation.

Following are general applications for the most commonly used wire gauge sizes. Always check the installation instructions or the manufacturer's specifications for wire gauge size before replacing any automotive wiring.

- 20 to 22 gauge: radio speaker wires
- 18 gauge: small bulbs and short leads
- 16 gauge: taillights, gas gauge, turn signals, windshield wipers
- 14 gauge: horn, radio power lead, headlights, cigarette lighter, brake lights
- 12 gauge: headlight switch-to-fuse box, rear window defogger, power windows and locks
- 10 gauge: alternator-to-battery
- 4, 2, or 0 (1/0) gauge: battery cables

WIRE GAUGE DIAMETER TABLE	
AMERICAN WIRE GAUGE (AWG)	WIRE DIAMETER IN INCHES
20	0.03196118
18	0.040303
16	0.0508214
14	0.064084
12	0.08080810
10	0.10189
8	0.128496
6	0.16202
5	0.18194
4	0.20431
3	0.22942
2	0.25763
1	0.2893
0	0.32486
00	0.3648

CHART 8–2

American wire gauge (AWG) number and the actual conductor diameter in inches.

? FREQUENTLY ASKED QUESTION

Do They Make 13 Gauge Wire?

Yes. AWG sizing of wire includes all gauge numbers, including 13, even though the most commonly used sizes are even numbered, such as 12, 14, or 16.

Because the sizes are so close, wire in every size is not commonly stocked, but can be ordered for a higher price. Therefore, if a larger wire size is needed, it is common practice to select the next lower, even-numbered gauge.

METRIC WIRE GAUGE Most manufacturers indicate on the wiring diagrams the **metric wire gauge** sizes measured in square millimeters (mm^2) of cross-sectional area. The following chart gives conversions or comparisons between metric gauge and AWG sizes. Notice that the metric wire size increases with size (area), whereas the AWG size gets smaller with larger size wire. ● **SEE CHART 8–3.**

The AWG number should be decreased (wire size increased) with increased lengths of wire. ● **SEE CHART 8–4.**

For example, a trailer may require 14 gauge wire to light all the trailer lights, but if the wire required is over 25 ft long, 12 gauge wire should be used. Most automotive wire, except for spark plug wire, is often called **primary wire** (named for the voltage range used in the primary ignition circuit) because it is designed to operate at or near battery voltage.

METRIC SIZE (MM^2)	AWG SIZE
0.5	20
0.8	18
1.0	16
2.0	14
3.0	12
5.0	10
8.0	8
13.0	6
19.0	4
32.0	2
52.0	0

CHART 8–3

Metric wire size in squared millimeters (mm^2) conversion chart to American wire gauge (AWG).

12 V	RECOMMENDED WIRE GAUGE (AWG) (FOR LENGTH IN FEET)*						
AMPS	3′	5′	7′	10′	15′	20′	25′
5	18	18	18	18	18	18	18
7	18	18	18	18	18	18	16
10	18	18	18	18	16	16	16
12	18	18	18	18	16	16	14
15	18	18	18	18	14	14	12
18	18	18	16	16	14	14	12
20	18	18	16	16	14	12	10
22	18	18	16	16	12	12	10
24	18	18	16	16	12	12	10
30	18	16	16	14	10	10	10
40	18	16	14	12	10	10	8
50	16	14	12	12	10	10	8
100	12	12	10	10	6	6	4
150	10	10	8	8	4	4	2
200	10	8	8	6	4	4	2

* When mechanical strength is a factor, use the next larger wire gauge.

CHART 8–4

Recommended AWG wire size increases as the length increases because all wire has internal resistance. The longer the wire is, the greater the resistance. The larger the diameter is, the lower the resistance.

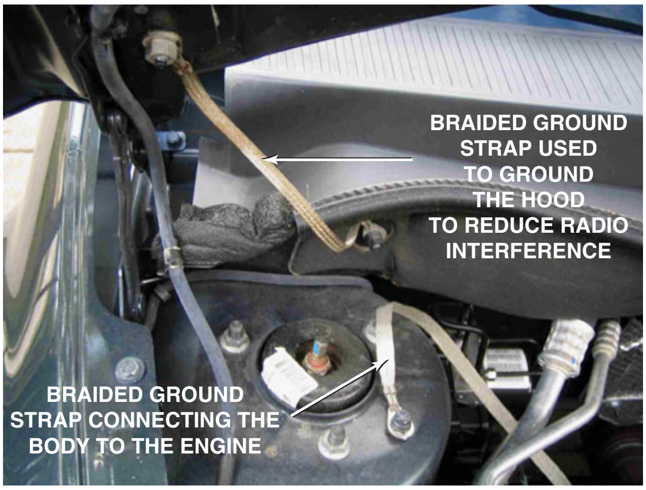


FIGURE 8–1 All lights and accessories ground to the body of the vehicle. Body ground wires such as this one are needed to conduct all of the current from these components back to the negative terminal of the battery. The body ground wire connects the body to the engine. Most battery negative cables attach to the engine.

FIGURE 8–2 Battery cables are designed to carry heavy starter current and are therefore usually 4 gauge or larger wire. Note that this battery has a thermal blanket covering to help protect the battery from high underhood temperatures. The wiring is also covered with plastic conduit called split-loom tubing.

GROUND WIRES

PURPOSE AND FUNCTION All vehicles use ground wires between the engine and body and/or between the body and the negative terminal of the battery. The two types of ground wires are:

- Insulated copper wire
- Braided ground straps

Braided grounds straps are uninsulated. It is not necessary to insulate a ground strap because it does not matter if it touches metal, as it already attaches to ground. Braided ground straps are more flexible than stranded wire. Because the engine will move slightly on its mounts, the braided ground strap must be able to flex without breaking. ● **SEE FIGURE 8–1.**

SKIN EFFECT The braided strap also dampens out some radio-frequency interference that otherwise might be transmitted through standard stranded wiring due to the skin effect.

The **skin effect** is the term used to describe how high-frequency AC electricity flows through a conductor. Direct current flows through a conductor, but alternating current tends to travel through the outside (skin) of the conductor. Because of the skin effect, most audio (speaker) cable is constructed of many small-diameter copper wires instead of fewer larger strands, because the smaller wire has a greater surface area and therefore results in less resistance to the flow of AC voltage.

NOTE: Body ground wires are necessary to provide a circuit path for the lights and accessories that ground to the body and flow to the negative battery terminal.

FREQUENTLY ASKED QUESTION

What Is a Twisted Pair?

A **twisted pair** is used to transmit low-voltage signals using two wires that are twisted together. Electromagnetic interference can create a voltage in a wire and twisting the two signal wires cancels out the induced voltage. A twisted pair means that the two wires have at least nine turns per foot (turns per meter). A rule of thumb is a twisted pair should have one twist per inch of length.

BATTERY CABLES

Battery cables are the largest wires used in the automotive electrical system. The cables are usually 4 gauge, 2 gauge, or 1 gauge wires (19 mm^2 or larger). ● **SEE FIGURE 8–2.**

Wires larger than 1 gauge are called 0 gauge (pronounced "ought"). Larger cables are labeled 2/0 or 00 (2 ought) and 3/0 or 000 (3 ought). Electrical systems that are 6 volts require battery cables two sizes larger than those used for 12 volt electrical systems, because the lower voltage used in antique vehicles resulted in twice the amount of current (amperes) to supply the same electrical power.

JUMPER CABLES

Jumper cables are 4 to 2/0 gauge electrical cables with large clamps attached and are used to connect a vehicle that has a discharged battery to a vehicle that has a good battery. Good-quality

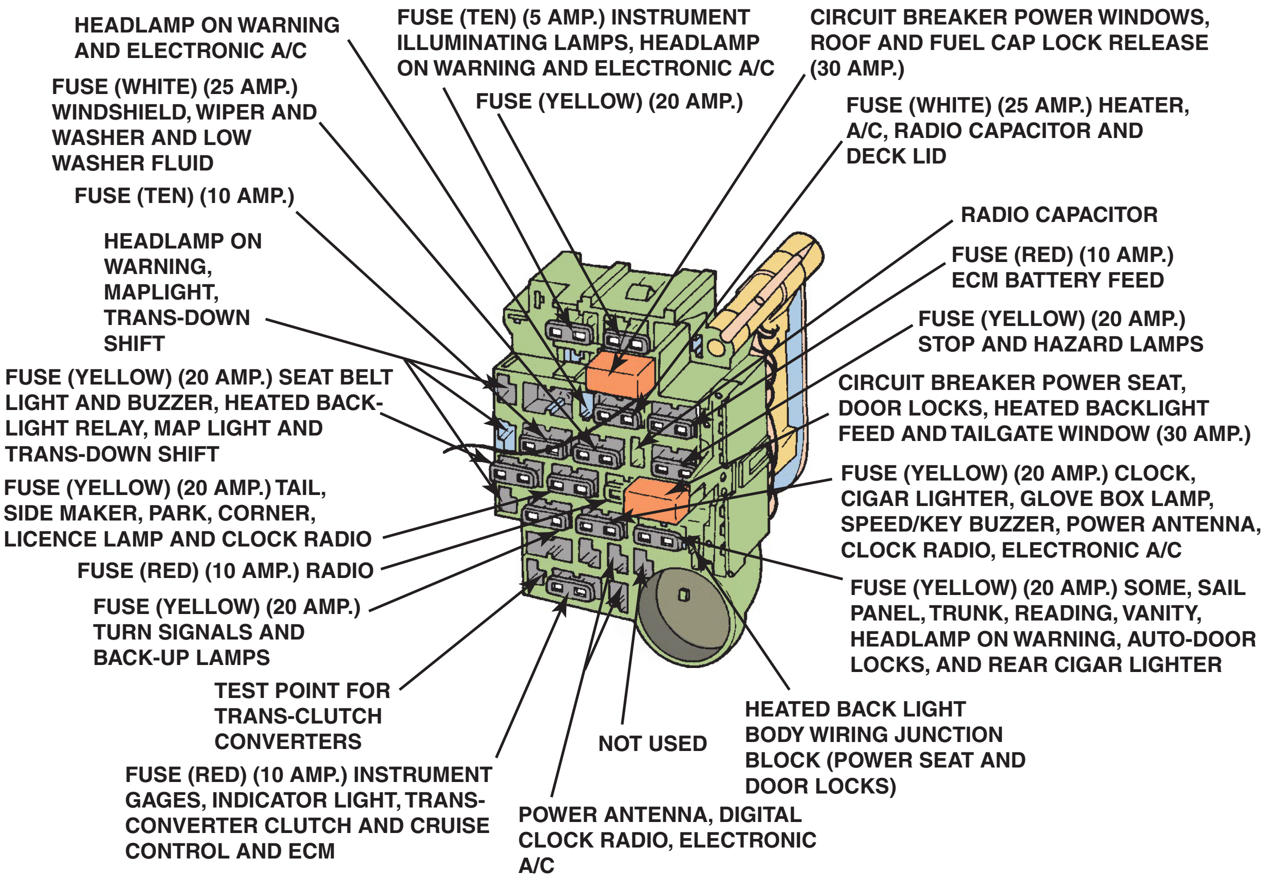


FIGURE 8–3 A typical automotive fuse panel.

jumper cables are necessary to prevent excessive voltage drops caused by cable resistance. Aluminum wire jumper cables should not be used, because even though aluminum is a good electrical conductor (although not as good as copper), it is less flexible and can crack and break when bent or moved repeatedly. The size should be 6 gauge or larger.

1/0 AWG welding cable can be used to construct an excellent set of jumper cables using welding clamps on both ends. Welding cable is usually constructed of many very fine strands of wire, which allow for easier bending of the cable as the strands of fine wire slide against each other inside the cable.

NOTE: Always check the wire gauge of any battery cables or jumper cables and do not rely on the outside diameter of the wire. Many lower cost jumper cables use smaller gauge wire, but may use thick insulation to make the cable look as if it is the correct size wire.

FUSES AND CIRCUIT PROTECTION DEVICES

CONSTRUCTION **Fuses** should be used in every circuit to protect the wiring from overheating and damage caused by excessive current flow as a result of a short circuit or other malfunction. The symbol for a fuse is a wavy line between two points: —o∿o—

A fuse is constructed of a fine tin conductor inside a glass, plastic, or ceramic housing. The tin is designed to melt and open the circuit if excessive current flows through the fuse. Each fuse is rated according to its maximum current-carrying capacity.

Many fuses are used to protect more than one circuit of the automobile. ● **SEE FIGURE 8–3.**

A typical example is the fuse for the cigarette lighter that also protects many other circuits, such as those for the courtesy lights, clock, and other circuits. A fault in one of these circuits can cause this fuse to melt, which will prevent the operation of all other circuits that are protected by the fuse.

NOTE: The SAE term for a cigarette lighter is *cigar lighter* because the diameter of the heating element is large enough for a cigar. The term *cigarette lighter* will be used throughout this book because it is the most common usage.

FUSE RATINGS Fuses are used to protect the wiring and components in the circuit from damage if an excessive amount of current flows. The fuse rating is normally about 20% higher than the normal current in the circuit. ● **SEE CHART 8–5** for a typical fuse rating based on the normal current in the circuit. In other words, the normal current flow should be about 80% of the fuse rating.

NORMAL CURRENT IN THE CIRCUIT (AMPERES)	FUSE RATING
7.5 A	10 A
16 A	20 A
24 A	30 A

CHART 8–5

The fuse rating should be 20% higher than the maximum current in the circuit to provide the best protection for the wiring and the component being protected.

AMPERAGE RATING	COLOR
1	Dark green
2	Gray
2.5	Purple
3	Violet
4	Pink
5	Tan
6	Gold
7.5	Brown
9	Orange
10	Red
14	Black
15	Blue
20	Yellow
25	White
30	Green

CHART 8–6

The amperage rating and the color of the blade fuse are standardized.

BLADE FUSES

Colored blade-type fuses are also referred to as ATO fuses and have been used since 1977. The color of the plastic of blade fuses indicates the maximum current flow, measured in amperes.

● **SEE CHART 8–6** for the color and the amperage rating of blade fuses.

Each fuse has an opening in the top of its plastic portion to allow access to its metal contacts for testing purposes. ● **SEE FIGURE 8–4.**

MINI FUSES

To save space, many vehicles use mini (small) blade fuses. Not only do they save space but they also allow the vehicle design engineer to fuse individual circuits instead of grouping many different components on one fuse. This improves customer satisfaction because if one component fails, it only affects that one circuit without stopping electrical power to several other circuits as well. This makes troubleshooting a lot easier too, because each circuit is separate. ● **SEE CHART 8–7** for the amperage rating and corresponding fuse color for mini fuses.

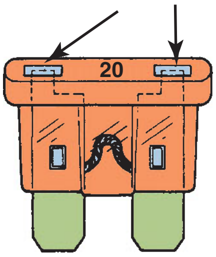


FIGURE 8–4 Blade-type fuses can be tested through openings in the plastic at the top of the fuse.

AMPERAGE RATING	COLOR
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	Natural
30	Green

CHART 8–7

Mini fuse amperage rating and colors.

AMPERAGE RATING	COLOR
20	Yellow
30	Green
40	Amber
50	Red
60	Blue
70	Brown
80	Natural

CHART 8–8

Maxi fuse amperage rating and colors.

MAXI FUSES

Maxi fuses are a large version of blade fuses and are used to replace fusible links in many vehicles. Maxi fuses are rated up to 80 amperes or more. ● **SEE CHART 8–8** for the amperage rating and corresponding color for maxi fuses.

● **SEE FIGURE 8–5** for a comparison of the various sizes of blade-type fuses.

PACIFIC FUSE ELEMENT

First used in the late 1980s, **Pacific fuse elements** (also called a **fuse link** or **auto link**) are used to protect wiring from a direct short-to-ground. The

FIGURE 8–5 Three sizes of blade-type fuses: mini on the left, standard or ATO type in the center, and maxi on the right.

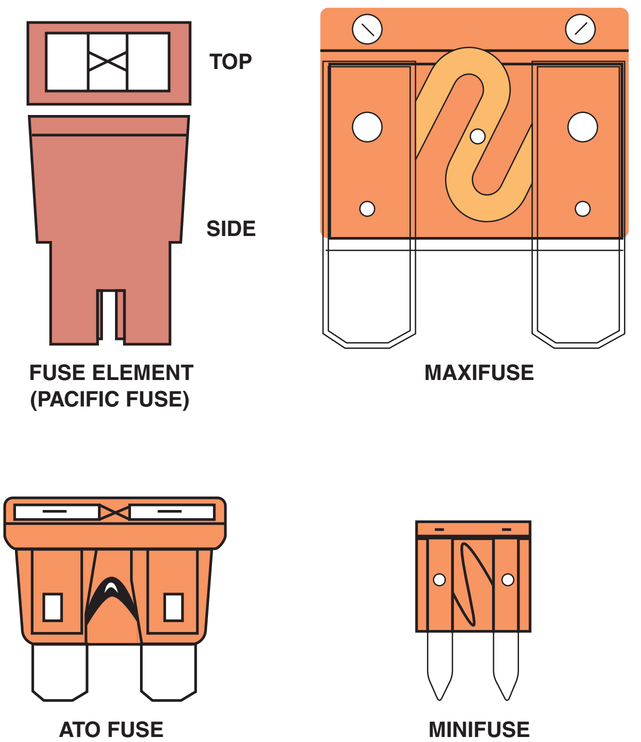


FIGURE 8–6 A comparison of the various types of protective devices used in most vehicles.

housing contains a short link of wire sized for the rated current load. The transparent top allows inspection of the link inside. ● **SEE FIGURE 8–6.**

TESTING FUSES It is important to test the condition of a fuse if the circuit being protected by the fuse does not operate. Most blown fuses can be detected quickly because the center conductor is melted. Fuses can also fail and open the circuit because of a poor connection in the fuse itself or in the fuse holder. Therefore, just because a fuse "looks okay" does not mean that it *is* okay. All fuses should be tested with a test light. The test light should be connected to first one side of the fuse and then the other. A test light should light on both sides. If the test light only lights on one side, the fuse is blown or open. If the test light does not light on either side of the fuse, then that circuit is not being supplied power. ● **SEE FIGURE 8–7.** An ohmmeter can be used to test fuses.

FIGURE 8–7 To test a fuse, use a test light to check for power at the power side of the fuse. The ignition switch and lights may have to be on before some fuses receive power. If the fuse is good, the test light should light on both sides (power side and load side) of the fuse.

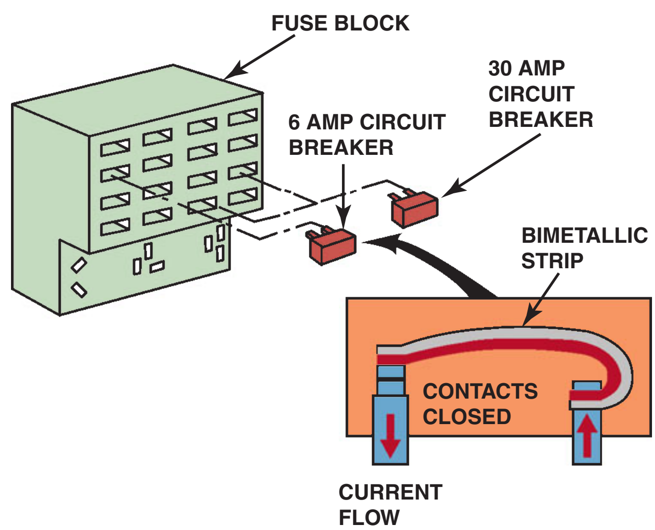


FIGURE 8–8 Typical blade circuit breaker fits into the same space as a blade fuse. If excessive current flows through the bimetallic strip, the strip bends and opens the contacts and stops current flow. When the circuit breaker cools, the contacts close again, completing the electrical circuit.

CIRCUIT BREAKERS Circuit breakers are used to prevent harmful overload (excessive current flow) in a circuit by opening the circuit and stopping the current flow to prevent overheating and possible fire caused by hot wires or electrical components. **Circuit breakers** are mechanical units made of two different metals (bimetallic) that deform when heated and open a set of contact points that work in the same manner as an "off" switch. ● **SEE FIGURE 8–8.**

Cycling-type circuit breakers, therefore, are reset when the current stops flowing, which causes the bimetallic strip to cool and the circuit to close again. A circuit breaker is used in circuits

FIGURE 8–9 Electrical symbols used to represent circuit breakers.

that could affect the safety of passengers if a conventional non-resetting fuse were used. The headlight circuit is an excellent example of the use of a circuit breaker rather than a fuse. A short or grounded circuit anywhere in the headlight circuit could cause excessive current flow and, therefore, the opening of the circuit. Obviously, a sudden loss of headlights at night could have disastrous results. A circuit breaker opens and closes the circuit rapidly, thereby protecting the circuit from overheating and also providing sufficient current flow to maintain at least partial headlight operation.

Circuit breakers are also used in other circuits where conventional fuses could not provide for the surges of high current commonly found in those circuits. See ● **FIGURE 8–9** for the electrical symbols used to represent a circuit breaker.

Examples are the circuits for the following accessories.

1. Power seats
2. Power door locks
3. Power windows

PTC CIRCUIT PROTECTORS

Positive temperature coefficient (PTC) circuit protectors are solid state (without moving parts). Like all other circuit protection devices, PTCs are installed in series in the circuit being protected. If excessive current flows, the temperature and resistance of the PTC increase.

This increased resistance reduces current flow (amperes) in the circuit and may cause the electrical component in the circuit not to function correctly. For example, when a PTC circuit protector is used in a power window circuit, the increased resistance causes the operation of the power window to be much slower than normal.

Unlike circuit breakers or fuses, PTC circuit protection devices do *not* open the circuit, but rather provide a very high resistance between the protector and the component. ● **SEE FIGURE 8–10.**

In other words, voltage will be available to the component. This fact has led to a lot of misunderstanding about how these circuit protection devices actually work. It is even more confusing when the circuit is opened and the PTC circuit protector cools down. When the circuit is turned back on, the component may operate normally for a short time; however, the PTC circuit protector will again get hot because of too much current flow. Its resistance again increases to limit current flow.

The electronic control unit (computer) used in most vehicles today incorporates thermal overload protection devices. ● **SEE FIGURE 8–11.**

Therefore, when a component fails to operate, do not blame the computer. The current control device is controlling current flow to protect the computer. Components that do not operate correctly should be checked for proper resistance and current draw.

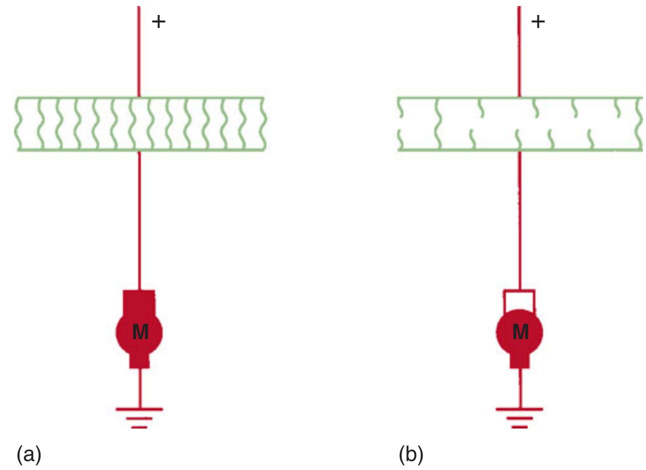


FIGURE 8–10 (a) The normal operation of a PTC circuit protector such as in a power window motor circuit showing the many conducting paths. With normal current flow, the temperature of the PTC circuit protector remains normal. (b) When current exceeds the amperage rating of the PTC circuit protector, the polymer material that makes up the electronic circuit protector increases in resistance. As shown, a high-resistance electrical path still exists even though the motor will stop operating as a result of the very low current flow through the very high resistance. The circuit protector will not reset or cool down until voltage is removed from the circuit.

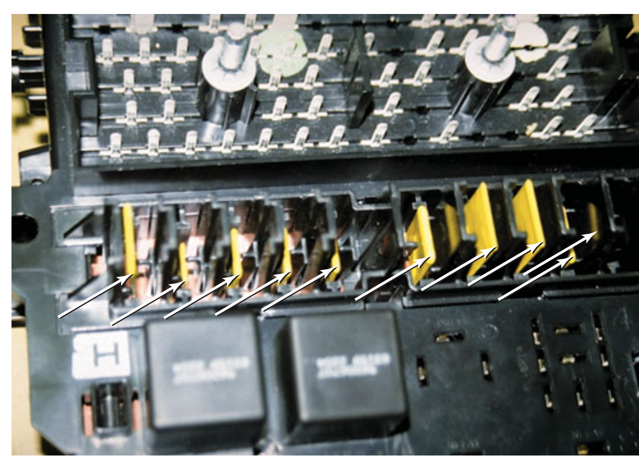


FIGURE 8–11 PTC circuit protectors are used extensively in the power distribution center of this Chrysler vehicle.

FUSIBLE LINKS

A **fusible link** is a type of fuse that consists of a short length (6 to 9 in. long) of standard copper-strand wire covered with a special nonflammable insulation. This wire is usually four wire numbers smaller than the wire of the circuits it protects. For example, a 12 gauge circuit is protected by a 16 gauge fusible link. The special thick insulation over the wire may make it look larger than other wires of the same gauge number. ● **SEE FIGURE 8–12.**

If excessive current flow (caused by a short-to-ground or a defective component) occurs, the fusible link will melt in half

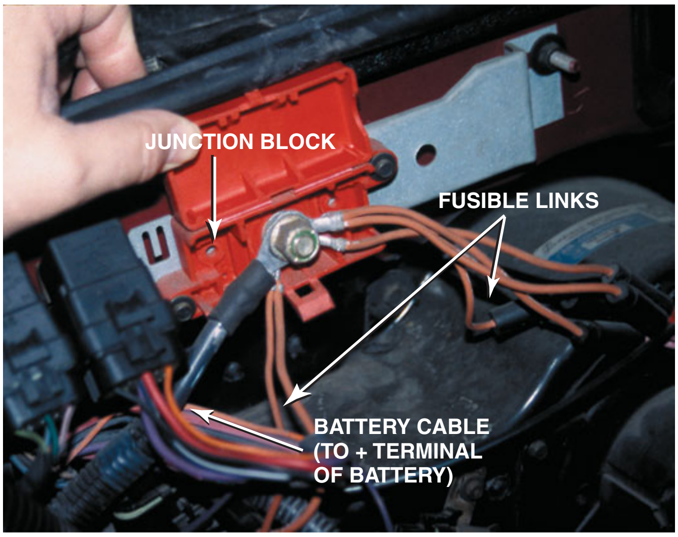


FIGURE 8–12 Fusible links are usually located close to the battery and are usually attached to a junction block. Notice that they are only 6 to 9 in. long and feed more than one fuse from each fusible link.

and open the circuit to prevent a fire hazard. Some fusible links are identified with "fusible link" tags at the junction between the fusible link and the standard chassis wiring, which represent only the junction. Fusible links are the backup system for circuit protection. All current except the current used by the starter motor flows through fusible links and then through individual circuit fuses. It is possible that a fusible link will melt and not blow a fuse. Fusible links are installed as close to the battery as possible so that they can protect the wiring and circuits coming directly from the battery.

MEGA FUSES Many newer vehicles are equipped with mega fuses instead of fusible links to protect high-amperage circuits. Circuits often controlled by mega fuses include:

- Charging circuit
- HID headlights
- Heated front or rear glass
- Multiple circuits usually protected by mega fuses
- Mega fuse rating for vehicles, including 80, 100, 125, 150, 175, 200, 225, and 250 amperes
  ● **SEE FIGURE 8–13.**

CHECKING FUSIBLE LINKS AND MEGA FUSES Fusible links and mega fuses are usually located near where electrical power is sent to other fuses or circuits, such as:

- Starter solenoid battery terminals
- Power distribution centers
- Output terminals of alternators
- Positive terminals of the battery

Fusible links can melt and not show any external evidence of damage. To check a fusible link, gently pull on each end to see if it stretches. If the insulation stretches, then the wire inside has melted and the fusible link must be replaced after determining what caused the link to fail.

Another way to check a fusible link is to use a test light or a voltmeter and check for available voltage at both ends of the fusible link. If voltage is available at only one end, then the link is electrically open and should be replaced.

FIGURE 8–13 A 125 ampere rated mega fuse used to control the current from the alternator.

TECH TIP

Find the Root Cause

If a mega fuse or fusible link fails, find the root cause before replacing it. A mega fuse can fail due to vibration or physical damage as a result of a collision or corrosion. Check to see if the fuse itself is loose and can be moved by hand. If loose, then simply replace the mega fuse. If a fusible link or mega fuse has failed due to excessive current, check for evidence of a collision or any other reason that could cause an excessive amount of current to flow. This inspection should include each electrical component being supplied current from the fusible link. After being sure that the root cause has been found and corrected, then replace the fusible link or mega fuse.

REPLACING A FUSIBLE LINK If a fusible link is found to be melted, perform the following steps.

STEP 1 Determine why the fusible link failed and repair the fault.

STEP 2 Check service information for the exact length, gauge, and type of fusible link required.

STEP 3 Replace the fusible link with the specified fusible link wire and according to the instructions found in the service information.

CAUTION: Always use the *exact* length of fusible link wire required because if it is too short, it will not have enough resistance to generate the heat needed to melt the wire and protect the circuits or components. If the wire is too long, it could melt during normal operation of the circuits it is protecting. Fusible link wires are usually longer than 6 in. and shorter than 9 in.

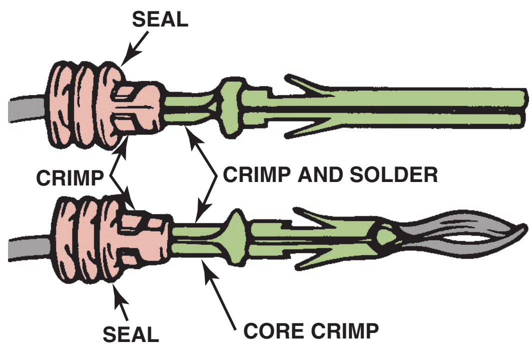


FIGURE 8–14 Some terminals have seals attached to help seal the electrical connections.

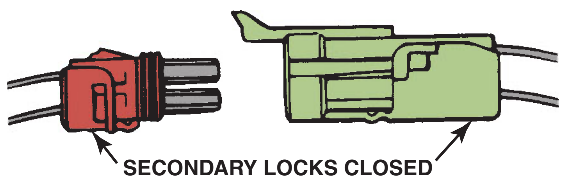


FIGURE 8–15 Separate a connector by opening the lock and pulling the two apart.

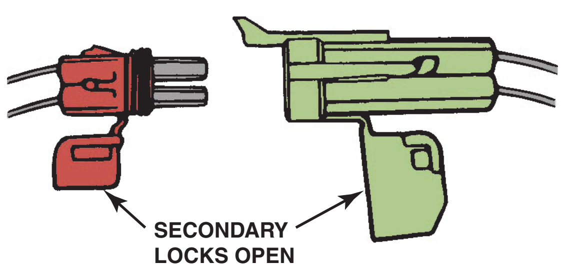


FIGURE 8–16 The secondary locks help retain the terminals in the connector.

TERMINALS AND CONNECTORS

A **terminal** is a metal fastener attached to the end of a wire, which makes the electrical connection. The term **connector** usually refers to the plastic portion that snaps or connects together, thereby making the mechanical connection. Wire terminal ends usually snap into and are held by a connector. Male and female connectors can then be snapped together, thereby completing an electrical connection. Connectors exposed to the environment are also equipped with a weather-tight seal. ● **SEE FIGURE 8–14.**

Terminals are retained in connectors by the use of a **lock tang.** Removing a terminal from a connector includes the following steps.

STEP 1 Release the **connector position assurance (CPA)**, if equipped, that keeps the latch of the connector from releasing accidentally.

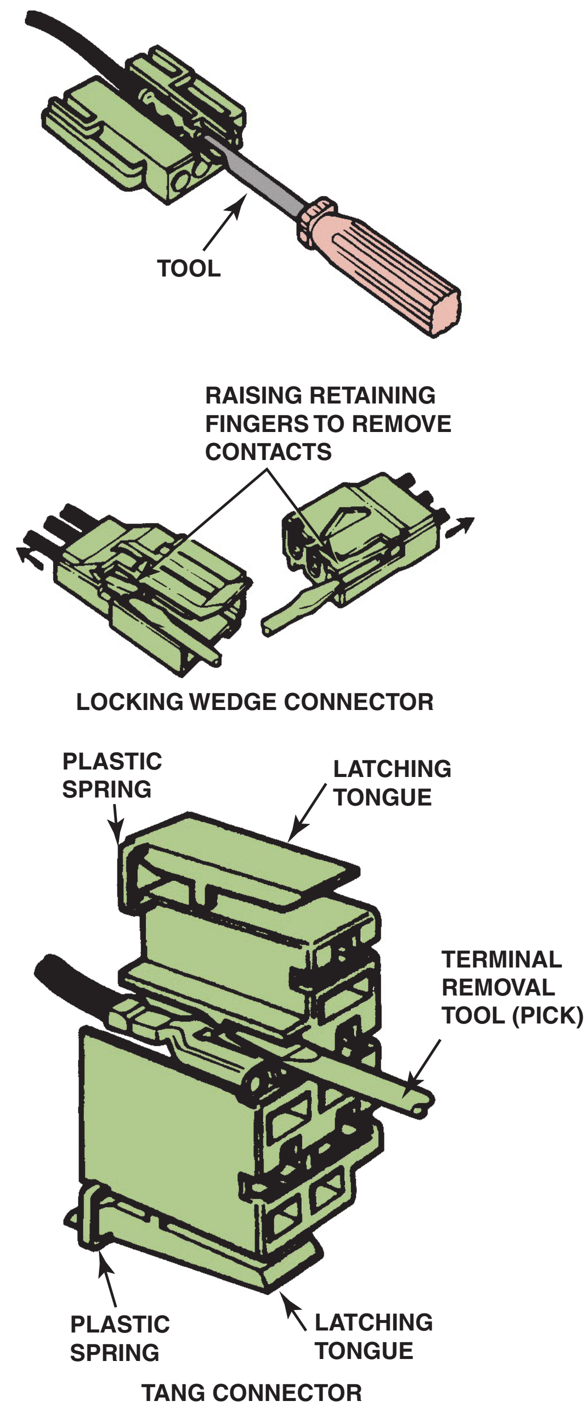


FIGURE 8–17 Use a small removal tool, sometimes called a pick, to release terminals from the connector.

STEP 2 Separate the male and female connector by opening the lock. ● **SEE FIGURE 8–15.**

STEP 3 Release the secondary lock, if equipped. ● **SEE FIGURE 8–16.**

STEP 4 Using a pick, look for the slot in the plastic connector where the lock tang is located, depress the lock tang, and gently remove the terminal from the connector. ● **SEE FIGURE 8–17.**

TECH TIP

Look for the "Green Crud"

Corroded connections are a major cause of intermittent electrical problems and open circuits. The usual sequence of conditions is as follows:

1. **Heat causes expansion.** This heat can be from external sources such as connectors being too close to the exhaust system. Another possible source of heat is a poor connection at the terminal, causing a voltage drop and heat due to the electrical resistance.
2. **Condensation occurs when a connector cools.** The moisture in the condensation causes rust and corrosion.
3. **Water gets into the connector.** The solution is, if corroded connectors are noticed, the terminal should be cleaned and the condition of the electrical connection to the wire terminal end(s) confirmed. Many vehicle manufacturers recommend using a dielectric silicone or lithium-based grease inside connectors to prevent moisture from getting into and attacking the connector.

WIRE REPAIR

SOLDER Many manufacturers recommend that all wiring repairs be soldered. Solder is an alloy of tin and lead used to make a good electrical contact between two wires or connections in an electrical circuit. However, a flux must be used to help clean the area and to help make the solder flow. Therefore, solder is made with a resin (rosin) contained in the center, called **rosin-core solder.**

CAUTION: Never use acid-core solder to repair electrical wiring as the acid will cause corrosion.

● **SEE FIGURE 8–18.**

An acid-core solder is also available but should only be used for soldering sheet metal. Solder is available with various percentages of tin and lead in the alloy. Ratios are used to identify these various types of solder, with the first number denoting the percentage of tin in the alloy and the second number giving the percentage of lead. The most commonly used solder is 50/50, which means that 50% of the solder is tin and the other 50% is lead. The percentages of each alloy primarily determine the melting point of the solder.

- 60/40 solder (60% tin/40% lead) melts at 361°F (183°C).
- 50/50 solder (50% tin/50% lead) melts at 421°F (216°C).
- 40/60 solder (40% tin/60% lead) melts at 460°F (238°C).

NOTE: The melting points stated here can vary depending on the purity of the metals used.

FIGURE 8–18 Always use rosin-core solder for electrical or electronic soldering. Also, use small-diameter solder for small soldering irons. Use large-diameter solder only for large-diameter (large-gauge) wire and higher-wattage soldering irons (guns).

FIGURE 8–19 A butane-powered soldering tool. The cap has a built-in striker to light a converter in the tip of the tool. This handy soldering tool produces the equivalent of 60 watts of heat. It operates for about 1/2 hour on one charge from a commonly available butane refill dispenser.

Because of the lower melting point, 60/40 solder is the most highly recommended solder to use, followed by 50/50.

SOLDERING GUNS When soldering wires, be sure to heat the wires (not the solder) using:

- An electric soldering gun or soldering pencil (60 to 150 watt rating)
- Butane-powered tool that uses a flame to heat the tip (about 60 watt rating)
  ● **SEE FIGURE 8–19.**

SOLDERING PROCEDURE Soldering a wiring splice includes the following steps.

STEP 1 While touching the soldering gun to the splice, apply solder to the junction of the gun and the wire.

STEP 2 The solder will start to flow. Do not move the soldering gun.

STEP 3 Just keep feeding more solder into the splice as it flows into and around the strands of the wire.

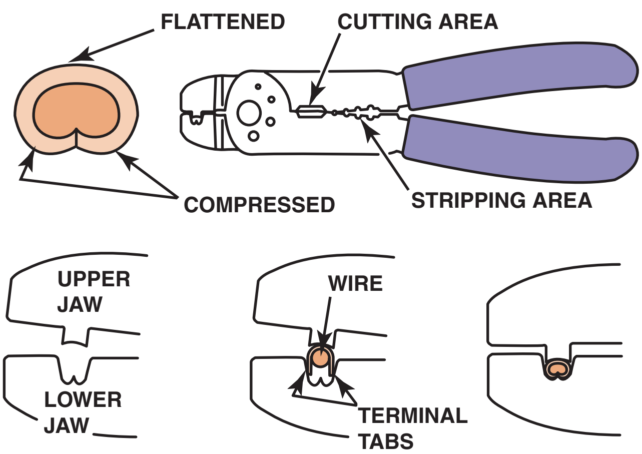


FIGURE 8–20 Notice that to create a good crimp the open part of the terminal is placed in the jaws of the crimping tool toward the anvil or the W-shape part.

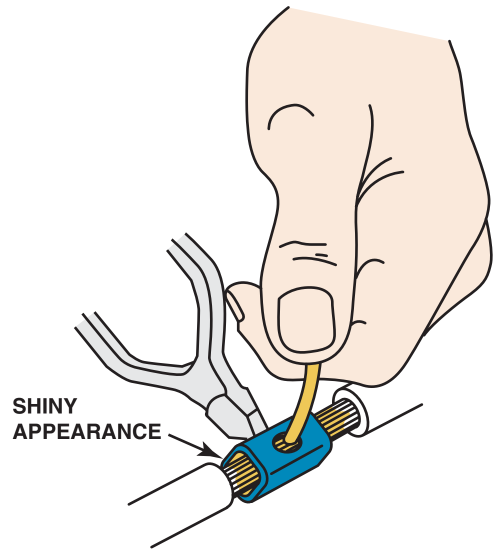


FIGURE 8–21 All hand-crimped splices or terminals should be soldered to be assured of a good electrical connection.

STEP 4 After the solder has flowed throughout the splice, remove the soldering gun and the solder from the splice and allow the solder to cool slowly.

The solder should have a shiny appearance. Dull-looking solder may be caused by not reaching a high enough temperature, which results in a **cold solder joint.** Reheating the splice and allowing it to cool often restores the shiny appearance.

CRIMPING TERMINALS

Terminals can be crimped to create a good electrical connection if the proper type of crimping tool is used. Most vehicle manufacturers recommend that a W-shaped crimp be used to force the strands of the wire into a tight space. ● **SEE FIGURE 8–20.**

Most vehicle manufacturers also specify that all hand-crimped terminals or splices be soldered. ● **SEE FIGURE 8–21.**

HEAT SHRINK TUBING

Heat shrink tubing is usually made from polyvinyl chloride (PVC) or polyolefin and shrinks to about half of its original diameter when heated; this is usually called a 2:1 shrink ratio. Heat shrink by itself does not provide protection against corrosion, because the ends of the tubing are not sealed against moisture. DaimlerChrysler Corporation recommends that all wire repairs that may be exposed to the elements be repaired and sealed using **adhesive-lined heat shrink tubing**. The tubing is usually made from flame-retardant flexible polyolefin with an internal layer of special thermoplastic adhesive. When heated, this tubing shrinks to one-third of its original diameter (3:1 shrink ratio) and the adhesive melts and seals the ends of the tubing. ● **SEE FIGURE 8–22.**

FIGURE 8–22 A butane torch especially designed for use on heat shrink applies heat without an open flame, which could cause damage.

CRIMP-AND-SEAL CONNECTORS

General Motors Corporation recommends the use of crimp-and-seal connectors as the method for wire repair. **Crimp-and-seal connectors** contain a sealant and shrink tubing in one piece and are not simply butt connectors. ● **SEE FIGURE 8–23.**

The usual procedure specified for making a wire repair using a crimp-and-seal connector is as follows:

STEP 1 Strip the insulation from the ends of the wire (about 5/16 in., or 8 mm).

STEP 2 Select the proper size of crimp-and-seal connector for the gauge of wire being repaired. Insert the wires into the splice sleeve and crimp.

NOTE: Only use the specified crimping tool to help prevent the pliers from creating a hole in the cover.

STEP 3 Apply heat to the connector until the sleeve shrinks down around the wire and a small amount of sealant is observed around the ends of the sleeve, as shown in ● **FIGURE 8–24.**

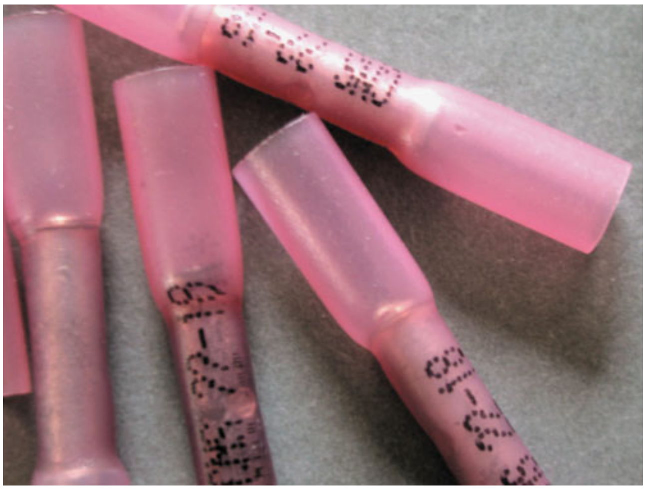


FIGURE 8–23 A typical crimp-and-seal connector. This type of connector is first lightly crimped to retain the ends of the wires and then it is heated. The tubing shrinks around the wire splice, and thermoplastic glue melts on the inside to provide an effective weather-resistant seal.

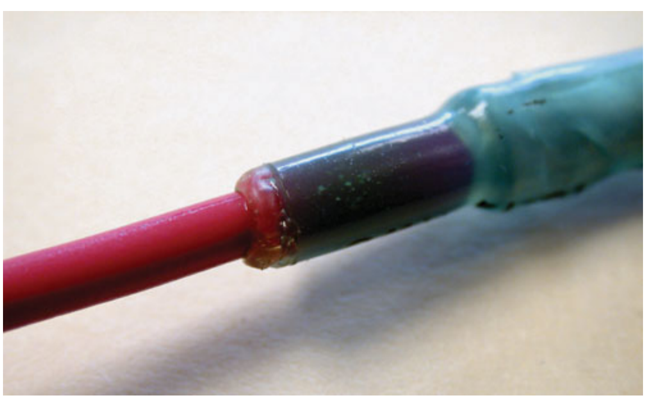


FIGURE 8–24 Heating the crimp-and-seal connector melts the glue and forms an effective seal against moisture.

ALUMINUM WIRE REPAIR Some vehicle manufacturers used plastic-coated solid aluminum wire for some body wiring. Because aluminum wire is brittle and can break as a result of vibration, it is only used where there is no possible movement of the wire, such as along the floor or sill area. This section of wire is stationary, and the wire changes back to copper at a junction terminal after the trunk or rear section of the vehicle, where movement of the wiring may be possible.

If any aluminum wire must be repaired or replaced, the following procedure should be used to be assured of a proper repair. The aluminum wire is usually found protected in a plastic conduit. This conduit is then normally slit, after which the wires can easily be removed for repair.

STEP 1 Carefully strip only about 1/4 in. (6 mm) of insulation from the aluminum wire, being careful not to nick or damage the aluminum wire case.

STEP 2 Use a crimp connector to join two wires together. Do not solder an aluminum wire repair. Solder will not readily adhere to aluminum because the heat causes an oxide coating on the surface of the aluminum.

STEP 3 The spliced, crimped connection must be coated with petroleum jelly to prevent corrosion.

STEP 4 The coated connection should be covered with shrinkable plastic tubing or wrapped with electrical tape to seal out moisture.

? FREQUENTLY ASKED QUESTION

What Method of Wire Repair Should I Use?

Good question. Vehicle manufacturers recommend all wire repairs performed under the hood, or where the repair could be exposed to the elements, be weatherproof. The most commonly recommended methods include:

- **Crimp and seal connector.** These connectors are special and are not like low cost insulated-type crimp connectors. This type of connector is recommended by General Motors and others and is sealed using heat after the mechanical crimp has secured the wire ends together.
- **Solder and adhesive-lined heat shrink tubing.** This method is recommended by Chrysler and it uses the special heat shrink that has glue inside that melts when heated to form a sealed connection. Regular heat shrink tubing can be used inside a vehicle, but should not be used where it can be exposed to the elements.
- **Solder and electrical tape.** This is acceptable to use inside the vehicle where the splice will not be exposed to the outside elements. It is best to use a crimp and seal even on the inside of the vehicle for best results.

? FREQUENTLY ASKED QUESTION

What Is in Lead-Free Solder?

Lead is an environmental and a health concern and all vehicle manufacturers are switching to lead-free solder. Lead free solder does not contain lead but usually a very high percentage of tin. Several formulations of lead-free solder include:

- 95% Tin; 5% Antimony (melting temperature 450°F (245°C)
- 97% Tin; 3% Copper (melting temperature 441°F (227°C)
- 96% Tin; 4% Silver (melting temperature 443°F (228°C)

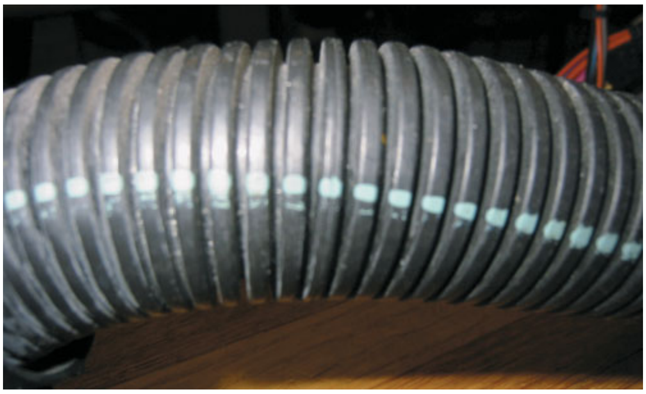


FIGURE 8–25 Conduit that has a paint strip is constructed of plastic that can withstand high underhood temperatures.

ELECTRICAL CONDUIT

Electrical conduit covers and protects wiring. The color used on electrical convoluted conduit tells the technician a lot if some information is known, such as the following:

- **Black conduit with a green or blue stripe.** This conduit is designed for high temperatures and is used under the hood and near hot engine parts. Do not replace high-temperature conduit with low-temperature conduit that does not have a strip when performing wire repairs. ● **SEE FIGURE 8–25.**
- **Blue or yellow conduit.** This color conduit is used to cover wires that have voltages ranging from 12 to 42 volts. Circuits that use this high voltage usually are for the electric power steering. While 42 volts does not represent a shock hazard, an arc will be maintained if a line circuit is disconnected. Use caution around these circuits. ● **SEE FIGURE 8–26.**
- **Orange conduit.** This color conduit is used to cover wiring that carries high-voltage current from 144 to 650 volts. These circuits are found in hybrid electric vehicles (HEVs). An electric shock from these wires can be fatal, so extreme caution has to be taken when working on or near the components that have orange conduit. Follow the vehicle manufacturer's instruction for de-powering the high-voltage circuits before work begins on any of the high-voltage components. ● **SEE FIGURE 8–27.**

(a)

(b)

FIGURE 8–26 (a) Blue conduit is used to cover circuits that carry up to 42 volts. (b) Yellow conduit can also be used to cover 42 volt wiring.

FIGURE 8–27 Always follow the vehicle manufacturer's instructions which include the use of linesman's (high-voltage) gloves if working on circuits that are covered in orange conduit.

SUMMARY

1. The higher the AWG size number, the smaller the wire diameter.
2. Metric wire is sized in square millimeters (mm^2) and the higher the number, the larger the wire.
3. All circuits should be protected by a fuse, fusible link, or circuit breaker. The current in the circuit should be about 80% of the fuse rating.
4. A terminal is the metal end of a wire, whereas a connector is the plastic housing for the terminal.
5. All wire repair should use either soldering or a crimp-and-seal connector.

REVIEW QUESTIONS

1. What is the difference between the American wire gauge (AWG) system and the metric system?
2. What is the difference between a wire and a cable?
3. What is the difference between a terminal and a connector?
4. How do fuses, PTC circuit protectors, circuit breakers, and fusible links protect a circuit?
5. How should a wire repair be done if the repair is under the hood where it is exposed to the outside?

CHAPTER QUIZ

1. The higher the AWG number, ________.
   - **a.** The smaller the wire diameter
   - **b.** The larger the wire diameter
   - **c.** The thicker the insulation
   - **d.** The more strands in the conductor core
2. Metric wire size is measured in units of ________.
   - **a.** Meters
   - **b.** Cubic centimeters
   - **c.** Square millimeters
   - **d.** Cubic millimeters
3. Which statement is true about fuse ratings?
   - **a.** The fuse rating should be less than the maximum current for the circuit.
   - **b.** The fuse rating should be higher than the normal current for the circuit.
   - **c.** Of the fuse rating, 80% should equal the current in the circuit.
   - **d.** Both b and c
4. Which statements are true about wire, terminals, and connectors?
   - **a.** Wire is called a lead, and the metal end is a connector.
   - **b.** A connector is usually a plastic piece where terminals lock in.
   - **c.** A lead and a terminal are the same thing.
   - **d.** Both a and c
5. The type of solder that should be used for electrical work is ________.
   - **a.** Rosin core
   - **b.** Acid core
   - **c.** 60/40 with no flux
   - **d.** 50/50 with acid paste flux
6. A technician is performing a wire repair on a circuit under the hood of the vehicle. Technician A says to use solder and adhesive-lined heat shrink tubing or a crimp and seal connector. Technician B says to solder and use electrical tape. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Two technicians are discussing fuse testing. Technician A says that a test light should light on both test points of the fuse if it is okay. Technician B says the fuse is defective if a test light only lights on one side of the fuse. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. What is true about the plastic conduit covering the wiring?
   - **a.** The color stripe is used to identify the temperature rating of the conduit
   - **b.** The color identifies the voltage level of the circuits being protected.
   - **c.** Protects the wiring.
   - **d.** All of the above
9. Many ground straps are uninsulated and braided because ________.
   - **a.** They are more flexible to allow movement of the engine without breaking the wire.
   - **b.** They are less expensive than conventional wire.
   - **c.** They help dampen radio-frequency interference (RFI).
   - **d.** Both a and c
10. What causes a fuse to blow?
    - **a.** A decrease in circuit resistance
    - **b.** An increase in the current flow through the circuit
    - **c.** A sudden decrease in current flow through the circuit
    - **d.** Both a and b

chapter 9

WIRING SCHEMATICS AND CIRCUIT TESTING

OBJECTIVES: After studying Chapter 9, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronics System Diagnosis). • Interpret wiring schematics. • Explain how relays work. • Discuss the various methods that can be used to locate a short circuit. • List the electrical troubleshooting diagnosis steps.

KEY TERMS: Coil 122 • DPDT 121 • DPST 121 • Gauss gauge 128 • Momentary switch 122 • N.C. 121 • N.O. 121 • Poles 121 • Relay 122 • Short circuit 127 • SPDT 121 • SPST 121 • Terminal 117 • Throws 121 • Tone generator tester 129 • Wiring schematic 116

WIRING SCHEMATICS AND SYMBOLS

TERMINOLOGY The service manuals of automotive manufacturers include wiring schematics of every electrical circuit in a vehicle. A **wiring schematic**, sometimes called a *diagram*, shows electrical components and wiring using symbols and lines to represent components and wires. A typical wiring schematic may include all of the circuits combined on several large foldout sheets, or they may be broken down to show individual circuits. All circuit schematics or diagrams include:

- Power-side wiring of the circuit
- All splices
- Connectors
- Wire size
- Wire color
- Trace color (if any)
- Circuit number
- Electrical components
- Ground return paths
- Fuses and switches

CIRCUIT INFORMATION Many wiring schematics include numbers and letters near components and wires that may confuse readers of the schematic. Most letters used near or on a wire identify the color or colors of the wire.

- The first color or color abbreviation is the color of the wire insulation.

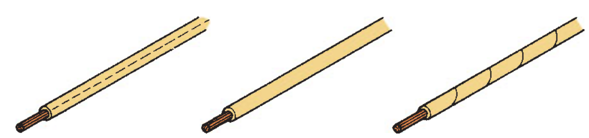


FIGURE 9–1 The center wire is a solid color wire, meaning that the wire has no other identifying tracer or stripe color. The two end wires could be labeled "BRN/WHT," indicating a brown wire with a white tracer or stripe.

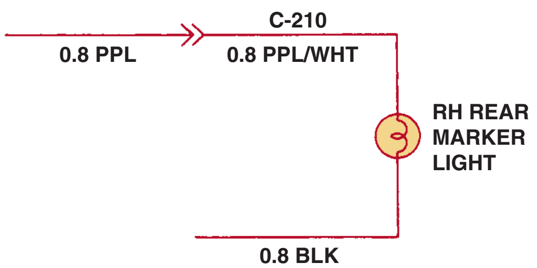


FIGURE 9–2 Typical section of a wiring diagram. Notice that the wire color changes at connection C210. The ".8" represents the metric wire size in square millimeters.

- The second color (if mentioned) is the color of the stripe or tracer on the base color. ● **SEE FIGURE 9–1.**

Wires with different color tracers are indicated by both colors with a slash (/) between them. For example, BRN/WHT means a brown wire with a white stripe or tracer. ● **SEE CHART 9–1.**

WIRE SIZE Wire size is shown on all schematics. ● **FIGURE 9–2** illustrates a rear side-marker bulb circuit diagram where ".8" indicates the metric wire gauge size in square millimeters (mm^2) and "PPL" indicates a solid purple wire.

The wire diagram also shows that the color of the wire changes at the number C210. This stands for "connector #210" and is used for reference purposes. The symbol for the connection can vary depending on the manufacturer. The color change from purple (PPL) to purple with a white tracer (PPL/WHT) is not important except for knowing where the wire changes color in the circuit. The wire gauge has remained the same on both sides of the connection (0.8 mm^2 or 18 gauge). The ground circuit is the ".8 BLK" wire. ● **FIGURE 9–3** shows many of the electrical and electronic symbols that are used in wiring and circuit diagrams.

ABBREVIATION	COLOR
BRN	Brown
BLK	Black
GRN	Green
WHT	White
PPL	Purple
PNK	Pink
TAN	Tan
BLU	Blue
YEL	Yellow
ORN	Orange
DK BLU	Dark blue
LT BLU	Light blue
DK GRN	Dark green
LT GRN	Light green
RED	Red
GRY	Gray
VIO	Violet

CHART 9–1

Typical abbreviations used on schematics to show wire color. Some vehicle manufacturers use two letters to represent a wire color. Check service information for the color abbreviations used.

TECH TIP

Read the Arrows

Wiring diagrams indicate connections by symbols that look like arrows. ● **SEE FIGURE 9–4** on page 119.

Do *not* read these "arrows" as pointers showing the direction of current flow. Also observe that the power side (positive side) of the circuit is usually the female end of the connector. If a connector becomes disconnected, it will be difficult for the circuit to become shorted to ground or to another circuit because the wire is recessed inside the connector.

SCHEMATIC SYMBOLS

In a schematic drawing, photos or line drawings of actual components are replaced with a symbol that represents the actual component. The following discussion centers on these symbols and their meanings.

BATTERY The plates of a battery are represented by long and short lines. ● **SEE FIGURE 9–5.**

The longer line represents the positive plate of a battery and the shorter line represents the negative plate of the battery. Therefore, each pair of short and long lines represents one cell of a battery. Because each cell of a typical automotive lead-acid battery has 2.1 volts, a battery symbol showing a 12 volt battery should have six pairs of lines. However, most battery symbols simply use two or three pairs of long and short lines and then list the voltage of the battery next to the symbol. As a result, the battery symbols are shorter and yet clear, because the voltage is stated. The positive terminal of the battery is often indicated with a plus sign (+), representing the positive post of the battery, and is placed next to the long line of the end cell. The negative terminal of the battery is represented by a negative sign (−) and is placed next to the shorter cell line. The negative battery terminal is connected to ground. ● **SEE FIGURE 9–6.**

WIRING Electrical wiring is shown as straight lines and with a few numbers and/or letters to indicate the following:

- **Wire size.** This can be either AWG, such as 18 gauge, or in square millimeters, such as 0.8 mm^2.
- **Circuit numbers.** Each wire in part of a circuit is labeled with the circuit number to help the service technician trace the wiring and to provide an explanation of how the circuit should work.
- **Wire color.** Most schematics also indicate an abbreviation for the color of the wire and place it next to the wire. Many wires have two colors: a solid color and a stripe color. In this case, the solid color is listed, followed by a dark slash (/) and the color of the stripe. For example, Red/Wht would indicate a red wire with a white tracer. ● **SEE FIGURE 9–7.**
- **Terminals.** The metal part attached at the end of a wire is called a **terminal.** A symbol for a terminal is shown in ● **FIGURE 9–8.**
- **Splices.** When two wires are electrically connected, the junction is shown with a black dot. The identification of the splice is an "S" followed by three numbers, such as S103. ● **SEE FIGURE 9–9.** When two wires cross in a schematic that are not electrically connected, one of the wires is shown as going over the other wire and does not connect. ● **SEE FIGURE 9–10.**
- **Connectors.** An electrical connector is a plastic part that contains one or more terminals. Although the terminals provide the electrical connection in a circuit, it is the

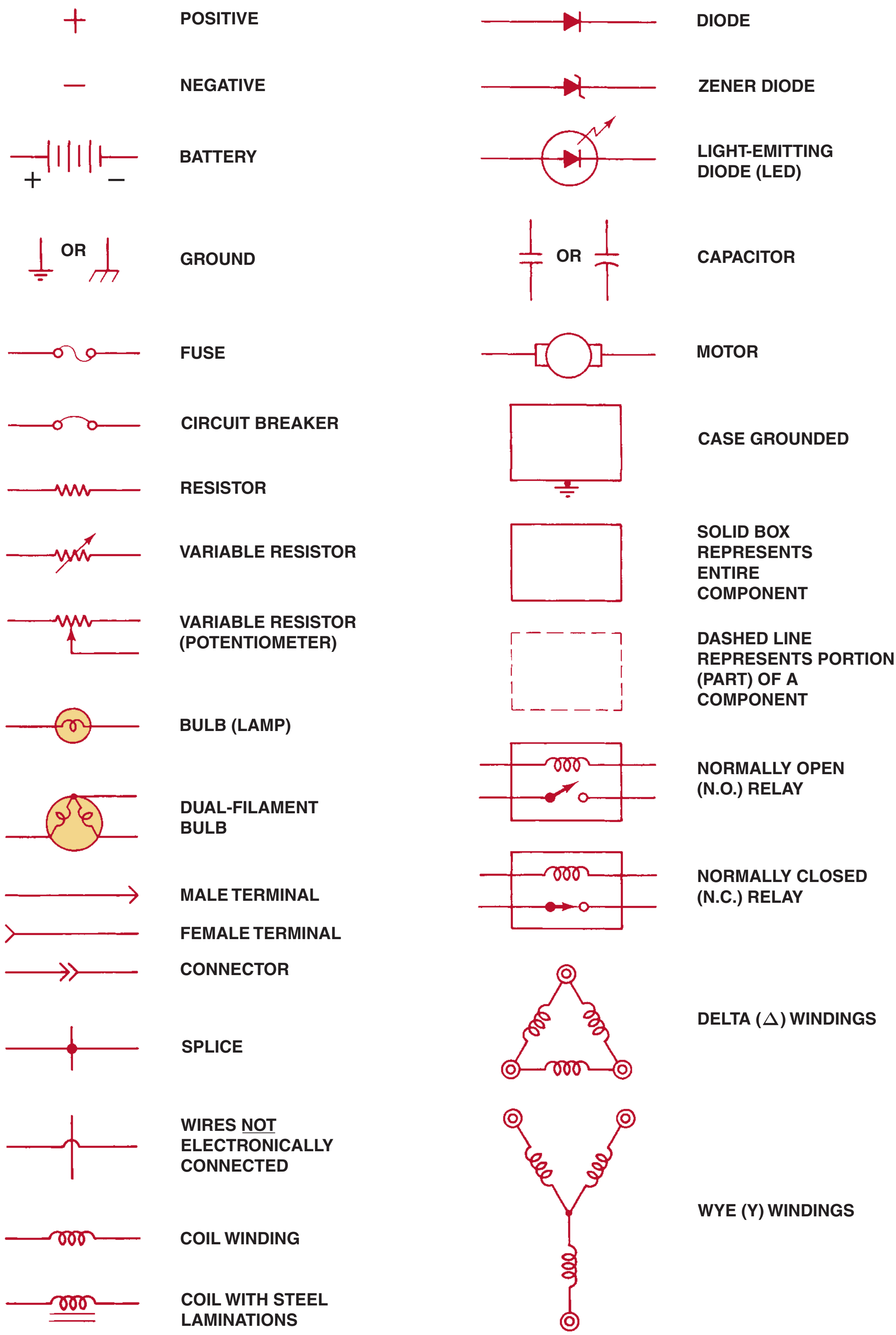


FIGURE 9–3 Typical electrical and electronic symbols used in automotive wiring and circuit diagrams.

FIGURE 9–4 In this typical connector, note that the positive terminal is usually a female connector.

FIGURE 9–5 The symbol for a battery. The positive plate of a battery is represented by the longer line and the negative plate by the shorter line. The voltage of the battery is usually stated next to the symbol.

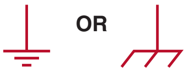


FIGURE 9–6 The ground symbol on the left represents earth ground. The ground symbol on the right represents a chassis ground.

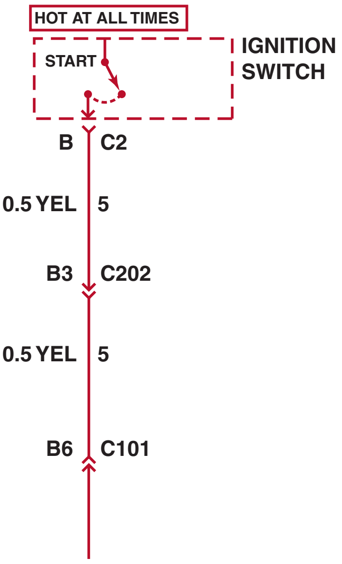


FIGURE 9–7 Starting at the top, the wire from the ignition switch is attached to terminal B of connector C2, the wire is 0.5 mm^2 (20 gauge AWG), and is yellow. The circuit number is 5. The wire enters connector C202 at terminal B3.

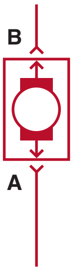


FIGURE 9–8 The electrical terminals are usually labeled with a letter or number.

FIGURE 9–9 Two wires that cross at the dot indicate that the two are electrically connected.

FIGURE 9–10 Wires that cross, but do not electrically contact each other, are shown with one wire bridging over the other.

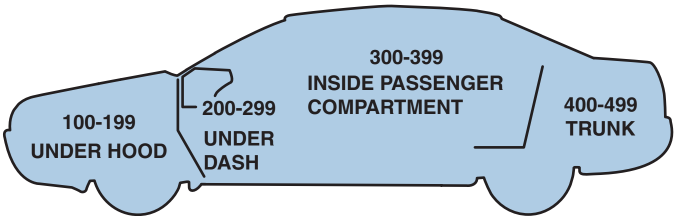


FIGURE 9–11 Connectors (C), grounds (G), and splices (S) are followed by a number, generally indicating the location in the vehicle. For example, G209 is a ground connection located under the dash.

plastic connector that keeps the terminals together mechanically.

- **Location.** Connections are usually labeled "C" and then three numbers. The three numbers indicate the general location of the connector. Normally, the connector number represents the general area of the vehicle, including:

100 to 199	Under the hood
200 to 299	Under the dash
300 to 399	Passenger compartment
400 to 499	Rear package or trunk area
500 to 599	Left-front door
600 to 699	Right-front door
700 to 799	Left-rear door
800 to 899	Right-rear door

Even-numbered connectors are on the right (passenger side) of the vehicle and odd-numbered connectors are on the left (driver's side) of the vehicle. For example, C102 is a connector located under the hood (between 100 and 199) on the right side of the vehicle (even number 102). ● **SEE FIGURE 9–11.**

- **Grounds and splices.** These are also labeled using the same general format as connectors. Therefore, a ground located under the dash on the driver's side could be labeled G305 (*G* means "ground" and the "305" means that it is located in the passenger compartment). ● **SEE FIGURE 9–12.**

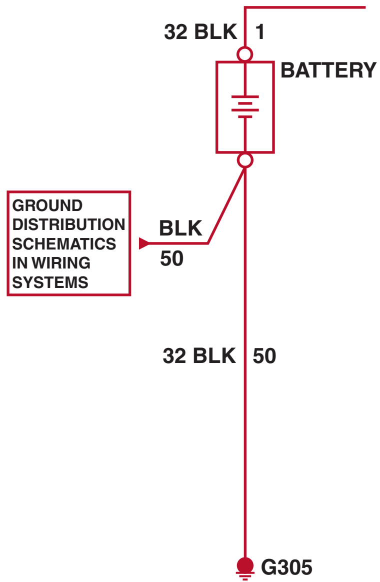


FIGURE 9–12 The ground for the battery is labeled G305 indicating the ground connector is located in the passenger compartment of the vehicle. The ground wire is black (BLK), the circuit number is 50, and the wire is 32 mm^2 (2 gauge AWG).

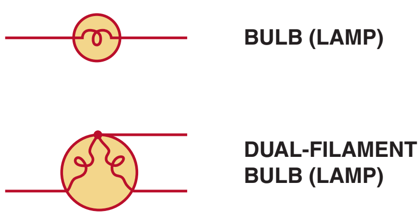


FIGURE 9–13 The symbol for light bulbs shows the filament inside a circle, which represents the glass ampoule of the bulb.

ELECTRICAL COMPONENTS Most electrical components have their own unique symbol that shows the basic function or parts.

- **Bulbs.** Light bulbs often use a filament, which heats and then gives off light when electrical current flows. The symbol used for a light bulb is a circle with a filament inside. A dual-filament bulb, such as is used for taillights and brake light/turn signals, is shown with two filaments. ● **SEE FIGURE 9–13.**

ELECTRIC MOTORS An electric motor symbol shows a circle with the letter *M* in the center and two electrical connections, one to the top and one at the bottom. ● **SEE FIGURE 9–14** for an example of a cooling fan motor.

RESISTORS Although resistors are usually part of another component, the symbol appears on many schematics and wiring diagrams. A resistor symbol is a jagged line representing resistance to current flow. If the resistor is variable, such as a thermistor, an arrow is shown running through the symbol of a fixed resistor. A potentiometer is a three-wire variable resistor,

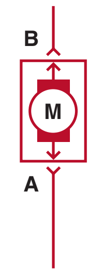


FIGURE 9–14 An electric motor symbol shows a circle with the letter *M* in the center and two black sections that represent the brushes of the motor. This symbol is used even though the motor is a brushless design.

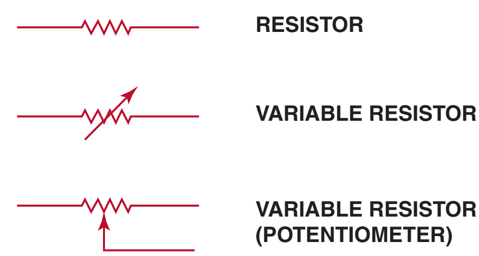


FIGURE 9–15 Resistor symbols vary depending on the type of resistor.

FIGURE 9–16 A rheostat uses only two wires—one is connected to a voltage source and the other is attached to the movable arm.

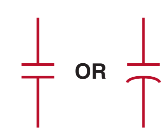


FIGURE 9–17 Symbols used to represent capacitors. If one of the lines is curved, this indicates that the capacitor being used has a polarity, while the one without a curved line can be installed in the circuit without concern about polarity.

shown with an arrow pointing toward the resistance part of a fixed resistor. ● **SEE FIGURE 9–15.**

A two-wire rheostat is usually shown as part of another unit, such as a fuel level sending unit. ● **SEE FIGURE 9–16.**

CAPACITORS Capacitors are usually part of an electronic component, but not a replaceable component unless the vehicle is an older model. Many older vehicles used capacitors to reduce radio interference and were installed inside alternators inside alternators or attached to or attached to wiring connectors. ● **SEE FIGURE 9–17.**

ELECTRIC HEATED UNIT Electric grid-type rear window defoggers and cigarette lighters are shown with a square box-type symbol. ● **SEE FIGURE 9–18.**

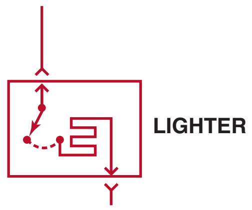


FIGURE 9–18 The gridlike symbol represents an electrically heated element.

FIGURE 9–19 A dashed outline represents a portion (part) of a component.

FIGURE 9–20 A solid box represents an entire component.

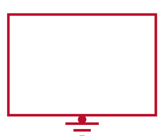


FIGURE 9–21 This symbol represents a component that is case grounded.

BOXED COMPONENTS If a component is shown in a box using a solid line, the box is the entire component. If a box uses dashed lines, it represents part of a component. A commonly used dashed-line box is a fuse panel. Often, just one or two fuses are shown in a dashed-line box. This means that a fuse panel has more fuses than shown. ● **SEE FIGURES 9–19 AND 9–20.**

SEPARATE REPLACEABLE PART Often components are shown on a schematic that cannot be replaced, but are part of a complete assembly. When looking at a schematic of General Motors vehicles, the following is shown.

- If a part name is underlined, it is a replaceable part.
- If a part is not underlined, it is not available as a replaceable part, but is included with other components shown and sold as an assembly.
- If the case itself is grounded, the ground symbol is attached to the component as shown in ● **FIGURE 9–21.**

SWITCHES Electrical switches are drawn on a wiring diagram in their normal position. This can be one of two possible positions.

- **Normally open.** The switch is not connected to its internal contacts and no current will flow. This type of switch is labeled **N.O.**
- **Normally closed.** The switch is electrically connected to its internal contacts and current will flow through the switch. This type of switch is labeled **N.C.**

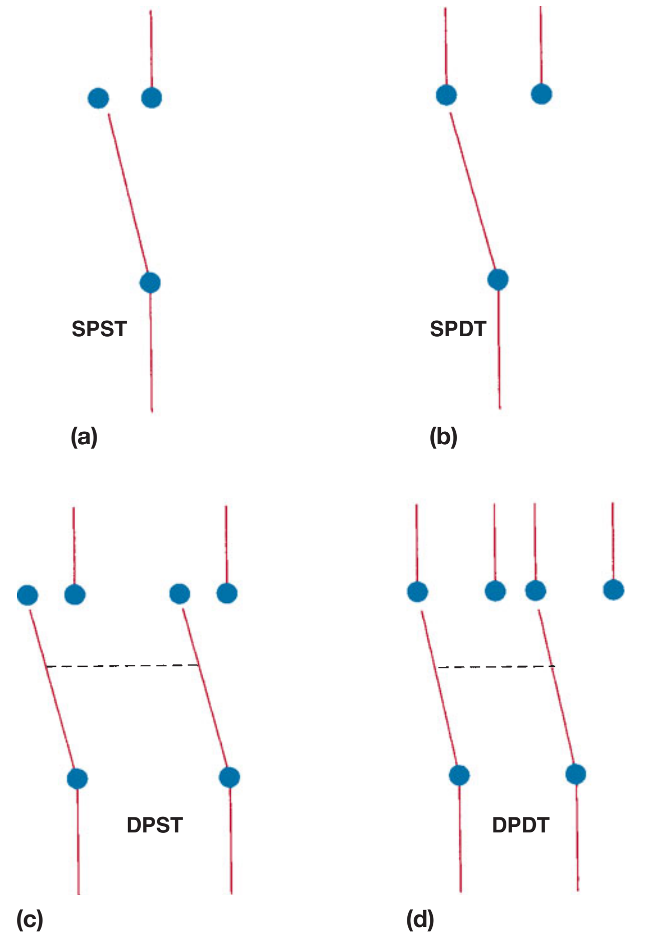


FIGURE 9–22 (a) A symbol for a single-pole, single-throw (SPST) switch. This type of switch is normally open (N.O.) because nothing is connected to the terminal that the switch is contacting in its normal position. (b) A single-pole, double-throw (SPDT) switch has three terminals. (c) A double-pole, single-throw (DPST) switch has two positions (off and on) and can control two separate circuits. (d) A double-pole, double-throw (DPDT) switch has six terminals—three for each pole. Note: Both (c) and (d) also show a dotted line between the two arms indicating that they are mechanically connected, called a "ganged switch".

Other switches can use more than two contacts.

The **poles** refer to the number of circuits completed by the switch and the **throws** refer to the number of output circuits. A **single-pole, single-throw (SPST)** switch has only two positions, on or off. A **single-pole, double-throw (SPDT)** switch has three terminals, one wire in and two wires out. A headlight dimmer switch is an example of a typical SPDT switch. In one position, the current flows to the low-filament headlight; in the other, the current flows to the high-filament headlight.

NOTE: A SPDT switch is not an on or off type of switch but instead directs power from the source to either the high-beam lamps or the low-beam lamps.

There are also **double-pole, single-throw (DPST)** switches and **double-pole, double-throw (DPDT)** switches. ● **SEE FIGURE 9–22.**

NOTE: All switches are shown on schematics in their normal position. This means that the headlight switch will be shown normally off, as are most other switches and controls.

MOMENTARY SWITCH A **momentary switch** is a switch primarily used to send a voltage signal to a module or controller to request that a device be turned on or off. The switch makes momentary contact and then returns to the open position. A horn switch is a commonly used momentary switch. The symbol that represents a momentary switch uses two dots for the contact with a switch above them. A momentary switch can be either normally open or normally closed. ● **SEE FIGURE 9–23.**

TECH TIP

Color-Coding Is Key to Understanding

Whenever diagnosing an electrical problem, it is common practice to print out the schematic of the circuit and then take it to the vehicle. A meter is then used to check for voltage at various parts of the circuit to help determine where there is a fault. The diagnosis can be made easier if the parts of the circuit are first color coded using markers or color pencils. A color-coding system that has been widely used is one developed by Jorge Menchu (**www.aeswave.com**).

The colors represent voltage conditions in various parts of a circuit. Once the circuit has been color coded, then the circuit can be tested using the factory wire colors as a guide. ● **SEE FIGURE 9–24**.

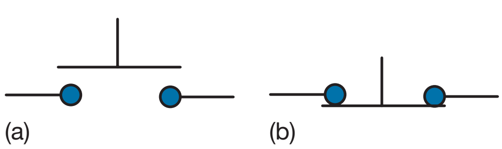


FIGURE 9–23 (a) A symbol for a normally open (N.O.) momentary switch. (b) A symbol for a normally closed (N.C.) momentary switch.

A momentary switch, for example, can be used to lock or unlock a door or to turn the air conditioning on or off. If the device is currently operating, the signal from the momentary switch will turn it off, and if it is off, the switch will signal the module to turn it on. The major advantage of momentary switches is that they can be lightweight and small, because the switch does not carry any heavy electrical current, just a small voltage signal. Most momentary switches use a membrane constructed of foil and plastic.

RELAY TERMINAL IDENTIFICATION

DEFINITION A **relay** is a magnetic switch that uses a movable armature to control a high-amperage circuit by using a low-amperage electrical switch.

ISO RELAY TERMINAL IDENTIFICATION Most automotive relays adhere to common terminal identification. The primary source for this common identification comes from the standards established by the International Standards Organization (ISO). Knowing this terminal information will help in the correct diagnosis and troubleshooting of any circuit containing a relay. ● **SEE FIGURES 9–25 AND 9–26.**

Relays are found in many circuits because they are capable of being controlled by computers, yet are able to handle enough current to power motors and accessories. Relays include the following components and terminals.

RELAY OPERATION

1. **Coil** (terminals 85 and 86)
   - A coil provides the magnetic pull to a movable armature (arm).
   - The resistance of most relay coils ranges from 50 to 150 ohms, but is usually between 60 and 100 ohms.
   - The ISO identification of the coil terminals are 86 and 85. The terminal number 86 represents the power

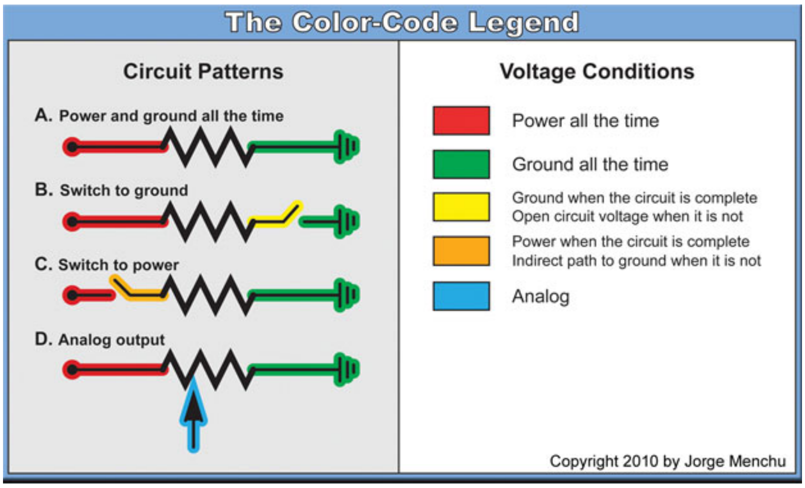


FIGURE 9–24 Using a marker and color-coding the various parts of the circuit makes the circuit easier to understand and helps diagnosing electrical problems easier. (*Courtesy of Jorge Menchu.*)

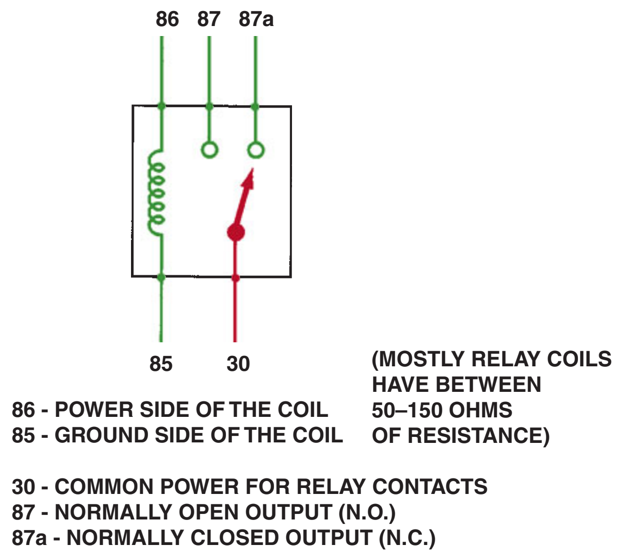


FIGURE 9–25 A relay uses a movable arm to complete a circuit whenever there is a power at terminal 86 and a ground at terminal 85. A typical relay only requires about 1/10 ampere through the relay coil. The movable arm then closes the contacts (#30 to #87) and can relay 30 amperes or more.

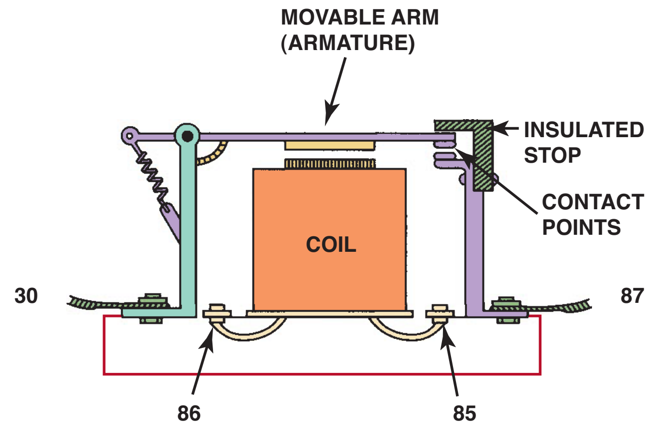


FIGURE 9–26 A cross-sectional view of a typical four-terminal relay. Current flowing through the coil (terminals 86 and 85) causes the movable arm (called the armature) to be drawn toward the coil magnet. The contact points complete the electrical circuit connected to terminals 30 and 87.

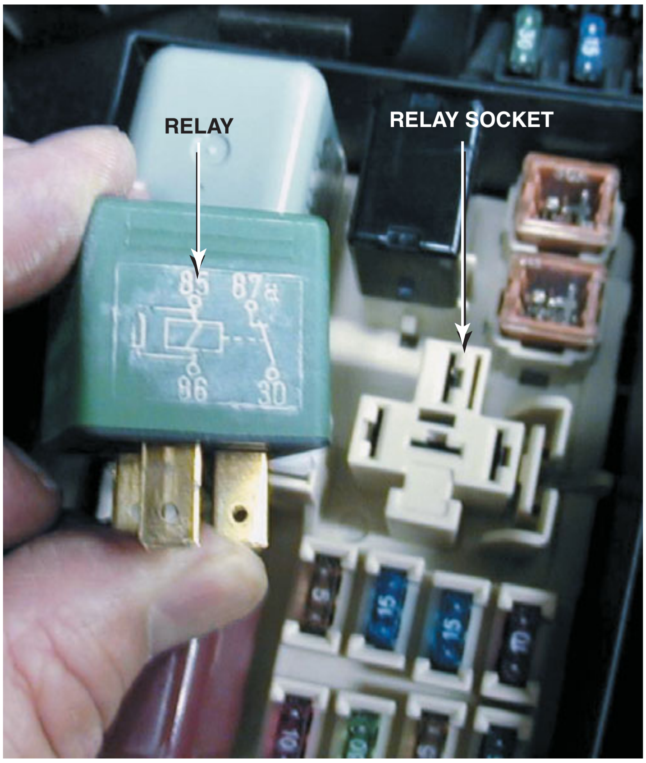


FIGURE 9–27 A typical relay showing the schematic of the wiring in the relay.

to the relay coil and the terminal labeled 85 represents the ground side of the relay coil.

- The relay coil can be controlled by supplying either power or ground to the relay coil winding.
- The coil winding represents the control circuit which uses low current to control the higher current through the other terminals of the relay. ● **SEE FIGURE 9–27.**

2. Other terminals used to control the load current

- The higher amperage current flow through a relay flows through terminals 30 and 87, and often 87a.
- Terminal 30 is usually where power is applied to a relay. Check service information for the exact operation of the relay being tested.
- When the relay is at rest without power and ground to the coil, the armature inside the relay electrically connects terminals 30 and 87a if the relay has five terminals. When there is power at terminal 85 and a ground at terminal 86 of the relay, a magnetic field is created in the coil winding, which draws the armature of the relay toward the coil. The armature, when energized electrically, connects terminals 30 and 87.

The maximum current through the relay is determined by the resistance of the circuit, and relays are designed to safely handle the designed current flow. ● **SEE FIGURES 9–28 AND 9–29.**

RELAY VOLTAGE SPIKE CONTROL Relays contain a coil and when power is removed, the magnetic field surrounding the coil collapses, creating a voltage to be induced in the coil winding. This induced voltage can be as high as 100 volts or more and can cause problems with other electronic devices in the vehicle. For example, the short high-voltage surge can be heard as a "pop" in the radio. To reduce the induced voltage, some relays contain a diode connected across the coil. ● **SEE FIGURE 9–30.**

When the current flows through the coil, the diode is not part of the circuit because it is installed to block current. However, when the voltage is removed from the coil, the resulting voltage induced in the coil windings has a reversed polarity to the applied voltage. Therefore, the voltage in the coil is

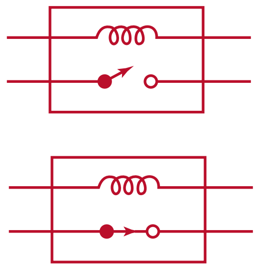


FIGURE 9–28 All schematics are shown in their normal, non-energized position.

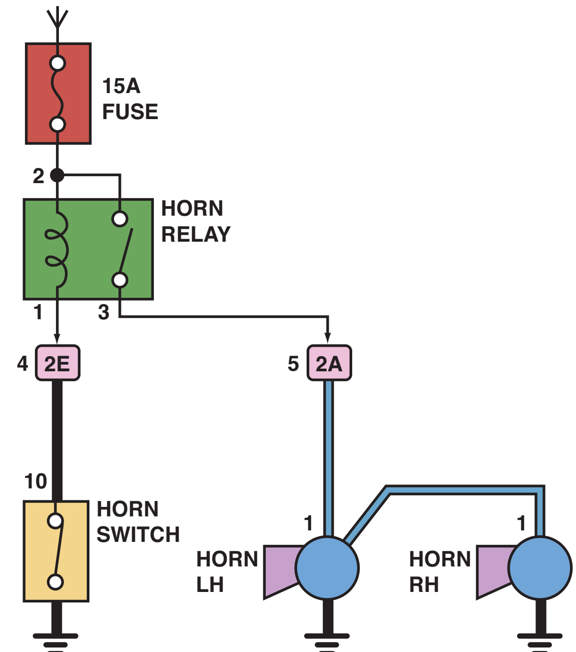


FIGURE 9–29 A typical horn circuit. Note that the relay contacts supply the heavy current to operate the horn when the horn switch simply completes a low-current circuit to ground, causing the relay contacts to close.

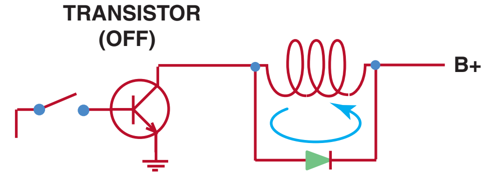


FIGURE 9–30 When the relay or solenoid coil current is turned off, the stored energy in the coil flows through the clamping diode and effectively reduces voltage spike.

TECH TIP

Divide the Circuit in Half

When diagnosing any circuit that has a relay, start testing at the relay and divide the circuit in half.

- **High current portion:** Remove the relay and check that there are 12 volts at the terminal 30 socket. If there is, then the power side is okay. Use an ohmmeter and check between terminal 87 socket and ground. If the load circuit has continuity, there should be some resistance. If OL, the circuit is electrically open.
- **Control circuit (low current):** With the relay removed from the socket, check that there is 12 volts to terminal 86 with the ignition on and the control switch on. If not, check service information to see if power should be applied to terminal 86, then continue troubleshooting the switch power and related circuit.
- **Check the relay itself:** Use an ohmmeter and measure for continuity and resistance.
  - Between terminals 85 and 86 (coil), there should be 60 to 100 ohms. If not, replace the relay.
  - Between terminals 30 and 87 (high-amperage switch controls), there should be continuity (low ohms) when there is power applied to terminal 85 and a ground applied to terminal 86 that operates the relay. If OL is displayed on the meter set to read ohms, the circuit is open which requires that the reply be replaced.
  - Between terminals 30 and 87a (if equipped), with the relay turned off, there should be low resistance (less than 5 ohms).

applied to the coil in a forward direction through the diode, which conducts the current back into the winding. As a result, the induced voltage spike is eliminated.

Most relays use a resistor connected in parallel with the coil winding. The use of a resistor, typically about 400 to 600 ohms, reduces the voltage spike by providing a path for the voltage created in the coil to flow back through the coil windings when the coil circuit is opened. See ● **FIGURE 9–31.**

FREQUENTLY ASKED QUESTION

What Is the Difference Between a Relay and a Solenoid?

Often, these terms are used differently among vehicle manufacturers, which can lead to some confusion.

Relay: A relay is an electromagnetic switch that uses a movable arm. Because a relay uses a movable arm, it is generally limited to current flow not exceeding 30 amperes.

Solenoid: A solenoid is an electromagnetic switch that uses a movable core. Because of this type of design, a solenoid is capable of handling 200 amperes or more and is used in the starter motor circuit and other high-amperage applications, such as in the glow plug circuit of diesel engines.

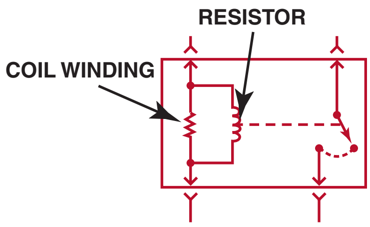


FIGURE 9–31 A resistor used in parallel with the coil windings is a common spike reduction method used in many relays.

REAL WORLD FIX

The Electric Mirror Fault Story

Often, a customer will notice just one fault even though other lights or systems may not be working correctly. For example, a customer noticed that the electric mirrors stopped working. The service technician checked all electrical components in the vehicle and discovered that the interior lights were also not working.

The interior lights were not mentioned by the customer as being a problem most likely because the driver only used the vehicle in daylight hours.

The service technician found the interior light and power accessory fuse blown. Replacing the fuse restored the proper operation of the electric outside mirror and the interior lights. However, what caused the fuse to blow? A visual inspection of the dome light, next to the electric sunroof, showed an area where a wire was bare. Evidence showed the bare wire had touched the metal roof, which could cause the fuse to blow. The technician covered the bare wire with a section of vacuum hose and then taped the hose with electrical tape to complete the repair.

LOCATING AN OPEN CIRCUIT

TERMINOLOGY An open circuit is a break in the electrical circuit that prevents current from flowing and operating an electrical device. Examples of open circuits include:

- Blown (open) light bulbs
- Cut or broken wires
- Disconnected or partially disconnected electrical connectors
- Electrically open switches
- Loose or broken ground connections or wires
- Blown fuse

PROCEDURE TO LOCATE AN OPEN CIRCUIT The typical procedure for locating an open circuit involves the following steps.

STEP 1 **Perform a thorough visual inspection.** Check the following:
- Look for evidence of a previous repair. Often, an electrical connector or ground connection can be accidentally left disconnected.
- Look for evidence of recent body damage or body repairs. Movement due to a collision can cause metal to move, which can cut wires or damage connectors or components.

STEP 2 **Print out the schematic.** Trace the circuit and check for voltage at certain places. This will help pinpoint the location of the open circuit.

STEP 3 **Check everything that does and does not work.** Often, an open circuit will affect more than one component. Check the part of the circuit that is common to the other components that do not work.

STEP 4 **Check for voltage.** Voltage is present up to the location of the open circuit fault. For example, if there is battery voltage at the positive terminal and the negative (ground) terminal of a two-wire light bulb socket with the bulb plugged in, then the ground circuit is open.

COMMON POWER OR GROUND

When diagnosing an electrical problem that affects more than one component or system, check the electrical schematic for a common power source or a common ground. ● **SEE FIGURE 9–32** for an example of lights being powered by one fuse (power source).

- Underhood light
- Inside lighted mirrors
- Dome light
- Left-side courtesy light
- Right-side courtesy light

Therefore, if a customer complains about one or more of the items listed, check the fuse and the common part of the circuit that feeds all of the affected lights. Check for a common ground if several components that seem unrelated are not functioning correctly.

CIRCUIT TROUBLESHOOTING PROCEDURE

Follow these steps when troubleshooting wiring problems.

STEP 1 Verify the malfunction. If, for example, the backup lights do not operate, make certain that the ignition is on (key on, engine off), with the gear selector in reverse, and check for operation of the backup lights.

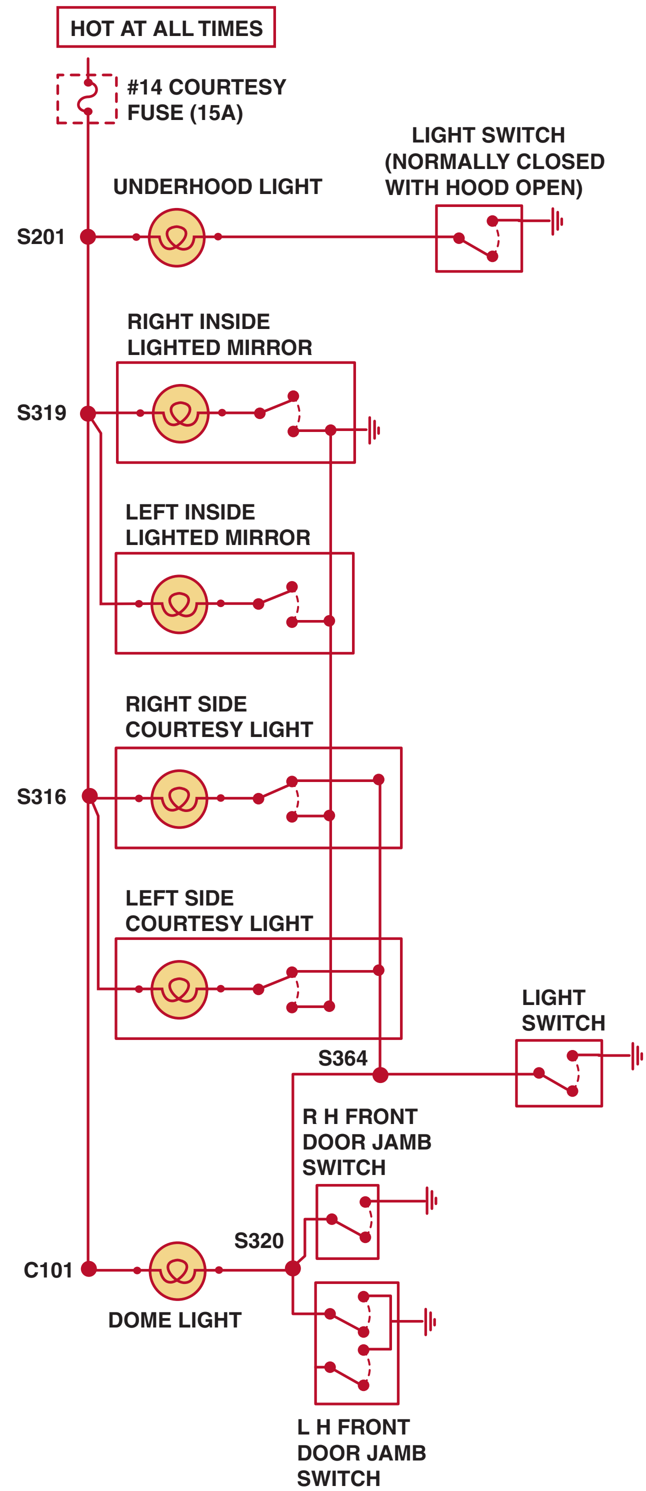


FIGURE 9–32 A typical wiring diagram showing multiple switches and bulbs powered by one fuse.

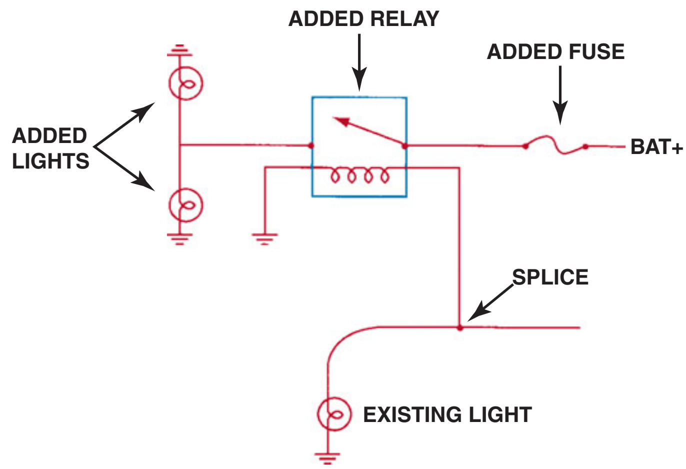


FIGURE 9–33 To add additional lighting, simply tap into an existing light wire and connect a relay. Whenever the existing light is turned on, the coil of the relay is energized. The arm of the relay then connects power from another circuit (fuse) to the auxiliary lights without overloading the existing light circuit.

TECH TIP

Do It Right—Install a Relay

Often the owners of vehicles, especially owners of pickup trucks and sport utility vehicles (SUVs), want to add additional electrical accessories or lighting. It is tempting in these cases to simply splice into an existing circuit. However, when another circuit or component is added, the current that flows through the newly added component is also added to the current for the original component. This additional current can easily overload the fuse and wiring. Do not simply install a larger amperage fuse; the wire gauge size was not engineered for the additional current and could overheat.

The solution is to install a relay, which uses a small coil to create a magnetic field that causes a movable arm to switch on a higher current circuit. The typical relay coil has from 50 to 150 ohms (usually 60 to 100 ohms) of resistance and requires just 0.24 to 0.08 ampere when connected to a 12 volt source. This small additional current will not be enough to overload the existing circuit. ● **SEE FIGURE 9–33** for an example of how additional lighting can be added.

STEP 2 Check everything else that does or does not operate correctly. For example, if the taillights are also not working, the problem could be a loose or broken ground connection in the trunk area that is shared by both the backup lights and the taillights.

STEP 3 Check the fuse for the backup lights. ● **SEE FIGURE 9–34.**

STEP 4 Check for voltage at the backup light socket. This can be done using a test light or a voltmeter.

If voltage is available at the socket, the problem is either a defective bulb or a poor ground at the socket or a ground wire connection to the body or frame. If no voltage is available at the socket, consult a wiring diagram for the type of vehicle

FIGURE 9–34 Always check the simple things first. Check the fuse for the circuit you are testing. Maybe a fault in another circuit controlled by the same fuse could have caused the fuse to blow. Use a test light to check that both sides of the fuse have voltage.

being tested. The wiring diagram should show all of the wiring and components included in the circuit. For example, the backup light current must flow through the fuse and ignition switch to the gear selector switch before traveling to the rear backup light socket. As stated in the second step, the fuse used for the backup lights may also be used for other vehicle circuits.

The wiring diagram can be used to determine all other components that share the same fuse. If the fuse is blown (open circuit), the cause can be a short in any of the circuits sharing the same fuse. Because the backup light circuit current must be switched on and off by the gear selector switch, an open in the switch can also prevent the backup lights from functioning.

FREQUENTLY ASKED QUESTION

Where to Start?

The common question is, where does a technician start the troubleshooting when using a wiring diagram (schematic)?

HINT 1 If the circuit contains a relay, start your diagnosis at the relay. The entire circuit can be tested at the terminals of the relay.

HINT 2 The easiest first step is to locate the unit on the schematic that is not working at all or not working correctly.

- **a.** Trace where the unit gets its ground connection.
- **b.** Trace where the unit gets its power connection.

Often a ground is used by more than one component. Therefore, ensure that everything else is working correctly. If not, then the fault may lie at the common ground (or power) connection.

HINT 3 Divide the circuit in half by locating a connector or a part of the circuit that can be accessed easily. Then check for power and ground at this midpoint. This step could save you much time.

HINT 4 Use a fused jumper wire to substitute a ground or a power source to replace a suspected switch or section of wire.

LOCATING A SHORT CIRCUIT

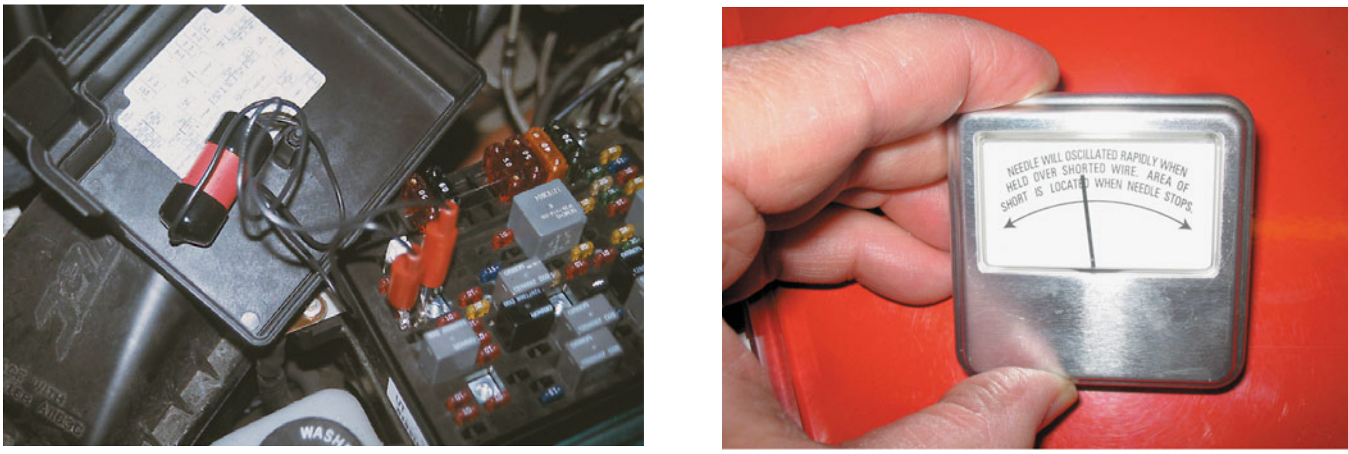
TERMINOLOGY A short circuit usually blows a fuse, and a replacement fuse often also blows in the attempt to locate the source of the short circuit. A **short circuit** is an electrical connection to another wire or to ground before the current flows through some or all of the resistance in the circuit. A short-to-ground will always blow a fuse and usually involves a wire on the power side of the circuit coming in contact with metal. Therefore, a thorough visual inspection should be performed around areas involving heat or movement, especially if there is evidence of a previous collision or previous repair that may not have been properly completed.

A short-to-voltage may or may not cause the fuse to blow and usually affects another circuit. Look for areas of heat or movement where two power wires could come in contact with each other. Several methods can be used to locate the short.

FUSE REPLACEMENT METHOD Disconnect one component at a time and then replace the fuse. If the new fuse blows, continue the process until you determine the location of the short. This method uses many fuses and is *not* a preferred method for finding a short circuit.

CIRCUIT BREAKER METHOD Another method is to connect an automotive circuit breaker to the contacts of the fuse holder with alligator clips. Circuit breakers are available that plug directly into the fuse panel, replacing a blade-type fuse. The circuit breaker will alternately open and close the circuit, protecting the wiring from possible overheating damage while still providing current flow through the circuit.

NOTE: A heavy-duty (HD) flasher can also be used in place of a circuit breaker to open and close the circuit. Wires and terminals must be made to connect the flasher unit where the fuse normally plugs in.



(a) (b)

FIGURE 9–35 (a) After removing the blown fuse, a pulsing circuit breaker is connected to the terminals of the fuse. (b) The circuit breaker causes current to flow, then stop, then flow again, through the circuit up to the point of the short-to-ground. By observing the Gauss gauge, the location of the short is indicated near where the needle stops moving due to the magnetic field created by the flow of current through the wire.

All components included in the defective circuit should be disconnected one at a time until the circuit breaker stops clicking. The unit that was disconnected and stopped the circuit breaker clicking is the unit causing the short circuit. If the circuit breaker continues to click with all circuit components unplugged, the problem is in the wiring *from* the fuse panel *to* any one of the units in the circuit. Visual inspection of all the wiring or further disconnecting will be necessary to locate the problem.

TEST LIGHT METHOD To use the test light method, simply remove the blown fuse and connect a test light to the terminals of the fuse holder (polarity does not matter). If there is a short circuit, current will flow from the power side of the fuse holder through the test light and on to ground through the short circuit, and the test light will then light. Unplug the connectors or components protected by the fuse until the test light goes out. The circuit that was disconnected, which caused the test light to go out, is the circuit that is shorted.

BUZZER METHOD The buzzer method is similar to the test light method, but uses a buzzer to replace a fuse and act as an electrical load. The buzzer will sound if the circuit is shorted and will stop when the part of the circuit that is grounded is unplugged.

OHMMETER METHOD The fourth method uses an ohmmeter connected to the fuse holder and ground. This is the recommended method of finding a short circuit, as an ohmmeter will indicate low ohms when connected to a short circuit. However, an ohmmeter should never be connected to an operating circuit. The correct procedure for locating a short using an ohmmeter is as follows:

1. Connect one lead of an ohmmeter (set to a low scale) to a good clean metal ground and the other lead to the circuit (load) side of the fuse holder.

CAUTION: Connecting the lead to the power side of the fuse holder will cause current flow through and damage to the ohmmeter.

2. The ohmmeter will read zero or almost zero ohms if the circuit or a component in the circuit is shorted.
3. Disconnect one component in the circuit at a time and watch the ohmmeter. If the ohmmeter reading goes to high ohms or infinity, the component just unplugged was the source of the short circuit.
4. If all of the components have been disconnected and the ohmmeter still reads low ohms, then disconnect electrical connectors until the ohmmeter reads high ohms. The location of the short to ground is then between the ohmmeter and the disconnected connector.

NOTE: Some meters, such as the Fluke 87, can be set to beep (alert) when the circuit closes or when the circuit opens—a very useful feature.

GAUSS GAUGE METHOD If a short circuit blows a fuse, a special pulsing circuit breaker (similar to a flasher unit) can be installed in the circuit in place of the fuse. Current will flow through the circuit until the circuit breaker opens the circuit. As soon as the circuit breaker opens the circuit, it closes again. This on-and-off current flow creates a pulsing magnetic field around the wire carrying the current. A **Gauss gauge** is a handheld meter that responds to weak magnetic fields. It is used to observe this pulsing magnetic field, which is indicated on the gauge as needle movement. This pulsing magnetic field will register on the Gauss gauge even through the metal body of the vehicle. A needle-type compass can also be used to observe the pulsing magnetic field. ● **SEE FIGURES 9–35 AND 9–36.**

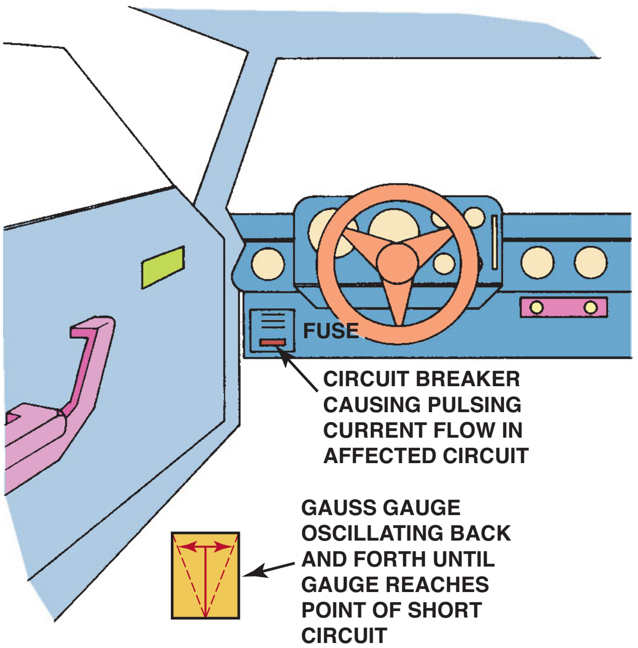


FIGURE 9–36 A Gauss gauge can be used to determine the location of a short circuit even behind a metal panel.

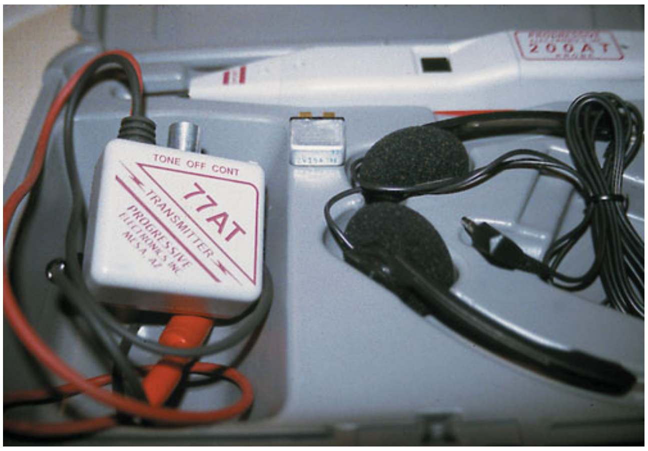


FIGURE 9–37 A tone generator-type tester used to locate open circuits and circuits that are shorted-to-ground. Included with this tester is a transmitter (tone generator), receiver probe, and headphones for use in noisy shops.

TECH TIP

Heat or Movement

Electrical shorts are commonly caused either by movement, which causes the insulation around the wiring to be worn away, or by heat melting the insulation. When checking for a short circuit, first check the wiring that is susceptible to heat, movement, and damage.

1. **Heat.** Wiring near heat sources, such as the exhaust system, cigarette lighter, or alternator
2. **Wire movement.** Wiring that moves, such as in areas near the doors, trunk, or hood
3. **Damage.** Wiring subject to mechanical injury, such as in the trunk, where heavy objects can move around and smash or damage wiring; can also occur as a result of an accident or a previous repair

ELECTRONIC TONE GENERATOR TESTER An electronic tone generator tester can be used to locate a short-to-ground or an open circuit. Similar to test equipment used to test telephone and cable television lines, a **tone generator tester** generates a tone that can be heard through a receiver (probe). ● **SEE FIGURE 9–37.**

The tone will be generated as long as there is a continuous electrical path along the circuit. The signal will stop if there is a short-to-ground or an open in the circuit. ● **SEE FIGURE 9–38.**

The windings in the solenoids and relays will increase the strength of the signal in these locations.

TECH TIP

Wiggle Test

Intermittent electrical problems are common yet difficult to locate. To help locate these hard-to-find problems, try operating the circuit and then start wiggling the wires and connections that control the circuit. If in doubt where the wiring goes, try moving all the wiring starting at the battery. Pay particular attention to wiring running near the battery or the windshield washer container. Corrosion can cause wiring to fail, and battery acid fumes and alcohol-based windshield washer fluid can start or contribute to the problem. If you notice any change in the operation of the device being tested while wiggling the wiring, look closer in the area you were wiggling until you locate and correct the actual problem.

ELECTRICAL TROUBLE-SHOOTING GUIDE

When troubleshooting any electrical component, remember the following hints to find the problem faster and more easily.

1. For a device to work, it must have two things: power and ground.
2. If there is no power to a device, an open power side (blown fuse, etc.) is indicated.
3. If there is power on both sides of a device, an open ground is indicated.
4. If a fuse blows immediately, a grounded power-side wire is indicated.

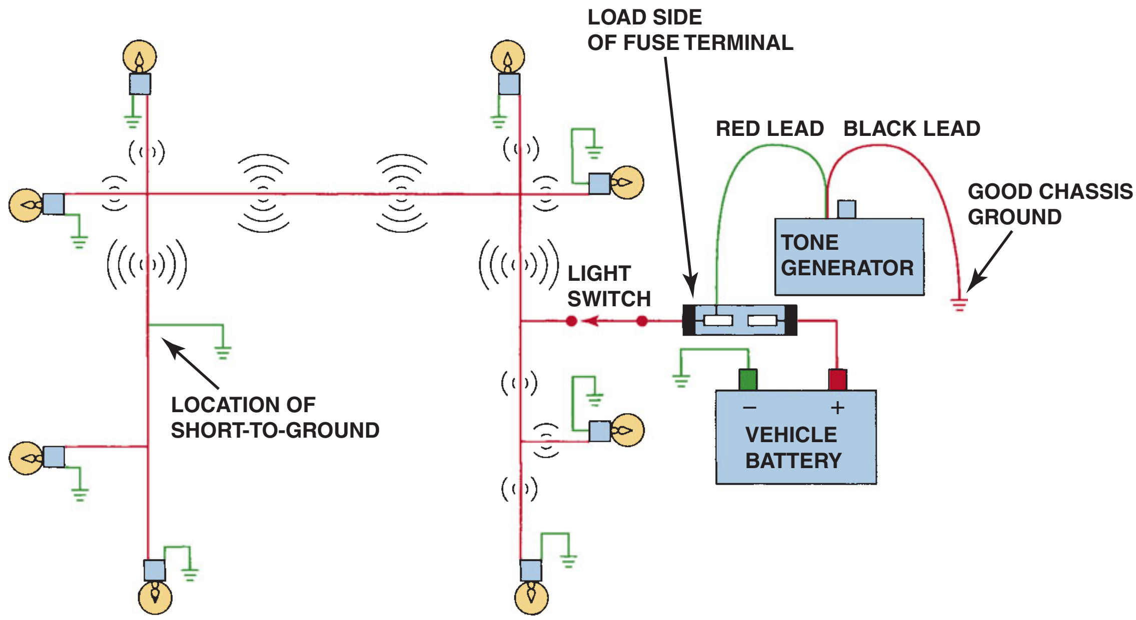


FIGURE 9–38 To check for a short-to-ground using a tone generator, connect the black transmitter lead to a good chassis ground and the red lead to the load side of the fuse terminal. Turn the transmitter on and check for tone signal with the receiver. Using a wiring diagram, follow the strongest signal to the location of the short-to-ground. There will be no signal beyond the fault, either a short-to-ground as shown or an open circuit.

5. Most electrical faults result from heat or movement.
6. Most noncomputer-controlled devices operate by opening and closing the power side of the circuit (power-side switch).
7. Most computer-controlled devices operate by opening and closing the ground side of the circuit (ground-side switch).

STEP-BY-STEP TROUBLESHOOTING PROCEDURE

Knowing what should be done and when it should be done is a major concern for many technicians trying to repair an electrical problem. The following field-tested procedure provides a step-by-step guide for troubleshooting an electrical fault.

STEP 1 Determine the customer concern (complaint) and get as much information as possible from the customer or service advisor.
- **a.** When did the problem start?
- **b.** Under what conditions does the problem occur?
- **c.** Have there been any recent previous repairs to the vehicle which could have created the problem?

STEP 2 Verify the customer's concern by actually observing the fault.

STEP 3 Perform a thorough visual inspection and be sure to check everything that does and does not work.

STEP 4 Check for technical service bulletins (TSBs).

STEP 5 Locate the wiring schematic for the circuit being diagnosed.

STEP 6 Check the factory service information and follow the troubleshooting procedure.
- **a.** Determine how the circuit works.
- **b.** Determine which part of the circuit is good, based on what works and what does not work.
- **c.** Isolate the problem area.

NOTE: Split the circuit in half to help isolate the problem and start at the relay (if the circuit has a relay).

STEP 7 Determine the root cause and repair the vehicle.

STEP 8 Verify the repair and complete the work order by listing the three Cs (complaint, cause, and correction).

REAL WORLD FIX

Shocking Experience

A customer complained that after driving for a while, he got a static shock whenever he grabbed the door handle when exiting the vehicle. The customer thought that there must be an electrical fault and that the shock was coming from the vehicle itself. In a way, the shock was caused by the vehicle, but it was not a fault. The service technician sprayed the cloth seats with an antistatic spray and the problem did not reoccur. Obviously, a static charge was being created by the movement of the driver's clothing on the seats and then discharged when the driver touched the metal door handle. ● **SEE FIGURE 9–39**.

FIGURE 9–39 Antistatic spray can be used by customers to prevent being shocked when they touch a metal object like the door handle.

SUMMARY

1. Most wiring diagrams include the wire color, circuit number, and wire gauge.
2. The number used to identify connectors, grounds, and splices usually indicates where they are located in the vehicle.
3. All switches and relays on a schematic are shown in their normal position either normally closed (N.C.) or normally open (N.O.).
4. A typical relay uses a small current through a coil (terminals 85 and 86) to operate the higher current part (terminals 30 and 87).
5. A short-to-voltage affects the power side of the circuit and usually involves more than one circuit.
6. A short-to-ground usually causes the fuse to blow and usually affects only one circuit.
7. Most electrical faults are a result of heat or movement.

REVIEW QUESTIONS

1. List the numbers used on schematics to indicate grounds, splices, and connectors and where they are used in the vehicle.
2. List and identify the terminals of a typical ISO type relay.
3. List three methods that can be used to help locate a short circuit.
4. How can a tone generator be used to locate a short circuit?

CHAPTER QUIZ

1. On a wiring diagram, S110 with a ".8 BRN/BLK" means ________.
   a. Circuit #.8, spliced under the hood
   b. A connector with 0.8 mm^2 wire
   c. A splice of a brown with black stripe, wire size being 0.8 mm^2 (18 gauge AWG)
   d. Both a and b
2. Where is connector C250?
   a. Under the hood
   b. Under the dash
   c. In the passenger compartment
   d. In the trunk

3. All switches illustrated in schematics are ________.
- **a.** Shown in their normal position
- **b.** Always shown in their on position
- **c.** Always shown in their off position
- **d.** Shown in their on position except for lighting switches

4. When testing a relay using an ohmmeter, which two terminals should be touched to measure the coil resistance?
- **a.** 87 and 30
- **b.** 86 and 85
- **c.** 87a and 87
- **d.** 86 and 87

5. Technician A says that a good relay should measure between 60 and 100 ohms across the coil terminals. Technician B says that OL should be displayed on an ohmmeter when touching terminals 30 and 87. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

6. Which relay terminal is the normally closed (N.C.) terminal?
- **a.** 30
- **b.** 85
- **c.** 87
- **d.** 87a

7. Technician A says that there is often more than one circuit being protected by each fuse. Technician B says that more than one circuit often shares a single ground connector. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

8. Two technicians are discussing finding a short-to-ground using a test light. Technician A says that the test light, connected in place of the fuse, will light when the circuit that has the short is disconnected. Technician B says that the test light should be connected to the positive (+) and negative (−) terminals of the battery during this test. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

9. A short circuit can be located using a ________.
- **a.** Test light
- **b.** Gauss gauge
- **c.** Tone generator
- **d.** All of the above

10. For an electrical device to operate, it must have ________.
- **a.** Power and a ground
- **b.** A switch and a fuse
- **c.** A ground and fusible link
- **d.** A relay to transfer the current to the device

chapter 10

CAPACITANCE AND CAPACITORS

OBJECTIVES: **After studying Chapter 10, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems). • Explain capacitance. • Describe how a capacitor can be used to filter electrical noise. • Describe how a capacitor can store an electrical charge. • Explain how a capacitor circuit can be used as a timer circuit.

KEY TERMS: Capacitance 133 • Condenser 133 • Dielectric 133 • Farads 136 • Leyden jar 133

CAPACITANCE

DEFINITION **Capacitance** is the ability of an object or surface to store an electrical charge. Around 1745, Ewald Christian von Kliest and Pieter van Musschenbroek independently discovered capacitance in an electric circuit. While engaged in separate studies of electrostatics, they discovered that an electric charge could be stored for a period of time. They used a device, now called a **Leyden jar,** for their experimentation, which consisted of a glass jar filled with water, with a nail piercing the stopper and dipping into the water.

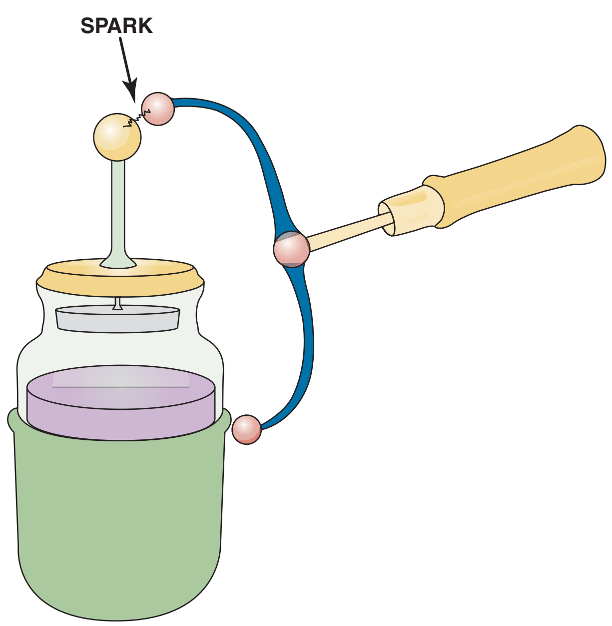


FIGURE 10–1 A Leyden jar can be used to store an electrical charge.

The two scientists connected the nail to an electrostatic charge. After disconnecting the nail from the source of the charge, they felt a shock by touching the nail, demonstrating that the device had stored the charge.

In 1747, John Bevis lined both the inside and outside of the jar with foil. This created a capacitor with two conductors (the inside and outside metal foil layers) equally separated by the insulating glass. ● **SEE FIGURE 10–1.** The Leyden jar was also used by Benjamin Franklin to store the charge from lightning as well as in other experiments. The natural phenomenon of lightning includes capacitance, because huge electrical fields develop between cloud layers or between clouds and the earth prior to a lightning strike.

NOTE: Capacitors are also called condensers. This term developed because electric charges collect, or condense, on the plates of a capacitor much like water vapor collects and condenses on a cold bottle or glass.

CAPACITOR CONSTRUCTION AND OPERATION

CONSTRUCTION A capacitor (also called a condenser) consists of two conductive plates with an insulating material between them. The insulating material is commonly called a **dielectric.** This substance is a poor conductor of electricity and can include air, mica, ceramic, glass, paper, plastic, or any similar nonconductive material. The dielectric constant is the relative strength of a material against the flow of electrical current. The higher the number is, the better the insulating properties. ● **SEE CHART 10–1.**

OPERATION When a capacitor is placed in a closed circuit, the voltage source (battery) forces electrons around the circuit. Because electrons cannot flow through the dielectric

MATERIAL	DIELECTRIC CONSTANT
Vacuum	1
Air	1.00059
Polystyrene	2.5
Paper	3.5
Mica	5.4
Flint glass	9.9
Methyl alcohol	35
Glycerin	56.2
Pure water	81

CHART 10–1

The higher the dielectric constant is, the better the insulating properties between the plates of the capacitor.

of the capacitor, excess electrons collect on what becomes the negatively charged plate. At the same time, the other plate loses electrons and, therefore, becomes positively charged. ● **SEE FIGURE 10–2.**

Current continues until the voltage charge across the capacitor plates becomes the same as the source voltage. At that time, the negative plate of the capacitor and the negative terminal of the battery are at the same negative potential. ● **SEE FIGURE 10–3.**

The positive plate of the capacitor and the positive terminal of the battery are also at equal positive potentials. There is then a voltage charge across the battery terminals and an equal voltage charge across the capacitor plates. The circuit is in balance, and there is no current. An electrostatic field now exists between the capacitor plates because of their opposite charges. It is this field that stores energy. In other words, a charged capacitor is similar to a charged battery. ● **SEE FIGURE 10–4.**

If the circuit is opened, the capacitor will hold its charge until it is connected into an external circuit through which it can discharge. When the charged capacitor is connected to an external circuit, it discharges. After discharging, both plates of the capacitor are neutral because all the energy from a circuit stored in a capacitor is returned when it is discharged. ● **SEE FIGURE 10–5.**

Theoretically, a capacitor holds its charge indefinitely. Actually, the charge slowly leaks off the capacitor through the dielectric. The better the dielectric, the longer the capacitor holds its charge. To avoid an electrical shock, any capacitor should be treated as if it were charged until it is proven to be discharged. To safely discharge a capacitor, use a test light with the clip attached to a good ground, and touch the pigtail or terminal with the point of the test light. ● **SEE FIGURE 10–6** for the symbol for capacitors as used in electrical schematics.

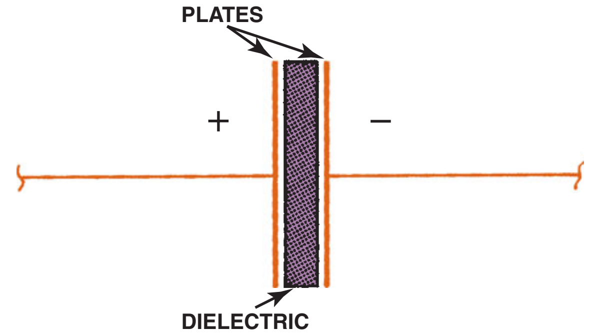


FIGURE 10–2 This simple capacitor, made of two plates separated by an insulating material, is called a dielectric.

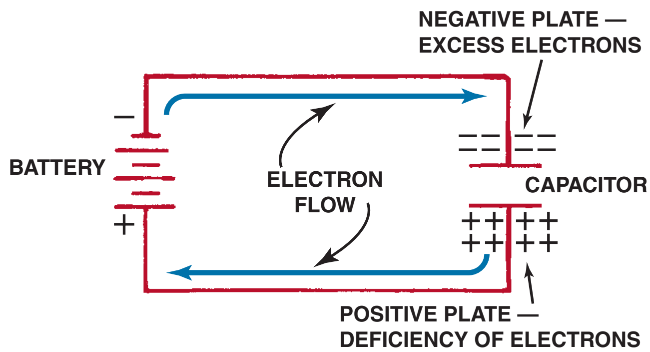


FIGURE 10–3 As the capacitor is charging, the battery forces electrons through the circuit.

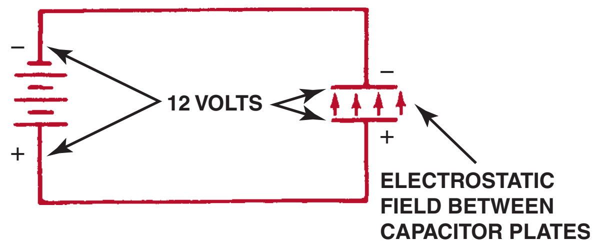


FIGURE 10–4 When the capacitor is charged, there is equal voltage across the capacitor and the battery. An electrostatic field exists between the capacitor plates. No current flows in the circuit.

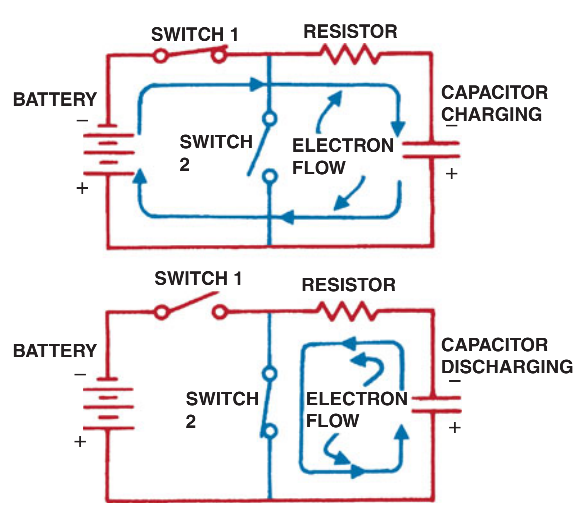


FIGURE 10–5 The capacitor is charged through one circuit (top) and discharged through another (bottom).

FACTORS OF CAPACITANCE

Capacitance is governed by three factors.

- The surface area of the plates
- The distance between the plates
- The dielectric material

The larger the surface area of the plates is, the greater the capacitance, because more electrons collect on a larger plate area than on a small one. The closer the plates are to each other, the greater the capacitance, because a stronger electrostatic field exists between charged bodies that are close together. The insulating qualities of the dielectric material also affect capacitance. The capacitance of a capacitor is higher if the dielectric is a very good insulator.

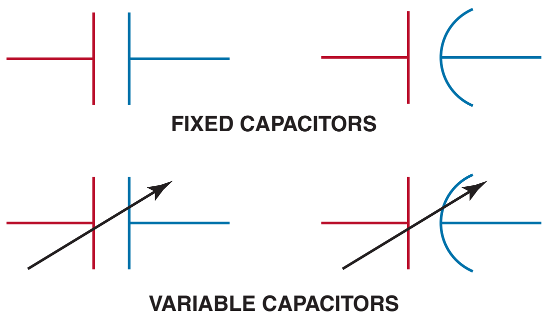


FIGURE 10–6 Capacitor symbols are shown in electrical diagrams. The negative plate is often shown curved.

? FREQUENTLY ASKED QUESTION

What Are "Points and Condenser"?

Points and condenser are used in point-type ignition systems.

Points. A set of points uses one stationary contact and a movable contact that is opened by a cam lobe inside the ignition distributor. When the points are closed, current flows through the primary windings of the ignition coil and creates a strong magnetic field. As the engine rotates, the distributor can open the contact points, which opens the circuit to the coil. The stored magnetic field in the coil collapses and generates a high-voltage arc from the secondary winding of the coil. It is this spark that is sent to the spark plugs that ignites the air-fuel mixture inside the engine.

Condenser. The condenser (capacitor) is attached to the points and the case of the condenser is grounded. When the points start to open, the charge built up in the primary winding of the coil would likely start to arc across the opening points. To prevent the points from arcing and to increase how rapidly the current is turned off, the condenser stores the current temporarily.

Points and condenser were used in vehicles and small gasoline engines until the mid-1970s. ● **SEE FIGURE 10–7.**

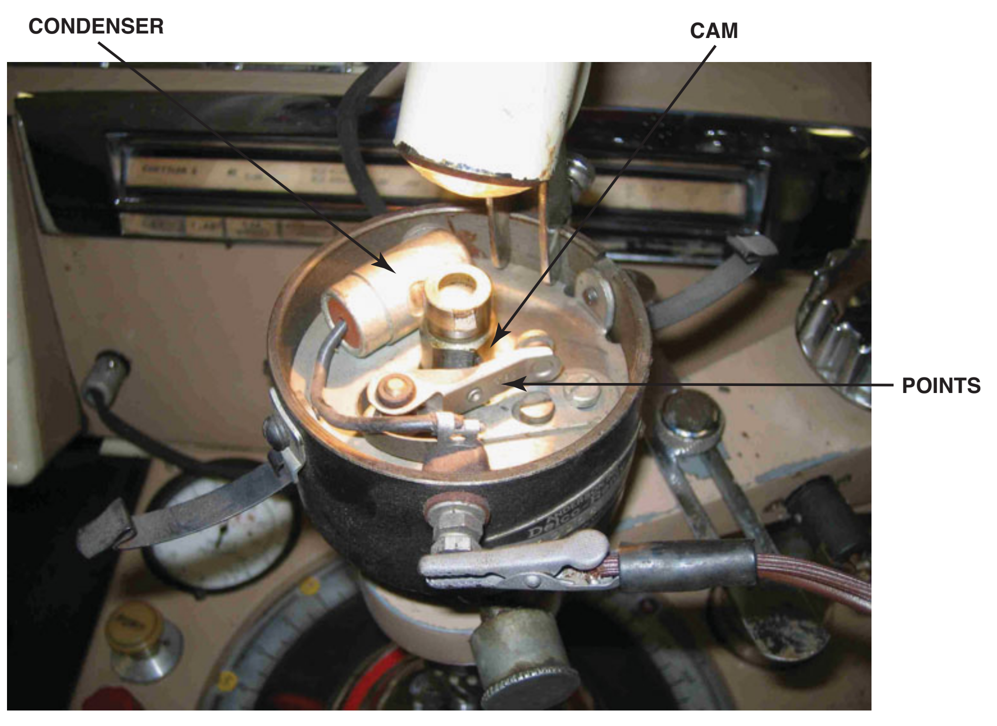


FIGURE 10–7 A point-type distributor shown with the condenser from an old vehicle being tested on a distributor machine.

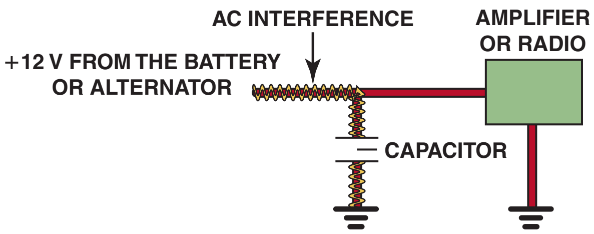


FIGURE 10–8 A capacitor blocks direct current (DC) but passes alternating current (AC). A capacitor makes a very good noise suppressor because most of the interference is AC and the capacitor will conduct this AC to ground before it can reach the radio or amplifier.

MEASUREMENT OF CAPACITANCE Capacitance is measured in **farads,** which is named after Michael Faraday (1791–1867), an English physicist. The symbol for farads is the letter *F*. If a charge of 1 coulomb is placed on the plates of a capacitor and the potential difference between them is 1 volt, then the capacitance is defined to be 1 farad, or 1 F. One coulomb is equal to the charge of 6.25×10^{18} electrons. One farad is an extremely large quantity of capacitance. Microfarads (0.000001 farad), or μF, are more commonly used.

The capacitance of a capacitor is proportional to the quantity of charge that can be stored in it for each volt difference in potential.

USES FOR CAPACITORS

SPIKE SUPPRESSION A capacitor can be used in parallel to a coil to reduce the resulting voltage spike that occurs when the circuit is opened. The energy stored to the magnet field of the coil is rapidly released at this time. The capacitor acts to absorb the high voltage produced and stop it from interfering with other electronic devices, such as automotive radio and video equipment.

NOISE FILTERING Interference in a sound system or radio is usually due to alternating current (AC) voltage created somewhere in the vehicle, such as in the alternator. A capacitor does the following:

- Blocks the flow of direct current (DC)
- Allows alternating current (AC) to pass

By connecting a capacitor (condenser) to the power lead of the radio or sound system amplifier, the AC voltage passes through the capacitor to the ground where the other end of the capacitor is connected. Therefore, the capacitor provides a path for the AC without affecting the DC power circuit. ● **SEE FIGURE 10–8.**

Because a capacitor stores a voltage charge, it opposes or slows any voltage change in a circuit. Therefore, capacitors are often used as voltage "shock absorbers." You sometimes find a capacitor attached to one terminal of an ignition coil. In this application, the capacitor absorbs and dampens changes in ignition voltage that interfere with radio reception.

FIGURE 10–9 A 1 farad capacitor used to boost the power to large speakers.

SUPPLEMENTAL POWER SOURCE A capacitor can be used to supply electrical power for short bursts in an audio system to help drive the speakers. Woofers and subwoofers require a lot of electrical current that often cannot be delivered by the amplifier itself. ● **SEE FIGURE 10–9.**

TIMER CIRCUITS Capacitors are used in electronic circuits as part of a timer, to control window defoggers, interior lighting, pulse wipers, and automatic headlights. The capacitors store energy and then are allowed to discharge through a resistance load. The greater the capacity of the capacitor and the higher the resistance load, the longer the time it takes for the capacitor to discharge.

COMPUTER MEMORY In most cases, the main memory of a computer is a high-speed random-access memory (RAM). One type of main memory, called dynamic random-access memory (DRAM), is the most commonly used type of RAM. A single memory chip is made up of several million memory cells. In a DRAM chip, each memory cell consists of a capacitor. When a capacitor is electrically charged, it is said to store the binary digit 1, and when discharged, it represents 0.

CONDENSER MICROPHONES A microphone converts sound waves into an electric signal. All microphones have a diaphragm that vibrates as sound waves strike. The vibrating diaphragm in turn causes an electrical component to create an output flow of current at a frequency proportional to the sound waves. A condenser microphone uses a capacitor for this purpose.

In a condenser microphone, the diaphragm is the negatively charged plate of a charged capacitor. When a sound wave compresses the diaphragm, the diaphragm is moved closer to the positive plate. Decreasing the distance between the plates increases the electrostatic attraction between them, which results in a flow of current to the negative plate. As the diaphragm moves out in response to sound waves, it also moves farther from the positive plate. Increasing the distance between the

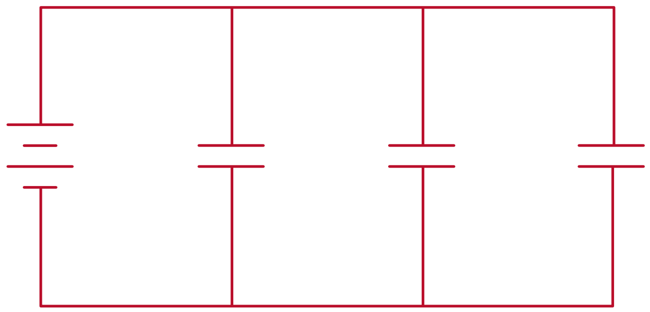


FIGURE 10–10 Capacitors in parallel effectively increase the capacitance.

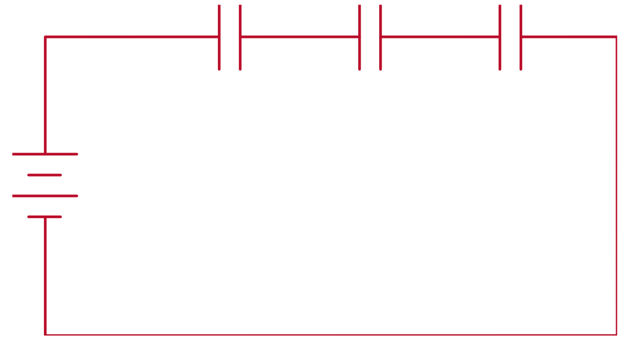


FIGURE 10–11 Capacitors in series decrease the capacitance.

plates decreases the electrostatic attraction between them. This results in a flow of current back to the positive plate. These alternating flows of current provide weak electronic signals that travel to an amplifier and then to a loudspeaker.

CAPACITORS IN CIRCUITS

CAPACITORS IN PARALLEL CIRCUITS Capacitance can be increased in a circuit by connecting capacitors in parallel. For example, if a greater boost is needed for a sound system, then additional capacitors should be connected in parallel because their value adds together. ● **SEE FIGURE 10–10.**

We know that capacitance of a capacitor can be increased by increasing the size of its plates. Connecting two or more capacitors in parallel in effect increases plate size. Increasing plate area makes it possible to store more charge and therefore creates greater capacitance. To determine total capacitance of several parallel capacitors, simply add up their individual values. The following is the formula for calculating total capacitance in a circuit containing capacitors in parallel.

$$C_T = C_1 + C_2 + C_3 \ldots$$

For example, 220 μF + 220 μF = 440 μF when connected in parallel.

CAPACITORS IN SERIES CIRCUITS Capacitance can be decreased in a circuit by capacitors in series, as shown in ● **FIGURE 10–11.**

We know that capacitance of a capacitor can be decreased by placing the plates farther apart. Connecting two or more capacitors in series in effect increases the distance between the plates and thickness of the dielectric, thereby decreasing the amount of capacitance.

Following is the formula for calculating total capacitance in a circuit containing two capacitors in series.

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

For example, $\frac{220\ \mu F \times 220\ \mu F}{220\ \mu F + 220\ \mu F} = \frac{48,400}{440} = 110\ \mu F$

NOTE: Capacitors are often used to reduce radio interference or to improve the performance of a high-power sound system. Additional capacitance can, therefore, be added by attaching another capacitor in parallel.

SUPPRESSION CAPACITORS Capacitors are installed across many circuits and switching points to absorb voltage fluctuations. Among other applications, they are used across the following:

- The primary circuit of some electronic ignition modules
- The output terminal of most alternators
- The armature circuit of some electric motors

Radio choke coils reduce current fluctuations resulting from self-induction. They are often combined with capacitors to act as electromagnetic interference (EMI) filter circuits for windshield wiper and electric fuel pump motors. Filters also may be incorporated in wiring connectors.

SUMMARY

1. Capacitors (condensers) are used in numerous automotive applications.
2. Capacitors can block direct current and pass alternating current.
3. Capacitors are used to control radio-frequency interference and are installed in various electronic circuits to control unwanted noise.
4. Capacitors connected in series reduce the capacitance, whereas if connected in parallel increase the capacitance.

REVIEW QUESTIONS

1. How does a capacitor store an electrical charge?
2. How should two capacitors be electrically connected if greater capacitance is needed?
3. Where can a capacitor be used as a power source?
4. How can a capacitor be used as a noise filter?

CHAPTER QUIZ

1. A capacitor ________.
   a. Stores electrons
   b. Passes AC
   c. Blocks DC
   d. All of the above
2. A capacitor can also be called a ________.
   a. Condenser
   b. Dielectric
   c. Farad
   d. DRAM
3. Capacitors are commonly used as a ________.
   a. Voltage supply
   b. Timer
   c. Noise filter
   d. All of the above
4. A charged capacitor acts like a ________.
   a. Switch
   b. Battery
   c. Resistor
   d. Coil
5. The unit of measurement for capacitor rating is the ________.
   a. Ohm
   b. Volt
   c. Farad
   d. Ampere
6. Two technicians are discussing the operation of a capacitor. Technician A says that a capacitor can create electricity. Technician B says that a capacitor can store electricity. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Capacitors block the flow of ________ current but allow ________ current to pass.
   a. Strong; weak
   b. AC; DC
   c. DC; AC
   d. Weak; strong
8. To increase the capacity, what could be done?
   a. Connect another capacitor in series.
   b. Connect another capacitor in parallel.
   c. Add a resistor between two capacitors.
   d. Both a and b
9. A capacitor can be used in what components?
   a. Microphone
   b. Radio
   c. Speaker
   d. All of the above
10. A capacitor used for spike protection will normally be placed in ________ to the load or circuit.
    a. Series
    b. Parallel
    c. Either series or parallel
    d. Parallel with a resistor in series

chapter 11 MAGNETISM AND ELECTROMAGNETISM

OBJECTIVES: **After studying Chapter 11, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems). • Explain magnetism. • Describe how magnetism and voltage are related. • Describe how an ignition coil works. • Explain how an electromagnet works.

KEY TERMS: Ampere-turns 143 • Counter electromotive force (CEMF) 146 • Electromagnet 143 • Electromagnetic induction 146 • Electromagnetic interference (EMI) 148 • Electromagnetism 141 • Flux density 140 • Flux lines 140 • Ignition control module (ICM) 147 • Left-hand rule 142 • Lenz's law 146 • Magnetic flux 140 • Magnetic induction 140 • Magnetism 139 • Mutual induction 146 • Permeability 141 • Pole 140 • Relay 143 • Reluctance 141 • Residual magnetism 140 • Right-hand rule 142 • Turns ratio 147

FUNDAMENTALS OF MAGNETISM

DEFINITION **Magnetism** is a form of energy that is caused by the motion of electrons in some materials. It is recognized by the attraction it exerts on other materials. Like electricity, magnetism cannot be seen. It can be explained in theory, however, because it is possible to see the results of magnetism and recognize the actions that it causes. Magnetite is the most naturally occurring magnet. Naturally magnetized pieces of magnetite, called *lodestone,* will attract and hold small pieces of iron. ● **SEE FIGURE 11–1.**

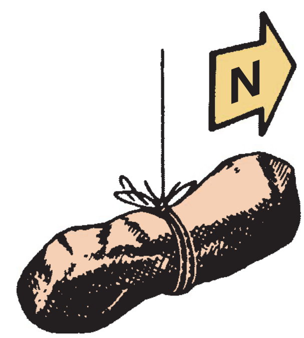


FIGURE 11–1 A freely suspended natural magnet (lodestone) will point toward the magnetic north pole.

TECH TIP

A Cracked Magnet Becomes Two Magnets

Magnets are commonly used in vehicle crankshaft, camshaft, and wheel speed sensors. If a magnet is struck and cracks or breaks, the result is two smaller-strength magnets. Because the strength of the magnetic field is reduced, the sensor output voltage is also reduced. A typical problem occurs when a magnetic crankshaft sensor becomes cracked, resulting in a no-start condition. Sometimes the cracked sensor works well enough to start an engine that is cranking at normal speeds but will not work when the engine is cold. ● **SEE FIGURE 11–2.**

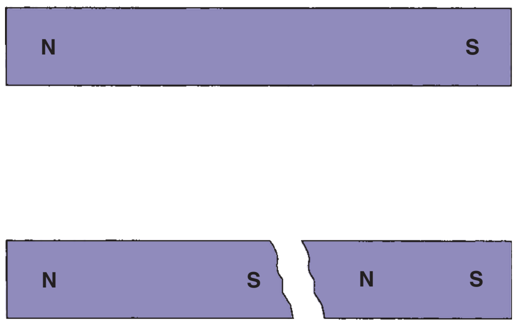


FIGURE 11–2 If a magnet breaks or is cracked, it becomes two weaker magnets.

Many other materials can be artificially magnetized to some degree, depending on their atomic structure. Soft iron is very easy to magnetize, whereas some materials, such as aluminum, glass, wood, and plastic, cannot be magnetized at all.

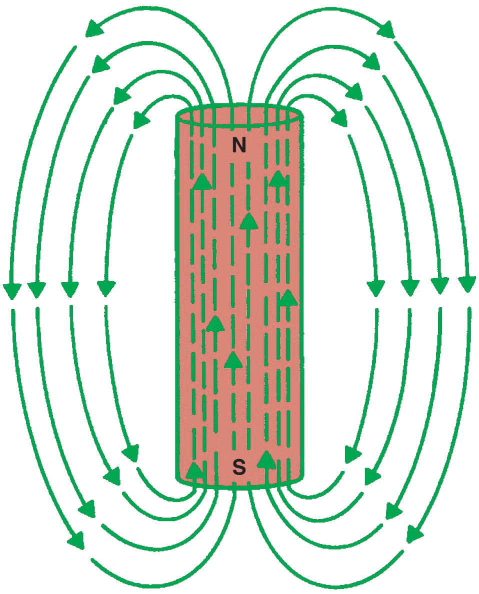


FIGURE 11–3 Magnetic lines of force leave the north pole and return to the south pole of a bar magnet.

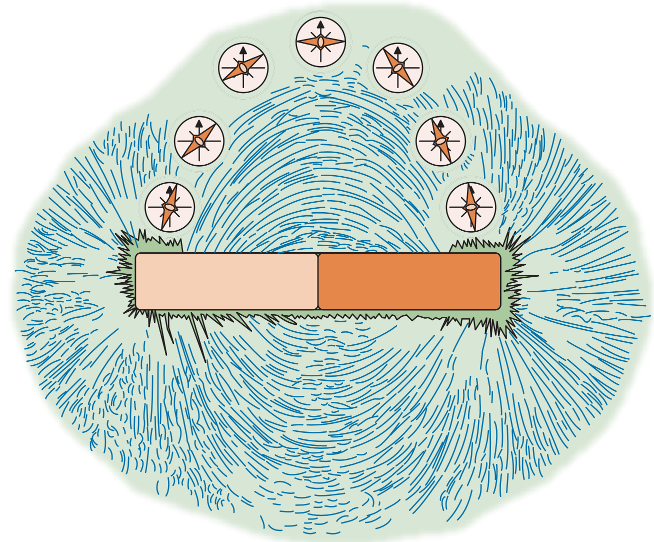


FIGURE 11–4 Iron filings and a compass can be used to observe the magnetic lines of force.

LINES OF FORCE The lines that create a field of force around a magnet are believed to be caused by the way groups of atoms are aligned in the magnetic material. In a bar magnet, the lines are concentrated at both ends of the bar and form closed, parallel loops in three dimensions around the magnet. Force does not flow along these lines the way electrical current flows, but the lines *do* have direction. They come out of the north end, or **pole**, of the magnet and enter at the other end. ● **SEE FIGURE 11–3.**

The opposite ends of a magnet are called its north and south poles. In reality, they should be called the "north seeking" and "south seeking" poles, because they seek the earth's North Pole and South Pole, respectively.

The more lines of force that are present, the stronger the magnet becomes. The magnetic lines of force, also called **magnetic flux** or **flux lines,** form a magnetic field. The terms *magnetic field, lines of force, flux,* and *flux lines* are used interchangeably.

Flux density refers to the number of flux lines per unit of area. A magnetic field can be measured using a Gauss gauge, named for German scientist Johann Carl Friedrick Gauss (1777–1855).

Magnetic lines of force can be seen by spreading fine iron filings or dust on a piece of paper laid on top of a magnet. A magnetic field can also be observed by using a compass. A compass is simply a thin magnet or magnetized iron needle balanced on a pivot. The needle will rotate to point toward the opposite pole of a magnet. The needle can be very sensitive to small magnetic fields. Because it is a small magnet, a compass usually has one north end (marked N) and one south end (marked S). ● **SEE FIGURE 11–4.**

MAGNETIC INDUCTION If a piece of iron or steel is placed in a magnetic field, it will also become magnetized. This process of creating a magnet by using a magnetic field is called **magnetic induction.**

> **TECH TIP**
>
> **Magnetize a Steel Needle**
>
> A piece of steel can be magnetized by rubbing a magnet in one direction along the steel. This causes the atoms to line up in the steel, so it acts like a magnet. The steel often will not remain magnetized, whereas the true magnet is permanently magnetized.
>
> When soft iron or steel is used, such as a paper clip, it will lose its magnetism quickly. The atoms in a magnetized needle can be disturbed by heating it or by dropping the needle on a hard object, which would cause the needle to lose its magnetism. Soft iron is used inside ignition coils because it will not keep its magnetism.

If the metal is then removed from the magnetic field, and it retains some magnetism, this is called **residual magnetism.**

ATTRACTING OR REPELLING The poles of a magnet are called north (N) and south (S) because, when a magnet is suspended freely, the poles tend to point toward the earth's North Pole and South Pole. Magnetic flux lines exit from the north pole and bend around to enter the south pole. An equal number of lines exit and enter, so magnetic force is equal at both poles of a magnet. Flux lines are concentrated at the poles, and therefore magnetic force (flux density) is stronger at the ends.

Magnetic poles behave like positively and negatively charged particles. When unlike poles are placed close together, the lines exit from one magnet and enter the other. The two magnets are pulled together by flux lines. If like poles are placed close together, the curving flux lines meet head on, forcing the magnets apart. Therefore, like poles of a magnet repel and unlike poles attract. ● SEE FIGURE 11–5.

PERMEABILITY Magnetic flux lines cannot be insulated. There is no known material through which magnetic force does not pass, if the force is strong enough. However, some materials allow the force to pass through more easily than others. This degree of passage is called **permeability.** Iron allows magnetic flux lines to pass through much more easily than air, so iron is highly permeable.

An example of this characteristic is the use of a reluctor wheel in magnetic-type camshaft position (CMP) and crankshaft position (CKP) sensors. The teeth on a reluctor cause the magnetic field to increase as each tooth gets closer to the sensor and decrease as the tooth moves away, thus creating an AC voltage signal. ● SEE FIGURE 11–6.

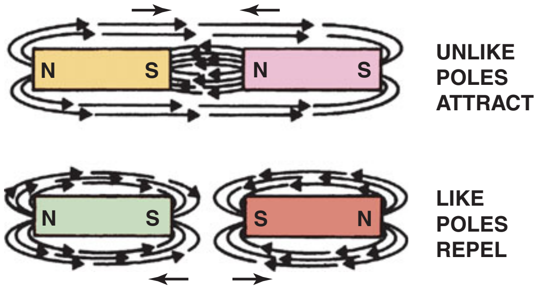


FIGURE 11–5 Magnetic poles behave like electrically charged particles—unlike poles attract and like poles repel.

RELUCTANCE Although there is no absolute insulation for magnetism, certain materials resist the passage of magnetic force. This can be compared to resistance without an electrical circuit. Air does not allow easy passage, so air has a high **reluctance.** Magnetic flux lines tend to concentrate in permeable materials and avoid materials with high reluctance. As with electricity, magnetic force follows the path of least resistance.

ELECTROMAGNETISM

DEFINITION Scientists did not discover that current-carrying conductors also are surrounded by a magnetic field until 1820. These fields may be made many times stronger than those surrounding conventional magnets. Also, the magnetic field strength around a conductor may be controlled by changing the current.

- As current increases, more flux lines are created and the magnetic field expands.
- As current decreases, the magnetic field contracts. The magnetic field collapses when the current is shut off.
- The interaction and relationship between magnetism and electricity is known as **electromagnetism.**

CREATING AN ELECTROMAGNET An easy way to create an electromagnet is to wrap a nail with 20 turns of insulated wire and connect the ends to the terminals of a 1.5 volt dry cell battery. When energized, the nail will become a magnet and will be able to pick up tacks or other small steel objects.

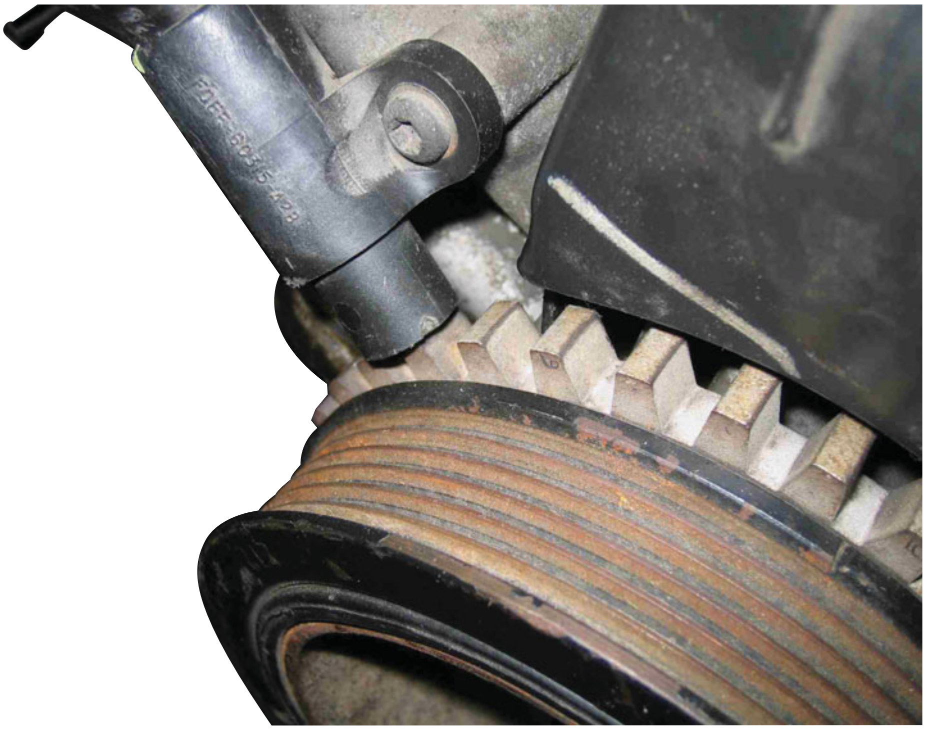


FIGURE 11–6 A crankshaft position sensor and reluctor (notched wheel).

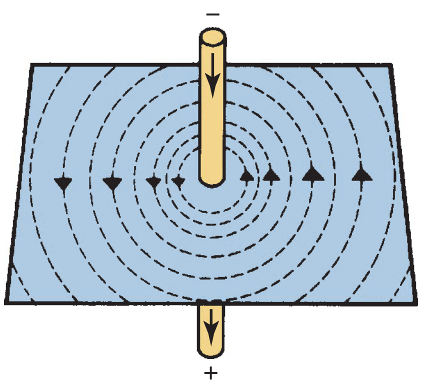


FIGURE 11–7 A magnetic field surrounds a straight, current-carrying conductor.

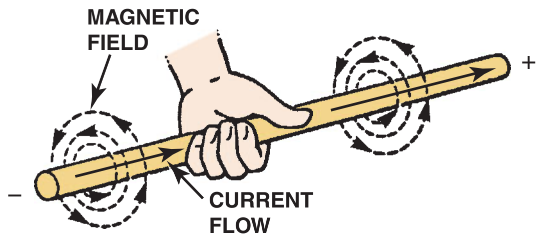


FIGURE 11–8 The left-hand rule for magnetic field direction is used with the electron flow theory.

FIGURE 11–9 The right-hand rule for magnetic field direction is used with the conventional theory of electron flow.

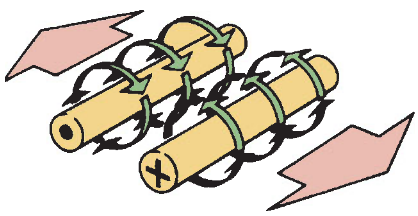


FIGURE 11–10 Conductors with opposing magnetic fields will move apart into weaker fields.

TECH TIP

Electricity and Magnetism

Electricity and magnetism are closely related because any electrical current flowing through a conductor creates a magnetic field. Any conductor moving through a magnetic field creates an electrical current. This relationship can be summarized as follows:

- Electricity creates magnetism.
- Magnetism creates electricity.

From a service technician's point of view, this relationship is important because wires carrying current should always be routed as the factory intended to avoid causing interference with another circuit or electronic component. This is especially important when installing or servicing spark plug wires, which carry high voltages and can cause high electromagnetic interference.

STRAIGHT CONDUCTOR The magnetic field surrounding a straight, current-carrying conductor consists of several concentric cylinders of flux that are the length of the wire. The amount of current flow (amperes) determines how many flux lines (cylinders) there will be and how far out they extend from the surface of the wire. ● **SEE FIGURE 11–7.**

LEFT-HAND AND RIGHT-HAND RULES Magnetic flux cylinders have direction, just as the flux lines surrounding a bar magnet have direction. The **left-hand rule** is a simple way to determine this direction. When you grasp a conductor with your left hand so that your thumb points in the direction of electron flow (− to +) through the conductor, your fingers curl around the wire in the direction of the magnetic flux lines. ● **SEE FIGURE 11–8.**

Most automotive circuits use the conventional theory of current (+ to −) and, therefore, the **right-hand rule** is used to determine the direction of the magnetic flux lines. ● **SEE FIGURE 11–9.**

FIELD INTERACTION The cylinders of flux surrounding current-carrying conductors interact with other magnetic fields. In the following illustrations, the cross symbol (+) indicates current moving inward, or away from you. It represents the tail of an arrow. The dot symbol (•) represents an arrowhead and indicates current moving outward. If two conductors carry current in opposite directions, their magnetic fields also carry current in opposite directions (according to the left-hand rule). If they are placed side by side, then the opposing flux lines between the conductors create a strong magnetic field. Current-carrying conductors tend to move out of a strong field into a weak field, so the conductors move away from each other. ● **SEE FIGURE 11–10.**

If the two conductors carry current in the same direction, then their fields are in the same direction. The flux lines between the two conductors cancel each other out, leaving a very weak field between them. The conductors are drawn into this weak field, and they tend to move toward each other.

MOTOR PRINCIPLE Electric motors, such as vehicle starter motors, use this magnetic field interaction to convert electrical energy into mechanical energy. If two conductors carrying current in opposite directions are placed between strong north and south poles, the magnetic field of the conductor interacts with the magnetic fields of the poles. The counterclockwise field of

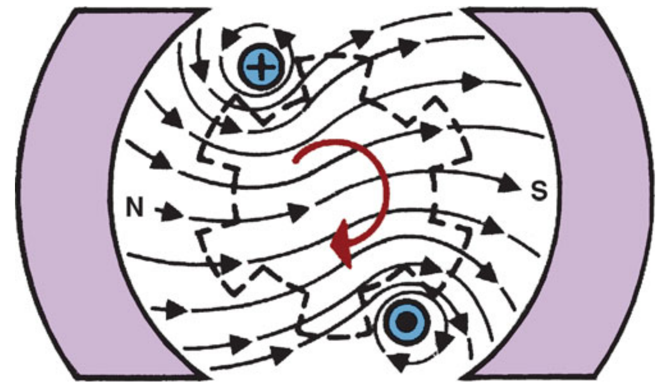


FIGURE 11–11 Electric motors use the interaction of magnetic fields to produce mechanical energy.

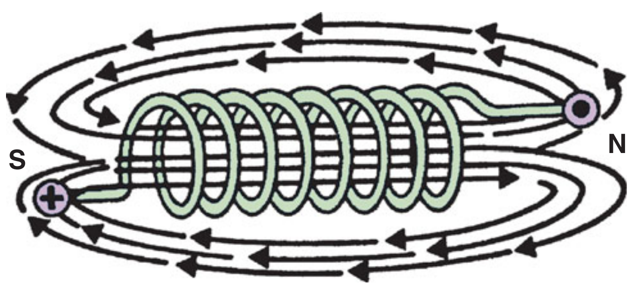


FIGURE 11–12 The magnetic lines of flux surrounding a coil look similar to those surrounding a bar magnet.

the top conductor adds to the fields of the poles and creates a strong field beneath the conductor. The conductor then tries to move up to get out of this strong field. The clockwise field of the lower conductor adds to the field of the poles and creates a strong field above the conductor. The conductor then tries to move down to get out of this strong field. These forces cause the center of the motor, where the conductors are mounted, to turn clockwise. ● **SEE FIGURE 11–11.**

COIL CONDUCTOR If several loops of wire are made into a coil, then the magnetic flux density is strengthened. Flux lines around a coil are the same as the flux lines around a bar magnet. ● **SEE FIGURE 11–12.**

They exit from the north pole and enter at the south pole. Use the left-hand rule to determine the north pole of a coil, as shown in ● **FIGURE 11–13.**

Grasp the coil with your left hand so that your fingers point in the direction of electron flow; your thumb will point toward the north pole of the coil.

ELECTROMAGNETIC STRENGTH The magnetic field surrounding a current-carrying conductor can be strengthened (increased) three ways.

- Place a soft iron core in the center of the coil.
- Increase the number of turns of wire in the coil.
- Increase the current flow through the coil windings.

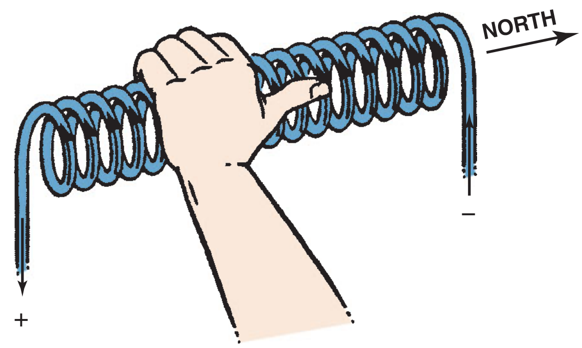


FIGURE 11–13 The left-hand rule for coils is shown.

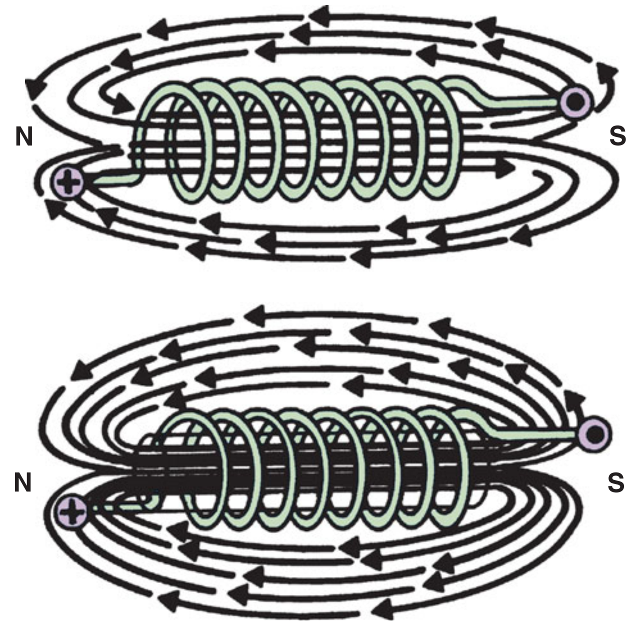


FIGURE 11–14 An iron core concentrates the magnetic lines of force surrounding a coil.

Because soft iron is highly permeable, magnetic flux lines pass through it easily. If a piece of soft iron is placed inside a coiled conductor, the flux lines concentrate in the iron core, rather than pass through the air, which is less permeable. The concentration of force greatly increases the strength of the magnetic field inside the coil. Increasing the number of turns in a coil and/or increasing the current flow through the coil results in greater field strength and is proportional to the number of turns. The magnetic field strength is often expressed in the units called **ampere-turns.** Coils with an iron core are called **electromagnets.** ● **SEE FIGURE 11–14.**

USES OF ELECTROMAGNETISM

RELAYS As mentioned in the previous chapter, a **relay** is a control device that allows a small amount of current to control a large amount of current in another circuit. A simple relay

	CONSTRUCTION	AMPERAGE RATING	USES	CALLED IN SERVICE INFORMATION
Relay	Uses a movable arm Coil: 60 to 100 ohms requiring 0.12 to 0.20 A to energize	1 to 30 A	Lower current switching, lower cost, more commonly used	Electromagnetic switch or relay
Solenoid	Uses a movable core Coil(s): 0.2 to 0.6 ohm requiring 20 to 60 A to energize	30 to 400 A	Higher cost, used in starter motor circuits and other high-amperage applications	Solenoid, relay or electromagnetic switch

CHART 11–1

Comparison between a relay and a solenoid.

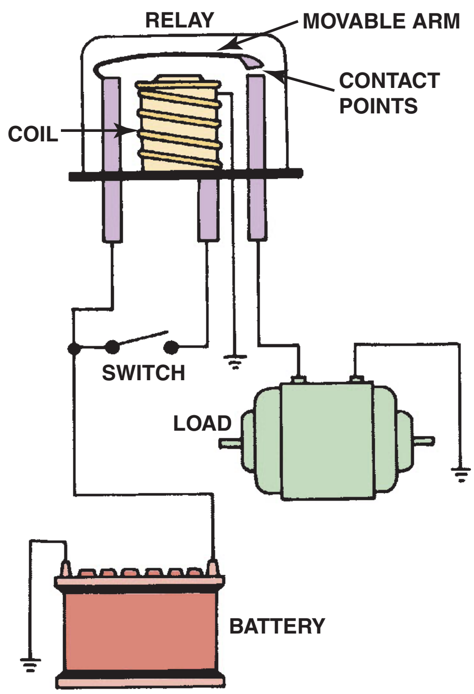


FIGURE 11–15 An electromagnetic switch that has a movable arm is referred to as a relay.

? FREQUENTLY ASKED QUESTION

Solenoid or Relay?

Often, either term is used to describe the same part in service information. ● **SEE CHART 11–1** for a summary of the differences.

contains an electromagnetic coil in series with a battery and a switch. Near the electromagnet is a movable flat arm, called an *armature*, of some material that is attracted by a magnetic field. ● **SEE FIGURE 11–15.**

The armature pivots at one end and is held a small distance away from the electromagnet by a spring (or by the spring steel of the movable arm itself). A contact point, made of a good conductor, is attached to the free end of the armature. Another contact point is fixed a small distance away. The two contact points are wired in series with an electrical load and the battery.

When the switch is closed, the following occurs.

1. Current travels from the battery through a coil, creating an electromagnet.
2. The magnetic field created by the current attracts the armature, pulling it down until the contact points close.
3. Closing the contacts allows current in the heavy current circuit from the battery to the load.

When the switch is open, the following occurs.

1. The electromagnet loses its magnetism when the current is shut off.
2. Spring pressure lifts the arm back up.
3. The heavy current circuit is broken by the opening of the contact points.

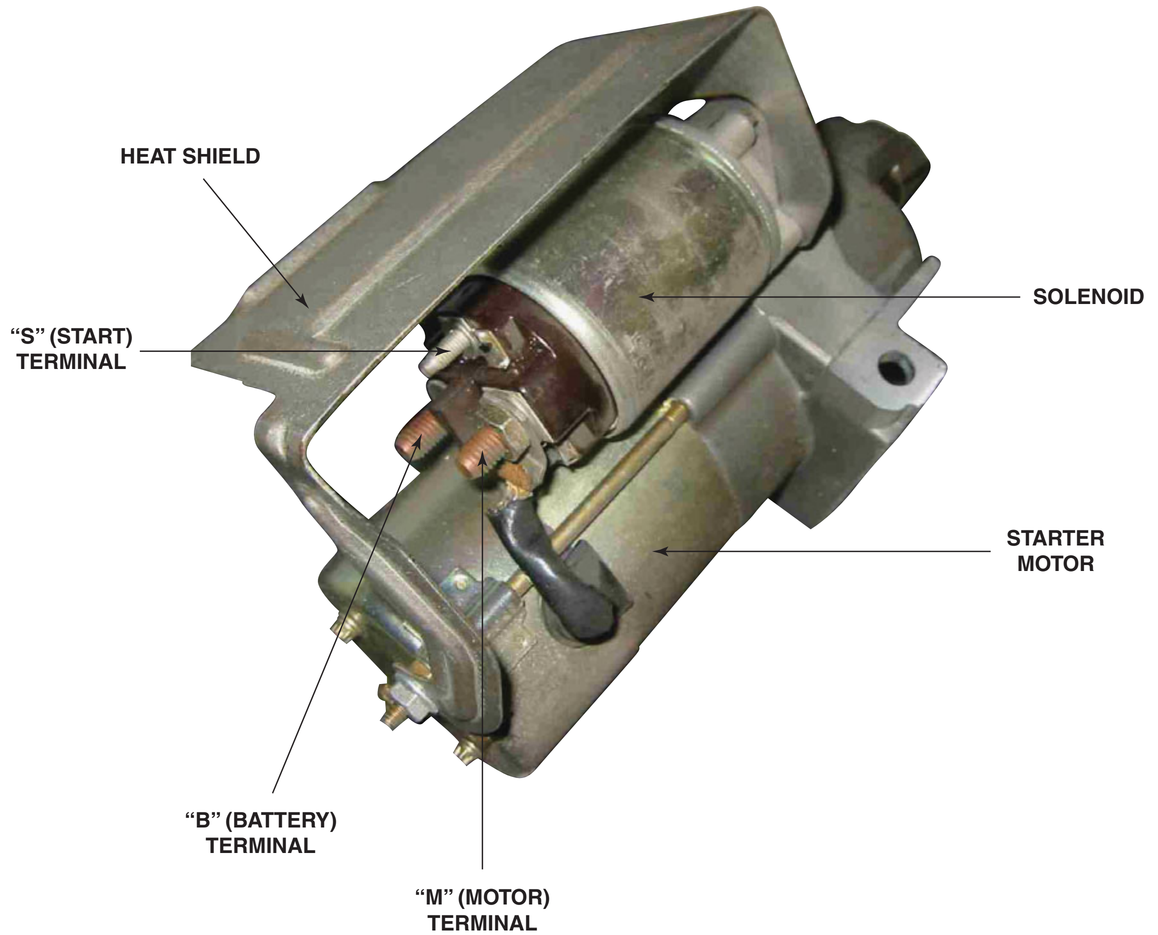
Relays also may be designed with normally closed contacts that open when current passes through the electromagnetic coil.

SOLENOID A solenoid is an example of an electromagnetic switch. A solenoid uses a movable core rather than a movable arm and is generally used in higher-amperage applications. A solenoid can be a separate unit or attached to a starter such as a starter solenoid. ● **SEE FIGURE 11–16.**

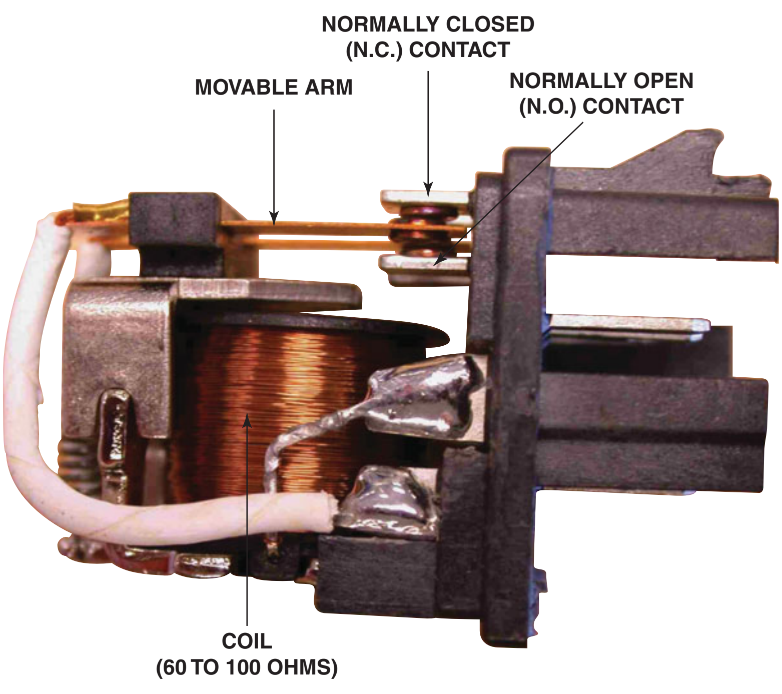
ELECTROMAGNETIC INDUCTION

PRINCIPLES INVOLVED Electricity can be produced by using the relative movement of an electrical conductor and a magnetic field. There are three items necessary to produce electricity (voltage) from magnetism.

1. Electrical conductor (usually a coil of wire)
2. Magnetic field
3. Movement of either the conductor or the magnetic field



(a)



(b)

FIGURE 11–16 (a) A starter with attached solenoid. All of the current needed by the starter flows through the two large terminals of the solenoid and through the solenoid contacts inside. (b) A relay is designed to carry lower current compared to a solenoid and uses a movable arm.

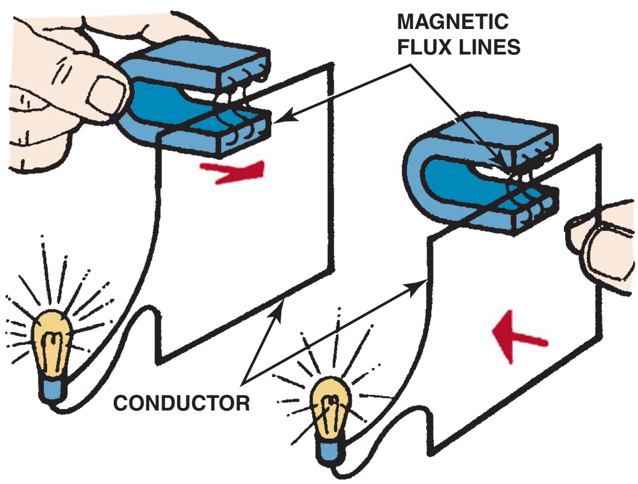


FIGURE 11–17 Voltage can be induced by the relative motion between a conductor and magnetic lines of force.

Therefore:

- Electricity creates magnetism.
- Magnetism can create electricity.

Magnetic flux lines create an electromotive force, or voltage, in a conductor if either the flux lines or the conductor is moving. This movement is called *relative motion*. This process is called induction, and the resulting electromotive force is called *induced voltage*. This creation of a voltage (electricity) in a conductor by a moving magnetic field is called **electromagnetic induction.** ● **SEE FIGURE 11–17.**

VOLTAGE INTENSITY

Voltage is induced when a conductor cuts across magnetic flux lines. The amount of the voltage depends on the rate at which the flux lines are broken. The more flux lines that are broken per unit of time, the greater the induced voltage. If a single conductor breaks 1 million flux lines per second, 1 volt is induced.

There are four ways to increase induced voltage.

- Increase the strength of the magnetic field, so there are more flux lines.
- Increase the number of conductors that are breaking the flux lines.
- Increase the speed of the relative motion between the conductor and the flux lines so that more lines are broken per time unit.
- Increase the angle between the flux lines and the conductor to a maximum of 90 degrees. There is no voltage induced if the conductors move parallel to, and do not break, any flux lines.

Maximum voltage is induced if the conductors break flux lines at 90 degrees. Induced voltage varies proportionately at angles between 0 and 90 degrees. ● **SEE FIGURE 11–18.**

Voltage can be electromagnetically induced and can be measured. Induced voltage creates current. The direction of induced voltage (and the direction in which current moves) is called *polarity* and depends upon the direction of the flux lines, as well as the direction of relative motion.

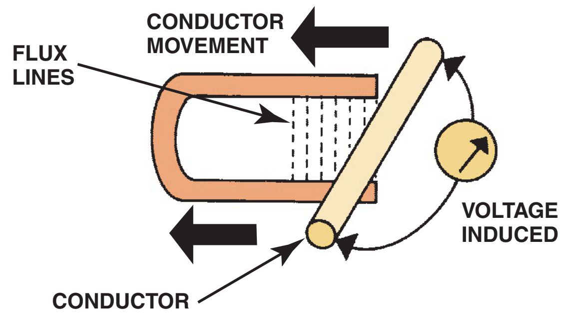


FIGURE 11–18 Maximum voltage is induced when conductors cut across the magnetic lines of force (flux lines) at a 90-degree angle.

LENZ'S LAW

An induced current moves so that its magnetic field opposes the motion that induced the current. This principle is called **Lenz's law.** The relative motion of a conductor and a magnetic field is opposed by the magnetic field of the current it has induced.

SELF-INDUCTION

When current begins to flow in a coil, the flux lines expand as the magnetic field forms and strengthens. As current increases, the flux lines continue to expand, cutting across the wires of the coil and actually inducing another voltage within the same coil. Following Lenz's law, this self-induced voltage tends to *oppose* the current that produces it. If the current continues to increase, the second voltage opposes the increase. When the current stabilizes, the countervoltage is no longer induced because there are no more expanding flux lines (no relative motion). When current to the coil is shut off, the collapsing magnetic flux lines self-induce a voltage in the coil that tries to maintain the original current. The self-induced voltage *opposes* and *slows* the *decrease* in the original current. The self-induced voltage that opposes changes in current flow is an inductor called **counter electromotive force (CEMF).**

MUTUAL INDUCTION

When two coils are close together, energy may be transferred from one to the other by magnetic coupling called mutual induction. **Mutual induction** means that the expansion or collapse of the magnetic field around one coil induces a voltage in the second coil.

IGNITION COILS

IGNITION COIL WINDINGS

Ignition coils use two windings and are wound on the same iron core.

- One coil winding is connected to a battery through a switch and is called the *primary winding*.
- The other coil winding is connected to an external circuit and is called the *secondary winding*.

When the switch is open, there is no current in the primary winding. There is no magnetic field and, therefore, no voltage in

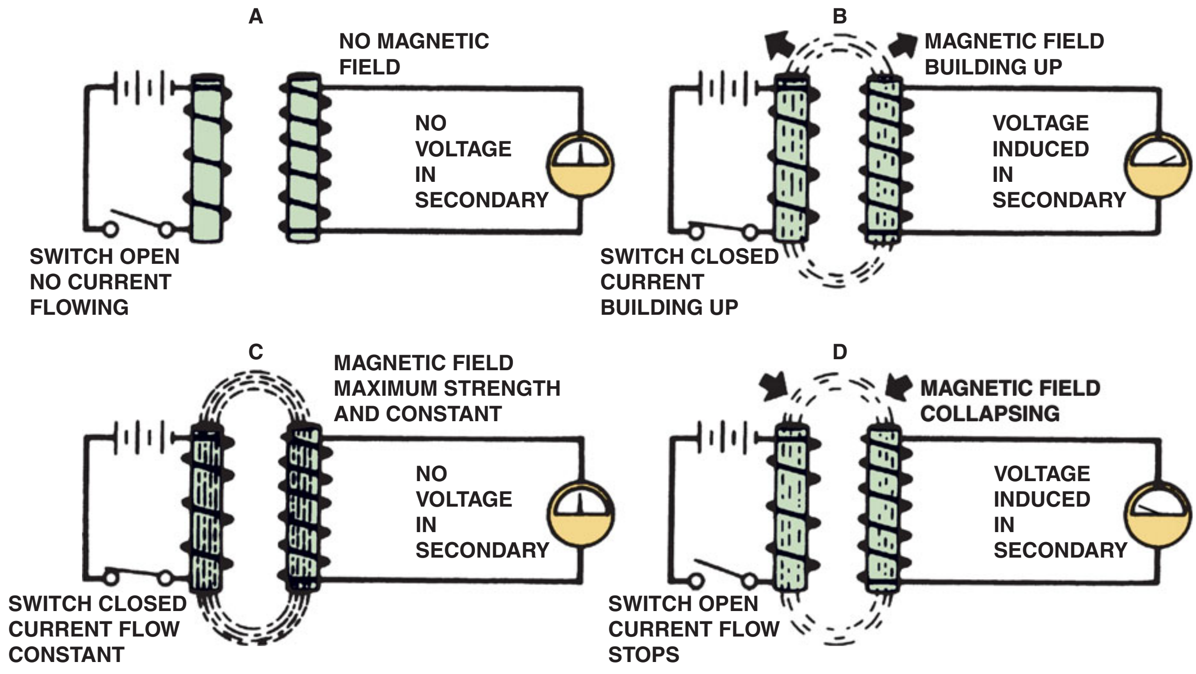


FIGURE 11–19 Mutual induction occurs when the expansion or collapse of a magnetic field around one coil induces a voltage in a second coil.

the secondary winding. When the switch is closed, current is introduced and a magnetic field builds up around both windings. The primary winding thus changes electrical energy from the battery into magnetic energy of the expanding field. As the field expands, it cuts across the secondary winding and induces a voltage in it. A meter connected to the secondary circuit shows current. ● **SEE FIGURE 11–19.**

When the magnetic field has expanded to its full strength, it remains steady as long as the same amount of current exists. The flux lines have stopped their cutting action. There is no relative motion and no voltage in the secondary winding, as shown on the meter.

When the switch is opened, primary current stops and the field collapses. As it does, flux lines cut across the secondary winding but in the opposite direction. This induces a secondary voltage with current in the opposite direction, as shown on the meter.

Mutual induction is used in ignition coils. In an ignition coil, low-voltage primary current induces a very high secondary voltage because of the different number of turns in the primary and secondary windings. Because the voltage is increased, an ignition coil is also called a *step-up transformer*.

- **Electrically connected windings.** Many ignition coils contain two separate but electrically connected windings of copper wire. This type of coil is called a "married" type and is used in older distributor-type ignition systems and in many coil-on-plug (COP) designs.
- **Electrically insulated windings.** Other coils are true transformers in which the primary and secondary windings are not electrically connected. This type of coil is often called a "divorced" type and is used in all waste-spark-type ignition systems. ● **SEE FIGURE 11–20.**

IGNITION COIL CONSTRUCTION The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil. Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge). These windings are called the secondary coil windings. Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge). These windings are called the primary coil windings. The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio** (approximately 100:1). In many coils, these windings are surrounded with a thin metal shield and insulating paper, and placed into a metal container. The metal container and shield help retain the magnetic field produced in the coil windings. The primary and secondary windings produce heat because of the electrical resistance in the turns of wire. Many coils contain oil to help cool the ignition coil. Other coil designs include the following:

- **Air-cooled, epoxy-sealed E coil.** The *E coil* is so named because the laminated, soft iron core is E shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. ● **SEE FIGURE 11–21.**
- **Spool design.** Used mostly for coil-on plug design, the coil windings are wrapped around a nylon or plastic spool or bobbin. ● **SEE FIGURE 11–22.**

IGNITION COIL OPERATION The negative terminal is attached to an **ignition control module (ICM,** or **igniter)**, which opens and closes the primary ignition circuit by opening or

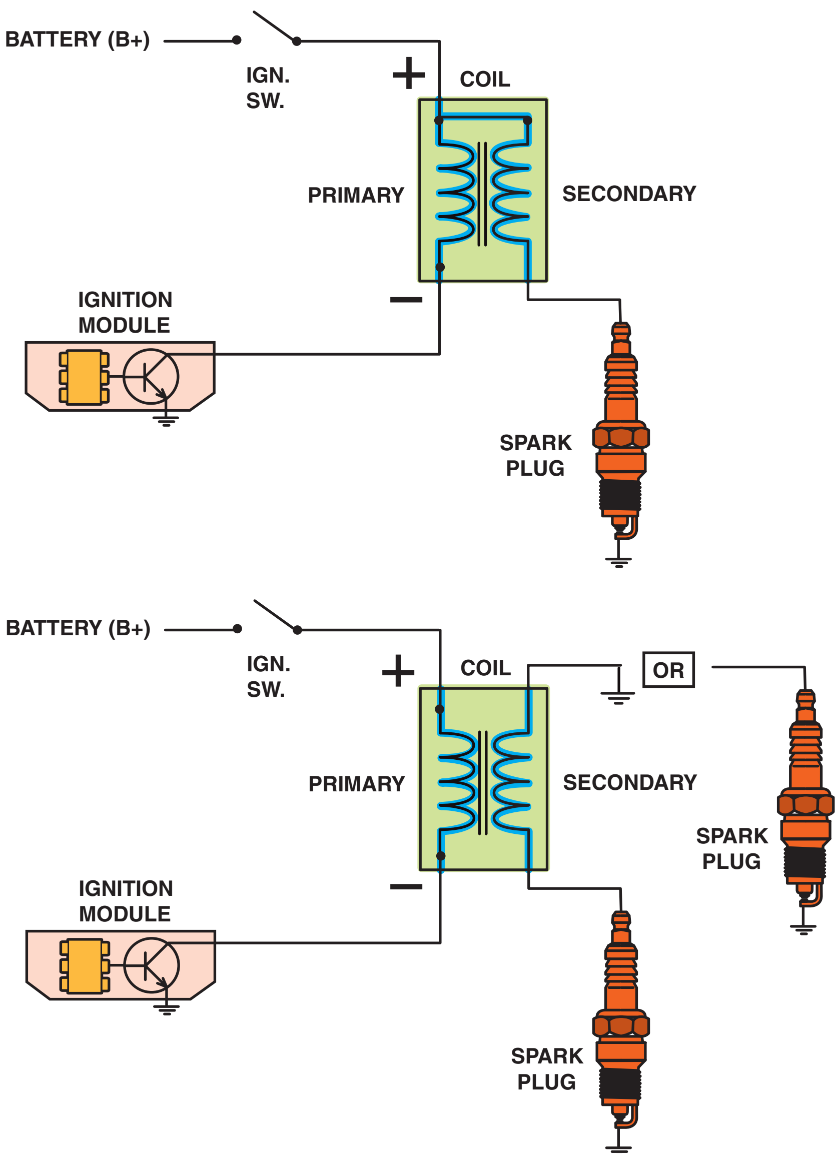


FIGURE 11–20 Some ignition coils are electrically connected, called married (top figure) whereas others use separated primary and secondary windings, called divorced (lower figure).

closing the ground return path of the circuit. When the ignition switch is on, voltage should be available at *both* the positive terminal and the negative terminal of the coil if the primary windings of the coil have continuity.

A spark is created by the following sequence of events.

- A magnetic field is created in the primary winding of the coil when there is 12 volts applied to the primary coil winding and the ignition control module grounds the other end on the coil.
- When the ignition control module (or powertrain control module) opens the ground circuit, the stored magnetic field collapses and creates a high voltage (up to 40,000 volts or more) in the secondary winding.
- The high-voltage pulse then flows to the spark plug and creates a spark at the ground electrode inside the engine that ignites the air-fuel mixture inside the cylinder.

ELECTROMAGNETIC INTERFERENCE

DEFINITION Until the advent of the onboard computer, **electromagnetic interference (EMI)** was not a source of real concern to automotive engineers. The problem was mainly one of *radio-frequency interference (RFI)*, caused primarily by the use of secondary ignition cables. Using spark plug wires that contained a high-resistance, nonmetallic core made of carbon, linen, or fiberglass strands impregnated with graphite mostly solved RFI from the secondary ignition system. RFI is a part of electromagnetic interference, which deals with interference that affects radio reception. All electronic devices used in vehicles are affected by EMI/RFI.

FIGURE 11–21 A GM waste-spark ignition coil showing the section of laminations that is shaped like the letter *E*. These mild steel laminations improve the efficiency of the coil.

FIGURE 11–22 The coil-on-plug (COP) design typically uses a bobbin-type coil.

HOW EMI IS CREATED Whenever there is current in a conductor, an electromagnetic field is created. When current stops and starts, as in a spark plug cable or a switch that opens and closes, the field strength changes. Each time this happens, it creates an electromagnetic signal wave. If it happens rapidly enough, the resulting high-frequency signal waves, or EMI, interfere with radio and television transmission or with other electronic systems such as those under the hood. This is an undesirable side effect of the phenomenon of electromagnetism.

Static electric charges caused by friction of the tires with the road, or the friction of engine drive belts contacting their pulleys, also produce EMI. Drive axles, driveshafts, and clutch or brake lining surfaces are other sources of static electric charges.

There are four ways of transmitting EMI, all of which can be found in a vehicle.

- Conductive coupling is actual physical contact through circuit conductors.
- Capacitive coupling is the transfer of energy from one circuit to another through an electrostatic field between two conductors.
- Inductive coupling is the transfer of energy from one circuit to another as the magnetic fields between two conductors form and collapse.
- Electromagnetic radiation is the transfer of energy by the use of radio waves from one circuit or component to another.

TECH TIP

Cell Phone Interference

A cellular phone emits a weak signal if it is turned on, even though it is not being used. This signal is picked up and tracked by cell phone towers. When the cell phone is called, it emits a stronger signal to notify the tower that it is on and capable of receiving a phone call. It is this "handshake" signal that can cause interference in the vehicle. Often this signal causes some static in the radio speakers even though the radio is off, but it can also cause a false antilock brake (ABS) trouble code to set. These signals from the cell phone create a voltage that is induced in the wires of the vehicle. Because the cell phone usually leaves with the customer, the service technician is often unable to verify the customer concern.

Remember, the interference occurs right *before* the cell phone rings. To fix the problem, connect an external antenna to the cell phone. This step will prevent the induction of a voltage in the wiring of the vehicle.

EMI SUPPRESSION DEVICES There are four general ways in which EMI is reduced.

- **Resistance suppression.** Adding resistance to a circuit to suppress RFI works only for high-voltage systems. This has been done by the use of resistance spark plug cables,

FIGURE 11–23 To help prevent underhood electromagnetic devices from interfering with the antenna input, it is important that all ground wires, including the one from this power antenna, be properly grounded.

resistor spark plugs, and the silicone grease used on the distributor cap and rotor of some electronic ignitions.

- **Suppression capacitors and coils.** Capacitors are installed across many circuits and switching points to absorb voltage fluctuations. Among other applications, they are used across the following:
  - The primary circuit of some electronic ignition modules
  - The output terminal of most alternators
  - The armature circuit of some electric motors

Coils reduce current fluctuations resulting from self-induction. They are often combined with capacitors to act as EMI filter circuits for windshield wiper and electric fuel pump motors. Filters also may be incorporated in wiring connectors.

- **Shielding.** The circuits of onboard computers are protected to some degree from external electromagnetic waves by their metal housings.
- **Ground wires or straps.** Ground wires or braided straps between the engine and chassis of an automobile help suppress EMI conduction and radiation by providing a low-resistance circuit ground path. Such suppression ground straps are often installed between rubber-mounted components and body parts. On some models, ground straps are installed between body parts, such as between the hood and a fender panel, where no electrical circuit exists. The strap has no other job than to suppress EMI. Without it, the sheet-metal body and hood could function as a large capacitor. The space between the fender and hood could form an electrostatic field and couple with the computer circuits in the wiring harness routed near the fender panel. ● **SEE FIGURE 11–23.**

SUMMARY

1. Most automotive electrical components use magnetism, the strength of which depends on both the amount of current (amperes) and the number of turns of wire of each electromagnet.
2. The strength of electromagnets is increased by using a soft iron core.
3. Voltage can be induced from one circuit to another.
4. Electricity creates magnetism and magnetism creates electricity.
5. Radio-frequency interference (RFI) is a part of electromagnetic interference (EMI).

REVIEW QUESTIONS

1. What is the relationship between electricity and magnetism?
2. What is the difference between mutual induction and self-induction?
3. What is the result if a magnet cracks?
4. How can EMI be reduced or controlled?

CHAPTER QUIZ

1. Technician A says that magnetic lines of force can be seen by placing iron filings on a piece of paper and then holding them over a magnet. Technician B says that the effects of magnetic lines of force can be seen using a compass. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Unlike magnetic poles ________, and like magnetic poles ________.
   a. Repel; attract
   b. Attract; repel
   c. Repel; repel
   d. Attract; attract
3. The conventional theory for current flow is being used to determine the direction of magnetic lines of force. Technician A says that the left-hand rule should be used. Technician B says that the right-hand rule should be used. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that a relay is an electromagnetic switch. Technician B says that a solenoid uses a movable core. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Two technicians are discussing electromagnetic induction. Technician A says that the induced voltage can be increased if the speed is increased between the conductor and the magnetic lines of force. Technician B says that the induced voltage can be increased by increasing the strength of the magnetic field. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. An ignition coil operates using the principle(s) of ________.
   a. Electromagnetic induction
   b. Self-induction
   c. Mutual induction
   d. All of the above
7. Electromagnetic interference can be reduced by using a ________.
   a. Resistance
   b. Capacitor
   c. Coil
   d. All of the above
8. An ignition coil is an example of a ________.
   a. Solenoid
   b. Step-down transformer
   c. Step-up transformer
   d. Relay
9. Magnetic field strength is measured in ________.
   a. Ampere-turns
   b. Flux
   c. Density
   d. Coil strength
10. Two technicians are discussing ignition coils. Technician A says that some ignition coils have the primary and secondary windings electrically connected. Technician B says that some coils have totally separate primary and secondary windings that are not electrically connected. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 12 ELECTRONIC FUNDAMENTALS

OBJECTIVES: After studying Chapter 12, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Identify semiconductor components. • Explain precautions necessary when working with semiconductor circuits. • Discuss where various electronic and semiconductor devices are used in vehicles. • Explain how diodes and transistors work. • Describe how to test diodes and transistors. • List the precautions that a service technician should follow to avoid damage to electronic components from electrostatic discharge.

KEY TERMS: Anode 154 • Base 160 • Bipolar transistor 160 • Burn in 155 • Cathode 154 • CHMSL 159 • Clamping diode 155 • Collector 160 • Control current 161 • Darlington pair 162 • Despiking diode 155 • Diode 153 • Doping 152 • Dual inline pins (DIP) 162 • Emitter 160 • ESD 167 • FET 161 • Forward bias 154 • Gate 163 • Germanium 152 • Heat sink 162 • Holes 153 • Hole theory 153 • Impurities 152 • Integrated circuit (IC) 162 • Inverter 167 • Junction 154 • Light emitting diode (LED) 157 • MOSFET 161 • NPN transistor 160 • NTC 159 • N-type material 152 • Op-amps 164 • Photodiodes 158 • Photons 158 • Photoresistor 158 • Phototransistor 162 • Peak inverse voltage (PIV) 157 • Peak reverse voltage (PRV) 157 • PNP transistor 160 • P-type material 153 • PWM 165 • Rectifier bridge 159 • Reverse bias 154 • SCR 159 • Semiconductors 152 • Silicon 152 • Spike protection resistor 156 • Suppression diode 155 • Thermistor 159 • Threshold voltage 161 • Transistor 160 • Zener diode 155

Electronic components are the heart of computers. Knowing how electronic components work helps take the mystery out of automotive electronics.

SEMICONDUCTORS

DEFINITION Semiconductors are neither conductors nor insulators. The flow of electrical current is caused by the movement of electrons in materials, known as conductors having *fewer* than four electrons in their atom's outer orbit. Insulators contain *more* than four electrons in their outer orbit and cannot conduct electricity because their atomic structure is stable (no free electrons).

Semiconductors are materials that contain exactly four electrons in the outer orbit of their atom structure and are, therefore, neither good conductors nor good insulators.

EXAMPLES OF SEMICONDUCTORS Two examples of semiconductor materials are **germanium** and **silicon,** which have exactly four electrons in their valance ring and no free electrons to provide current flow. However, both of these semiconductor materials can be made to conduct current if another material is added to provide the necessary conditions for electron movement.

CONSTRUCTION When another material is added to a semiconductor material in very small amounts, it is called **doping.** The doping elements are called **impurities;** therefore, after their addition, the germanium and silicon are no longer considered *pure* elements. The material added to pure silicon or germanium to make it electrically conductive represents only one atom of impurity for every *100 million* atoms of the pure semiconductor material. The resulting atoms are still electrically *neutral,* because the number of electrons still equals the number of protons of the combined materials. These combined materials are classified into two groups depending on the number of electrons in the bonding between the two materials.

- N-type materials
- P-type materials

N-TYPE MATERIAL **N-type material** is silicon or germanium that is doped with an element such as *phosphorus*, *arsenic*, or *antimony*, each having five electrons in its outer orbit. These five electrons are combined with the four electrons of the silicon or germanium to total nine electrons. There is room for only eight electrons in the bonding between the semiconductor material and the doping material. This leaves extra electrons, and even though the material is still electrically neutral, these extra electrons tend to repel other electrons outside the material. ● **SEE FIGURE 12–1.**

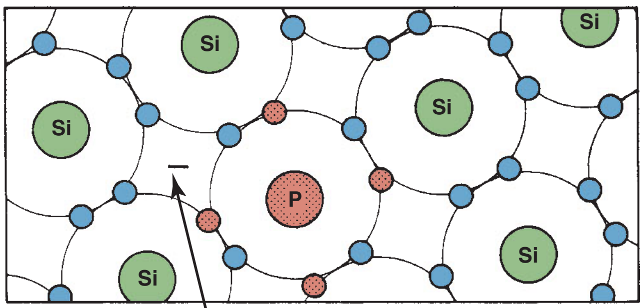


FIGURE 12–1 N-type material. Silicon (Si) doped with a material (such as phosphorus) with five electrons in the outer orbit results in an extra free electron.

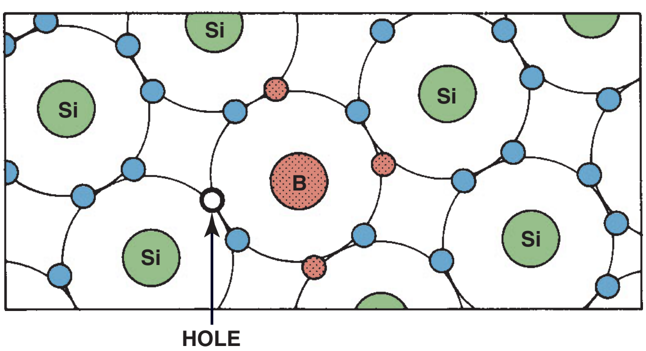


FIGURE 12–2 P-type material. Silicon (Si) doped with a material, such as boron (B), with three electrons in the outer orbit results in a hole capable of attracting an electron.

P-TYPE MATERIAL **P-type material** is produced by doping silicon or germanium with the element *boron* or the element *indium*. These impurities have only three electrons in their outer shell and, when combined with the semiconductor material, result in a material with seven electrons, one electron *less* than is required for atom bonding. This lack of one electron makes the material able to attract electrons, even though the material still has a neutral charge. This material tends to attract electrons to fill the **holes** for the missing eighth electron in the bonding of the materials. ● **SEE FIGURE 12–2.**

SUMMARY OF SEMICONDUCTORS

The following is a summary of semiconductor fundamentals.

1. The two types of semiconductor materials are P type and N type. N-type material contains extra electrons; P-type material contains holes due to missing electrons. The number of excess electrons in an N-type material must remain constant, and the number of holes in the P-type material must also remain constant. Because electrons are interchangeable, movement of electrons in or out of the material is possible to maintain a balanced material.
2. In P-type semiconductors, electrical conduction occurs mainly as the result of holes (absence of electrons). In N-type semiconductors, electrical conduction occurs mainly as the result of electrons (excess of electrons).
3. Hole movement results from the jumping of electrons into new positions.
4. Under the effect of a voltage applied to the semiconductor, electrons travel toward the positive terminal and holes move toward the negative terminal. The direction of hole current agrees with the conventional direction of current flow.

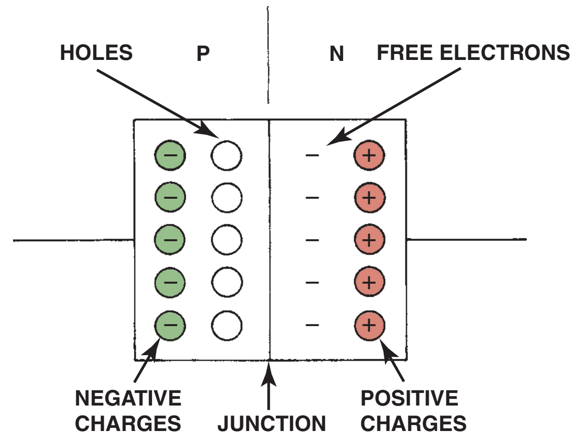


FIGURE 12–3 Unlike charges attract and the current carriers (electrons and holes) move toward the junction.

FREQUENTLY ASKED QUESTION

What Is the Hole Theory?

Current flow is expressed as the movement of electrons from one atom to another. In semiconductor and electronic terms, the movement of electrons fills the holes of the P-type material. Therefore, as the holes are filled with electrons, the unfilled holes move opposite to the flow of the electrons. This concept of hole movement is called the **hole theory** of current flow. The holes move in the direction opposite that of electron flow. For example, think of an egg carton, where if an egg is moved in one direction, the holes created move in the opposite direction. ● **SEE FIGURE 12–3.**

DIODES

CONSTRUCTION A **diode** is an electrical one-way check valve made by combining a P-type material and an N-type material. The word *diode* means “having two electrodes.” Electrodes

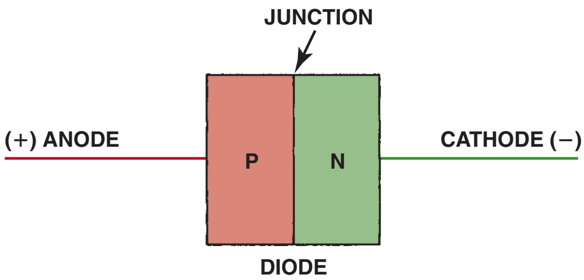


FIGURE 12–4 A diode is a component with P-type and N-type materials together. The negative electrode is called the cathode and the positive electrode is called the anode.

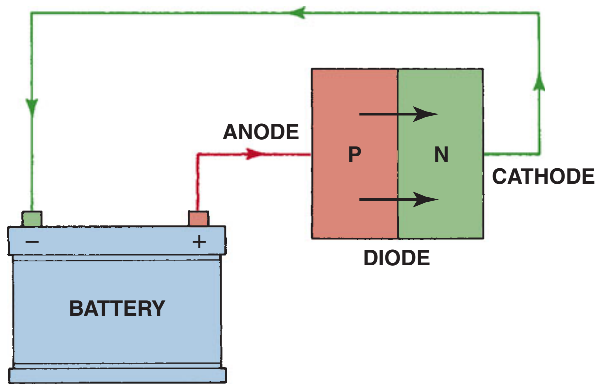


FIGURE 12–5 Diode connected to a battery with correct polarity (battery positive to P type and battery negative to N-type). Current flows through the diode. This condition is called forward bias.

are electrical connections: The positive electrode is called the **anode;** the negative electrode is called the **cathode.** The point where the two types of materials join is called the **junction.** ● **SEE FIGURE 12–4.**

OPERATION The N-type material has one extra electron, which can flow into the P-type material. The P type has a need for electrons to fill its holes. If a battery were connected to the diode positive (+) to P-type material and negative (−) to N-type material, then the electrons that left the N-type material and flowed into the P-type material to fill the holes would be quickly replaced by the electron flow from the battery. Current flows through a forward-bias diode for the following reasons.

- Electrons move toward the holes (P-type material).
- Holes move toward the electrons (N-type material). ● **SEE FIGURE 12–5.**

As a result, current would flow through the diode with low resistance. This condition is called **forward bias.**

If the battery connections were reversed and the positive side of the battery was connected to the N-type material, the electrons would be pulled toward the battery and away from the junction of the N-type and P-type materials. (Remember, unlike charges attract, whereas like charges repel.) Because electrical conduction requires the flow of electrons across the junction of the N-type and P-type materials and because the battery connections are actually reversed, the diode offers very high resistance to current flow. This condition is called **reverse bias.** ● **SEE FIGURE 12–6.**

Therefore, diodes allow current flow only when current of the correct polarity is connected to the circuit.

- Diodes are used in alternators to control current flow in one direction, which changes the AC voltage generated into DC voltage.
- Diodes are also used in computer controls, relays, air-conditioning circuits, and many other circuits to prevent possible damage due to reverse current flows that may be generated within the circuit. ● **SEE FIGURE 12–7.**

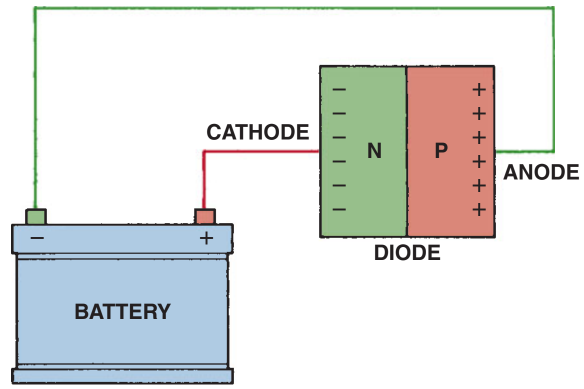


FIGURE 12–6 Diode connected with reversed polarity. No current flows across the junction between the P-type and N-type materials. This connection is called reverse bias.

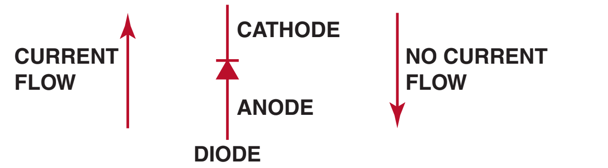


FIGURE 12–7 Diode symbol and electrode names. The stripe on one end of a diode represents the cathode end of the diode.

FREQUENTLY ASKED QUESTION

What Is the Difference Between Electricity and Electronics?

Electronics usually means that solid-state devices are used in the electrical circuits. Electricity as used in automotive applications usually means electrical current flow through resistance and loads without the use of diodes, transistors, or other electronic devices.

TECH TIP

"Burn In" to Be Sure

A common term heard in the electronic and computer industry is **burn in,** which means to operate an electronic device, such as a computer, for a period from several hours to several days.

Most electronic devices fail in infancy, or during the first few hours of operation. This early failure occurs if there is a manufacturing defect, especially at the P-N junction of any semiconductor device. The junction will usually fail after only a few operating cycles.

What does this information mean to the average person? When purchasing a personal or business computer, have the computer burned in before delivery. This step helps ensure that all of the circuits have survived infancy and that the chances of chip failure are greatly reduced. Purchasing sound or television equipment that has been on display may be a good value, because during its operation as a display model, the burn-in process has been completed. The automotive service technician should be aware that if a replacement electronic device fails shortly after installation, the problem may be a case of early electronic failure.

NOTE: Whenever there is a failure of a replacement part, the technician should always check for excessive voltage or heat to and around the problem component.

FIGURE 12–8 A zener diode blocks current flow until a certain voltage is reached, then it permits current to flow.

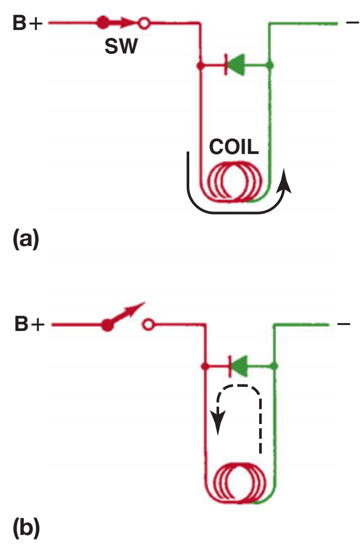


FIGURE 12–9 (a) Notice that when the coil is being energized, the diode is reverse biased and the current is blocked from passing through the diode. The current flows through the coil in the normal direction. (b) When the switch is opened, the magnetic field surrounding the coil collapses, producing a high-voltage surge in the reverse polarity of the applied voltage. This voltage surge forward biases the diode, and the surge is dissipated harmlessly back through the windings of the coil.

ZENER DIODES

CONSTRUCTION A **zener diode** is a specially constructed diode designed to operate with a reverse-bias current. Zener diodes were named in 1934 for their inventor, Clarence Melvin Zener, an American professor of physics.

OPERATION A zener diode acts as any diode in that it blocks reverse-bias current, but only up to a certain voltage. Above this certain voltage (called the *breakdown voltage* or the zener region), a zener diode will conduct current in the opposite direction without damage to the diode. A zener diode is heavily doped, and the reverse-bias voltage does not harm the material. The voltage drop across a zener diode remains practically the same before and after the breakdown voltage, and this factor makes a zener diode perfect for voltage regulation. Zener diodes can be constructed for various breakdown voltages and can be used in a variety of automotive and electronic applications, especially for electronic voltage regulators used in the charging system. ● **SEE FIGURE 12–8.**

HIGH-VOLTAGE SPIKE PROTECTION

CLAMPING DIODES Diodes can be used as a high-voltage clamping device when the power (+) is connected to the cathode (−) of the diode. If a coil is pulsed on and off, a high-voltage spike is produced whenever the coil is turned off. To control and direct this possibly damaging high-voltage spike, a diode can be installed across the leads to the coil to redirect the high-voltage spike back through the coil windings to prevent possible damage to the rest of the vehicle's electrical or electronic circuits. A diode connected across the terminals of a coil to control voltage spikes is called a **clamping diode.** Clamping diodes can also be called **despiking** or **suppression diodes.** ● **SEE FIGURE 12–9.**

CLAMPING DIODE APPLICATION Diodes were first used on A/C compressor clutch coils at the same time electronic devices were first used. The diode was used to help

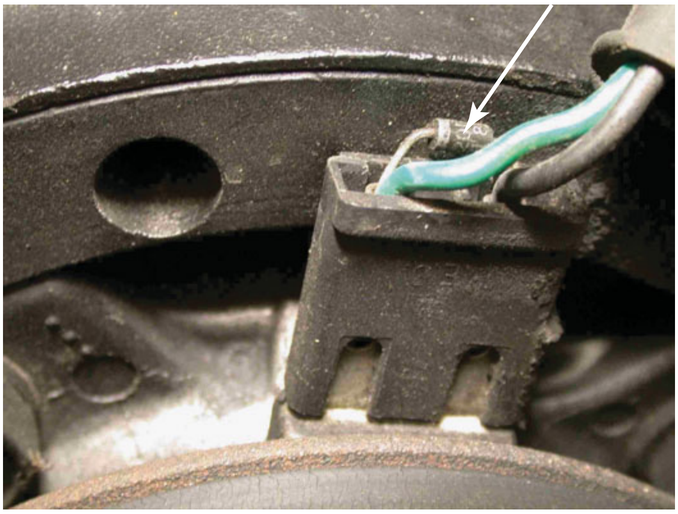


FIGURE 12–10 A diode connected to both terminals of the air-conditioning compressor clutch used to reduce the high-voltage spike that results when a coil (compressor clutch coil) is de-energized.

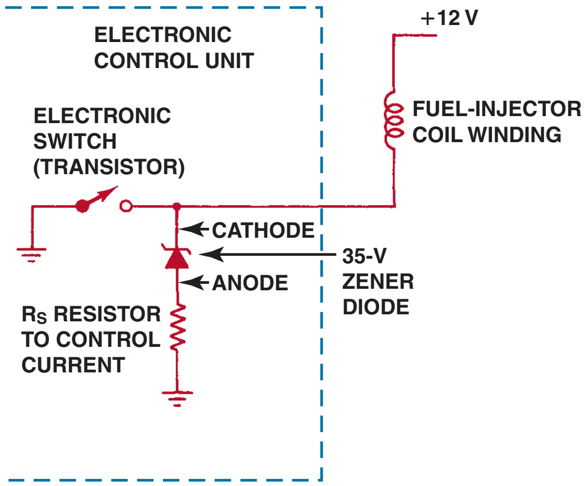


FIGURE 12–12 A zener diode is commonly used inside automotive computers to protect delicate electronic circuits from high-voltage spikes. A 35 volt zener diode will conduct any voltage spike higher than 35 voltage resulting from the discharge of the fuel injector coil safely to ground through a current-limiting resistor in series with the zener diode.

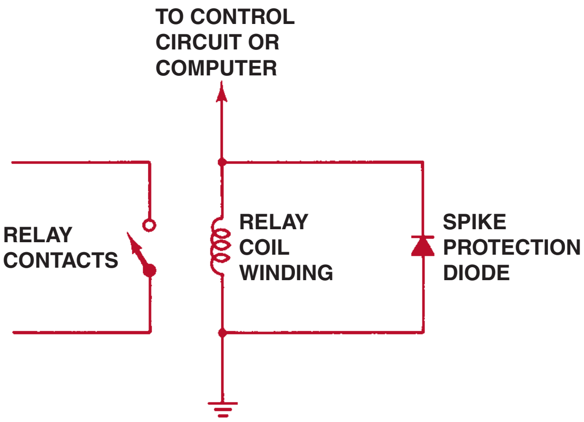


FIGURE 12–11 Spike protection diodes are commonly used in computer-controlled circuits to prevent damaging high-voltage surges that occur any time current flowing through a coil is stopped.

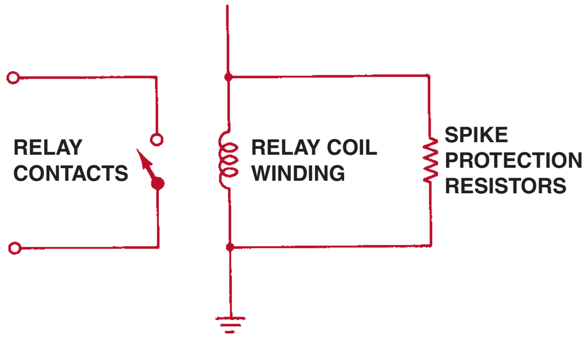


FIGURE 12–13 A despiking resistor is used in many automotive applications to help prevent harmful high-voltage surges from being created when the magnetic field surrounding a coil collapses when the coil circuit is opened.

prevent the high voltage spike generated inside the A/C clutch coil from damaging delicate to delicate electronic circuits anywhere in the vehicle's electrical system. ● **SEE FIGURE 12–10.**

Because most automotive circuits eventually are electrically connected to each other in parallel, a high-voltage surge anywhere in the vehicle could damage electronic components in other circuits.

The circuits most likely to be affected by the high-voltage surge, if the diode fails, are the circuits controlling the operation of the A/C compressor clutch and any component that uses a coil, such as those of the blower motor and climate control units.

Many relays are equipped with a diode to prevent a voltage spike when the contact points open and the magnetic field in the coil winding collapses. ● **SEE FIGURE 12–11.**

DESPIKING ZENER DIODES Zener diodes can also be used to control high-voltage spikes and keep them from damaging delicate electronic circuits. Zener diodes are most commonly used in electronic fuel-injection circuits that control the firing of the injectors. If clamping diodes were used in parallel with the injection coil, the resulting clamping action would tend to delay the closing of the fuel injector nozzle. A zener diode is commonly used to clamp only the higher voltage portion of the resulting voltage spike without affecting the operation of the injector. ● **SEE FIGURE 12–12.**

DESPIKING RESISTORS All coils must use some protection against high-voltage spikes that occur when the voltage is removed from any coil. Instead of a diode installed in parallel with the coil windings, a resistor can be used, called a **spike protection resistor.** ● **SEE FIGURE 12–13.**

Resistors are often preferred for two reasons.

Reason 1	Coils will usually fail when shorted rather than open, as this shorted condition results in greater current flow in the circuit. A diode installed in the reverse-bias direction cannot control this extra current, whereas a resistor in parallel can help reduce potentially damaging current flow if the coil becomes shorted.
Reason 2	The protective diode can also fail, and diodes usually fail by shorting before they blow open. If a diode becomes shorted, excessive current can flow through the coil circuit, perhaps causing damage. A resistor usually fails open and, therefore, even in failure could not in itself cause a problem.

Resistors on coils are often used in relays and in climate-control circuit solenoids to control vacuum to the various air management system doors as well as other electronically controlled applications.

DIODE RATINGS

SPECIFICATIONS Most diodes are rated according to the following:

- Maximum current flow in the forward-bias direction. Diodes are sized and rated according to the amount of current they are designed to handle in the forward-bias direction. This rating is normally from 1 to 5 amperes for most automotive applications.
- This rating of resistance to reverse-bias voltage is called the **peak inverse voltage (PIV)** rating, or the **peak reverse voltage (PRV)** rating. It is important that the service technician specifies and uses only a replacement diode that has the same or a higher rating than specified by the vehicle manufacturer for both amperage and PIV rating. Typical 1 A diodes use an industry numbering code that indicates the PIV rating. For example:

  1N 4001-50 V PIV

  1N 4002-100 V PIV

  1N 4003-200 V PIV (most commonly used)

  1N 4004-400 V PIV

  1N 4005-600 V PIV
- The "1N" means that the diode has one P-N junction. A higher rating diode can be used with no problems (except for slightly higher cost, even though the highest rated diode generally costs less than $1). Never substitute a *lower* rated diode than is specified.

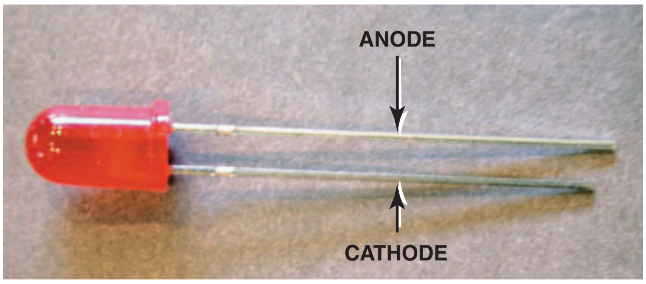


FIGURE 12–14 A typical light-emitting diode (LED). This particular LED is designed with a built-in resistor so that 12 volts DC may be applied directly to the leads without an external resistor. Normally a 300 to 500 ohm, 0.5 watt resistor is required to be attached in series with the LED, to control current flow to about 0.020 A (20 mA) or damage to the P-N junction may occur.

DIODE VOLTAGE DROP The voltage drop across a diode is about the same voltage as that required to forward bias the diode. If the diode is made from germanium, the forward voltage is 0.3 to 0.5 volt. If the diode is made from silicon, the forward voltage is 0.5 to 0.7 volt.

NOTE: When diodes are tested using a digital multimeter, the meter will display the voltage drop across the P-N junction (about 0.5 to 0.7 volt) when the meter is set to the *diode-check* position.

LIGHT-EMITTING DIODES

OPERATION All diodes radiate some energy during normal operation. Most diodes radiate heat because of the junction barrier voltage drop (typically 0.6 volt for silicon diodes). **Light emitting diode (LED)** radiate light when current flows through the diode in the forward-bias direction. ● **SEE FIGURE 12–14.**

The forward-bias voltage required for an LED ranges between 1.5 and 2.2 volts.

An LED will only light if the voltage at the anode (positive electrode) is at least 1.5 to 2.2 volts higher than the voltage at the cathode (negative electrode).

NEED FOR CURRENT LIMITING If an LED were connected across a 12 volt automotive battery, the LED would light brightly, but only for a second or two. Excessive current (amperes) that flows across the P-N junction of any electronic device can destroy the junction. A resistor *must* be connected in series with every diode (including LEDs) to control current flow across the P-N junction. This protection should include the following:

1. The value of the resistor should be from 300 to 500 ohms for each P-N junction. Commonly available resistors in this range include 470, 390, and 330 ohm resistors.
2. The resistors can be connected to either the anode or the cathode end. (Polarity of the resistor does not matter.) Current flows through the LED in series with the resistor, and

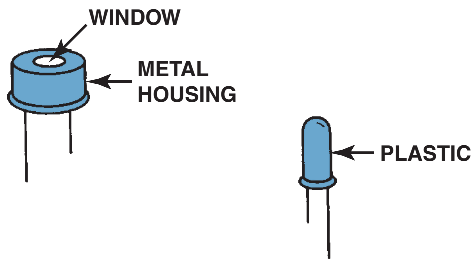


FIGURE 12–15 Typical photodiodes. They are usually built into a plastic housing so that the photodiode itself may not be visible.

FREQUENTLY ASKED QUESTION

How Does an LED Emit Light?

An LED contains a chip that houses P-type and N-type materials. The junction between these regions acts as a barrier to the flow of electrons between the two materials. When a voltage of 1.5 to 2.2 volts of the correct polarity is applied, current will flow across the junction. As the electrons enter the P-type material, it combines with the holes in the material and releases energy in the form of light (called **photons**). The amount and color the light produces depends on materials used in the creation of the semiconductor material.

LEDs are very efficient compared to conventional incandescent bulbs, which depend on heat to create light. LEDs generate very little heat, with most of the energy consumed converted directly to light. LEDs are reliable and are being used for taillights, brake lights, daytime running lights, and headlights in some vehicles.

the resistor will control the current flow through the LED regardless of its position in the circuit.

3. Resistors protecting diodes can be actual resistors or other current-limiting loads such as lamps or coils. With the current-limiting devices to control the current, the average LED will require about 20 to 30 milliamperes (mA), or 0.020 to 0.030 ampere.

PHOTODIODES

PURPOSE AND FUNCTION All semiconductor P-N junctions emit energy, mostly in the form of heat or light such as with an LED. In fact, if an LED is exposed to bright light, a voltage potential is established between the anode and the cathode. **Photodiodes** are specially constructed to respond to various

FIGURE 12–16 Symbol for a photodiode. The arrows represent light striking the P-N junction of the photodiode.

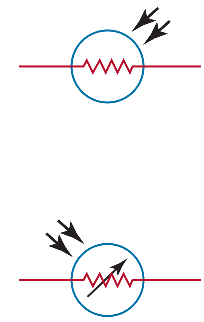


FIGURE 12–17 Either symbol may be used to represent a photoresistor.

wavelengths of light with a "window" built into the housing. ● **SEE FIGURE 12–15.**

Photodiodes are frequently used in steering wheel controls for transmitting tuning, volume, and other information from the steering wheel to the data link and the unit being controlled. If several photodiodes are placed on the steering column end and LEDs or phototransistors are placed on the steering wheel side, then data can be transmitted between the two moving points without the interference that could be caused by physical contact types of units.

CONSTRUCTION A photodiode is sensitive to light. When light energy strikes the diode, electrons are released and the diode will conduct in the forward-bias direction. (The light energy is used to overcome the barrier voltage.)

The resistance across the photodiode decreases as the intensity of the light increases. This characteristic makes the photodiode a useful electronic device for controlling some automotive lighting systems such as automatic headlights. The symbol for a photodiode is shown in ● **FIGURE 12–16.**

PHOTORESISTORS

A **photoresistor** is a semiconductor material (usually cadmium sulfide) that changes resistance with the presence or absence of light.

Dark = High resistance

Light = Low resistance

Because resistance is reduced when the photoresistor is exposed to light, the photoresistor can be used to control headlight dimmer relays and for automotive headlights. ● **SEE FIGURE 12–17.**

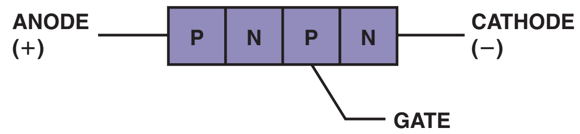


FIGURE 12–18 Symbol and terminal identification of an SCR.

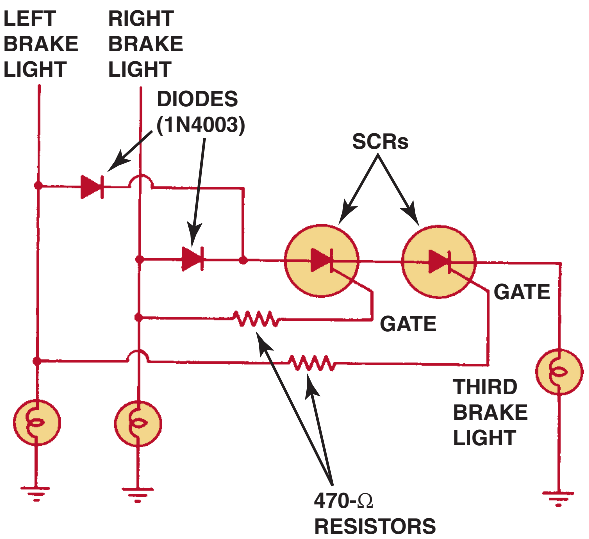


FIGURE 12–19 Wiring diagram for a center high-mounted stoplight (CHMSL) using SCRs.

SILICON-CONTROLLED RECTIFIERS

CONSTRUCTION A **silicon-controlled rectifier (SCR)** is commonly used in the electronic circuits of various automotive applications. An SCR is a semiconductor device that looks like two diodes connected end to end. ● **SEE FIGURE 12–18.**

If the anode is connected to a higher voltage source than the cathode in a circuit, no current will flow as would occur with a diode. If, however, a positive voltage source is connected to the gate of the SCR, then current can flow from anode to cathode with a typical voltage drop of 1.2 volts (double the voltage drop of a typical diode, at 0.6 volt).

Voltage applied to the gate is used to turn the SCR on. However, if the voltage source at the gate is shut off, the current will still continue to flow through the SCR until the source current is stopped.

USES OF AN SCR SCRs can be used to construct a circuit for a **center high-mounted stoplight (CHMSL)**. If this third stoplight were wired into either the left- or the right-side brake light circuit, the CHMSL would also flash whenever the turn signals were used for the side that was connected to the CHMSL. When two SCRs are used, both brake lights must be activated to supply current to the CHMSL. The current to the CHMSL is shut off when both SCRs lose their power source (when the brake pedal is released, which stops the current flow to the brake lights). ● **SEE FIGURE 12–19.**

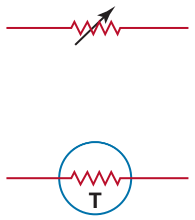


FIGURE 12–20 Symbols used to represent a thermistor.

	COPPER WIRE	NTC THERMISTOR
Cold	Lower resistance	Higher resistance
Hot	Higher resistance	Lower resistance

CHART 12–1

The resistance changes opposite that of a copper wire with changes in temperature.

THERMISTORS

CONSTRUCTION A **thermistor** is a semiconductor material such as silicon that has been doped to provide a given resistance. When the thermistor is heated, the electrons within the crystal gain energy and electrons are released. This means that a thermistor actually produces a small voltage when heated. If voltage is applied to a thermistor, its resistance decreases because the thermistor itself is acting as a current carrier rather than as a resistor at higher temperatures.

USES OF THERMISTORS A thermistor is commonly used as a temperature-sensing device for coolant temperature and intake manifold air temperature. Because thermistors operate in a manner opposite to that of a typical conductor, they are called **negative temperature coefficient (NTC)** thermistors; their resistance decreases as the temperature increases. ● **SEE CHART 12–1**.

Thermistor symbols are shown in ● **FIGURE 12–20.**

RECTIFIER BRIDGES

DEFINITION The word *rectify* means "to set straight"; therefore, a rectifier is an electronic device (such as a diode) used to convert a changing voltage into a straight or constant voltage. A **rectifier bridge** is a group of diodes that is used to change

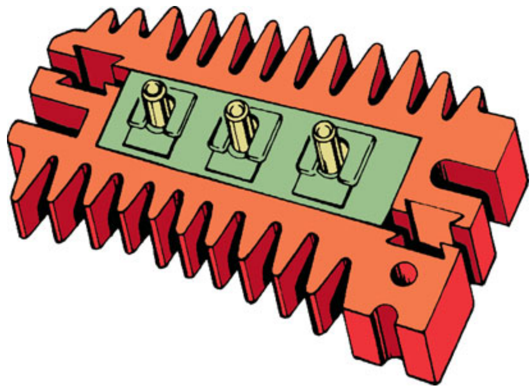


FIGURE 12–21 This rectifier bridge contains six diodes; the three on each side are mounted in an aluminum-finned unit to help keep the diode cool during alternator operation.

alternating current (AC) into direct current (DC). A rectifier bridge is used in alternators to rectify the AC voltage produced in the stator (stationary windings) of the alternator into DC voltage. These rectifier bridges contain six diodes: one pair of diodes (one positive and one negative) for each of the three stator windings. ● **SEE FIGURE 12–21.**

TRANSISTORS

PURPOSE AND FUNCTION A **transistor** is a semiconductor device that can perform the following electrical functions.

1. Act as an electrical switch in a circuit
2. Act as an amplifier of current in a circuit
3. Regulate the current in a circuit

The word *transistor,* derived from the words *transfer* and *resistor,* is used to describe the transfer of current across a resistor. A transistor is made of three alternating sections or layers of P-type and N-type materials. This type of transistor is usually called a **bipolar transistor.**

CONSTRUCTION A transistor that has P-type material on each end, with N-type material in the center, is called a **PNP transistor.** Another type, with the exact opposite arrangement, is called an **NPN transistor.**

The material at one end of a transistor is called the **emitter** and the material at the other end is called the **collector.** The **base** is in the center and the voltage applied to the base is used to control current through a transistor.

TRANSISTOR SYMBOLS All transistor symbols contain an arrow indicating the emitter part of the transistor. The arrow points in the direction of current flow (conventional theory).

When an arrowhead appears in any semiconductor symbol, it stands for a P-N junction and it points from the P-type material toward the N-type material. The arrow on a transistor is always attached to the *emitter* side of the transistor. ● **SEE FIGURE 12–22.**

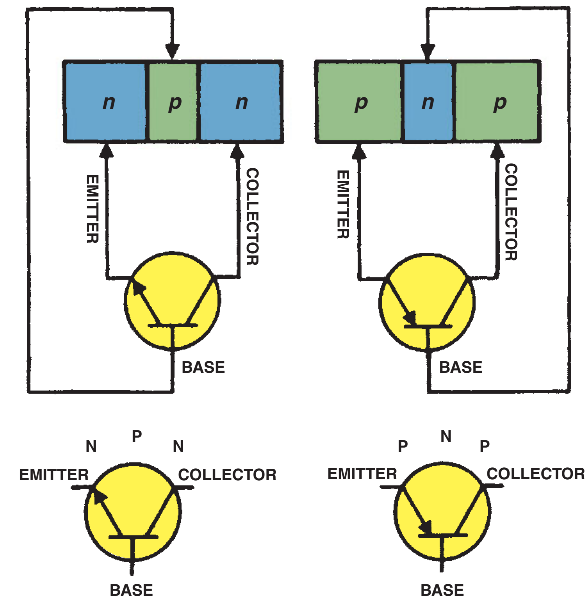


FIGURE 12–22 Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher amperage current to flow from the collector and the emitter.

	RELAY	TRANSISTOR
Low-current circuit	Coil (terminals 85 and 86)	Base and emitter
High-current circuit	Contacts terminals 30 and 87	Collector and emitter

CHART 12–2

Comparison between the control (low-current) and high-current circuits of a transistor compared to a mechanical relay.

? FREQUENTLY ASKED QUESTION

Is a Transistor Similar to a Relay?

Yes, in many cases a transistor is similar to a relay. Both use a low current to control a higher current circuit. ● **SEE CHART 12–2.**

A relay can only be on or off. A transistor can provide a variable output if the base is supplied a variable current input.

HOW A TRANSISTOR WORKS A transistor is similar to two back-to-back diodes that can conduct current in only one direction. As in a diode, N-type material can conduct electricity

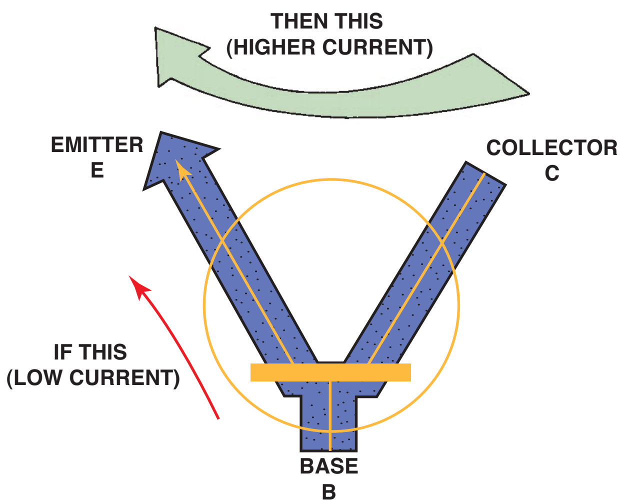


FIGURE 12–23 Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher amperage current to flow from the collector and the emitter.

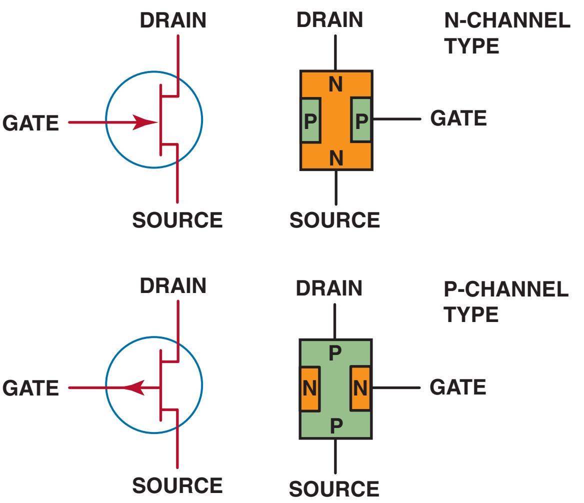


FIGURE 12–24 The three terminals of a field-effect transistor (FET) are called the source, gate, and drain.

FREQUENTLY ASKED QUESTION

What Does the Arrow Mean on a Transistor Symbol?

The arrow on a transistor symbol is always on the emitter and points toward the N-type material. The arrow on a diode also points toward the N-type material. To know which type of transistor is being shown, note which direction the arrow points.

- PNP: pointing in
- NPN: not pointing in

by means of its supply of free electrons, and P-type material conducts by means of its supply of positive holes.

A transistor will allow current flow if the electrical conditions allow it to switch on, in a manner similar to the working of an electromagnetic relay. The electrical conditions are determined, or switched, by means of the base, or *B*. The base will carry current only when the proper voltage and polarity are applied. The main circuit current flow travels through the other two parts of the transistor: the emitter *E* and the collector *C*. ● **SEE FIGURE 12–23.**

If the base current is turned off or on, the current flow from collector to emitter is turned off or on. The current controlling the base is called the **control current.** The control current must be high enough to switch the transistor on or off. (This control voltage, called the **threshold voltage,** must be above approximately 0.3 volt for germanium and 0.6 volt for silicon transistors.) This control current can also "throttle" or regulate the main circuit, in a manner similar to the operation of a water faucet.

HOW A TRANSISTOR AMPLIFIES A transistor can amplify a signal if the signal is strong enough to trigger the base of a transistor on and off. The resulting on-off current flow through the transistor can be connected to a higher powered electrical circuit. This results in a higher powered circuit being controlled by a lower powered circuit. This low-powered circuit's cycling is exactly duplicated in the higher powered circuit, and therefore any transistor can be used to amplify a signal. However, because some transistors are better than others for amplification, specialized types of transistors are used for each specialized circuit function.

FIELD-EFFECT TRANSISTORS

Field-effect transistors (FETs) have been used in most automotive applications since the mid-1980s. They use less electrical current and rely mostly on the strength of a small voltage signal to control the output. The parts of a typical FET include the *source, gate,* and *drain.* ● **SEE FIGURE 12–24.**

Many field-effect transistors are constructed of metal oxide semiconductor (MOS) materials, called **MOSFETs.** MOSFETs are highly sensitive to static electricity and can be easily damaged if exposed to excessive current or high-voltage surges (spikes). Most automotive electronic circuits use MOSFETs, which explains why it is vital for the service technician to use caution to avoid doing anything that could result in a high-voltage spike, and perhaps destroy an expensive computer module. Some vehicle manufacturers recommend that technicians wear an antistatic wristband when working with modules that contain MOSFETs. Always follow the vehicle manufacturer's instructions found in service information to avoid damaging electronic modules or circuits.

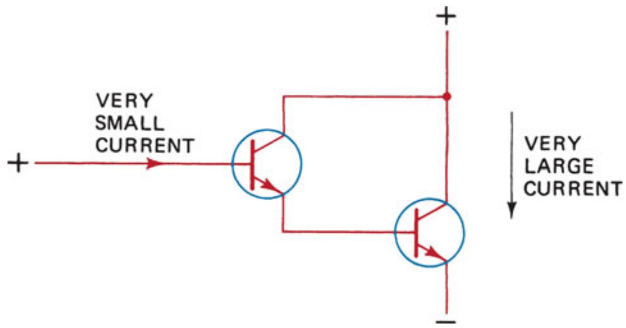


FIGURE 12–25 A Darlington pair consists of two transistors wired together, allowing for a very small current to control a larger current flow circuit.

FIGURE 12–26 Symbols for a phototransistor. (a) This symbol uses the line for the base; (b) this symbol does not.

? FREQUENTLY ASKED QUESTION

What Is a Darlington Pair?

A **Darlington pair** consists of two transistors wired together. This arrangement permits a very small current flow to control a large current flow. The Darlington pair is named for Sidney Darlington, an American physicist for Bell Laboratories from 1929 to 1971. Darlington amplifier circuits are commonly used in electronic ignition systems, computer engine control circuits, and many other electronic applications. ● **SEE FIGURE 12–25.**

PHOTOTRANSISTORS

Similar in operation to a photodiode, a **phototransistor** uses light energy to turn on the base of a transistor. A phototransistor is an NPN transistor that has a large exposed base area to permit light to act as the control for the transistor. Therefore, a phototransistor may or may not have a base lead. If not, then it has only a collector and emitter lead. When the phototransistor is connected to a powered circuit, the light intensity is amplified by the gain of the transistor. Phototransistors, along with photo diodes, are frequently used in steering wheel controls. ● **SEE FIGURE 12–26.**

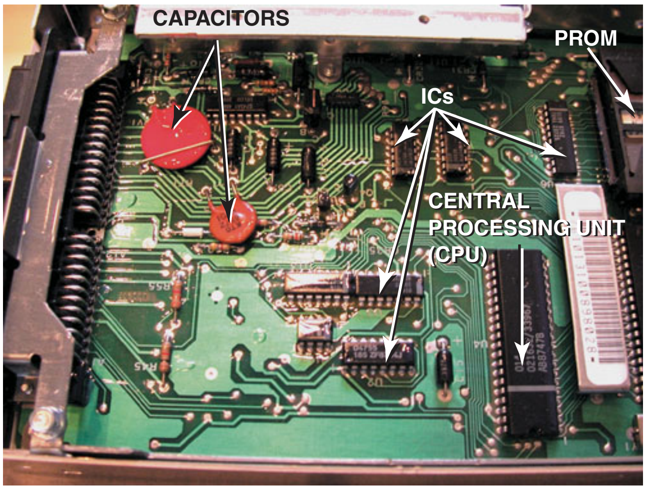


FIGURE 12–27 A typical automotive computer with the case removed to show all of the various electronic devices and integrated circuits (ICs). The CPU is an example of a DIP chip and the large red and orange devices are ceramic capacitors.

INTEGRATED CIRCUITS

PURPOSE AND FUNCTION Solid-state components are used in many electronic semiconductors and/or circuits. They are called "solid state" because they have no moving parts, just higher or lower voltage levels within the circuit. Discrete (individual) diodes, transistors, and other semiconductor devices were often used to construct early electronic ignition and electronic voltage regulators. Newer style electronic devices use the same components, but they are now combined (integrated) into one group of circuits, and are thus called an **integrated circuit (IC)**.

CONSTRUCTION Integrated circuits are usually encased in a plastic housing called a CHIP with two rows of inline pins. This arrangement is called the **dual inline pins (DIP)** chips. ● **SEE FIGURE 12–27.**

Therefore, most computer circuits are housed as an integrated circuit in a DIP chip.

HEAT SINK **Heat sink** is a term used to describe any area around an electronic component that, because of its shape or design, can conduct damaging heat away from electronic parts. Examples of heat sinks include the following:

1. Ribbed electronic ignition control units
2. Cooling slits and cooling fan attached to an alternator
3. Special heat-conducting grease under the electronic ignition module in General Motors HEI distributor ignition systems and other electronic systems

Heat sinks are necessary to prevent damage to diodes, transistors, and other electronic components due to heat buildup. Excessive heat can damage the junction between the N-type and P-type materials used in diodes and transistors.

FREQUENTLY ASKED QUESTION

What Causes a Transistor or Diode to Blow?

Every automotive diode and transistor is designed to operate within certain voltage and amperage ranges for individual applications. For example, transistors used for switching are designed and constructed differently from transistors used for amplifying signals.

Because each electronic component is designed to operate satisfactorily for its particular application, any severe change in operating current (amperes), voltage, or heat can destroy the *junction.* This failure can cause either an open circuit (no current flows) or a short (current flows through the component all the time when the component should be blocking the current flow).

TRANSISTOR GATES

PURPOSE AND FUNCTION An understanding of the basic operation of electronic gates is important to understanding how computers work. A **gate** is an electronic circuit whose output depends on the location and voltage of two inputs.

CONSTRUCTION Whether a transistor is on or off depends on the voltage at the base of the transistor. If the voltage is at least a 0.6 volt difference from that of the emitter, the transistor is turned on. Most electronic and computer circuits use 5 volts as a power source. If two transistors are wired together, several different outputs can be received depending on how the two transistors are wired. ● **SEE FIGURE 12–28.**

OPERATION If the voltage at *A* is higher than that of the emitter, the top transistor is turned on; however, the bottom transistor is off unless the voltage at *B* is also higher. If both transistors are turned on, the output signal voltage will be high. If only one of the two transistors is on, the output will be zero (off or no voltage). Because it requires both *A* and *B* to be on to result in a voltage output, this circuit is called an *AND gate*. In other words, both transistors have to be on before the gate opens and allows a voltage output. Other types of gates can be constructed using various connections to the two transistors. For example:

AND gate. Requires both transistors to be on to get an output.

OR gate. Requires either transistor to be on to get an output.

NAND (NOT-AND) gate. Output is on unless both transistors are on.

NOR (NOT-OR) gate. Output is on only when both transistors are off.

Gates represent logic circuits that can be constructed so that the output depends on the voltage (on or off; high or low) of the inputs to the bases of transistors. Their inputs can come from sensors or other circuits that monitor sensors, and their outputs can be used to operate an output device if amplified and controlled by other circuits. For example, the blower motor will be commanded on when the following events occur, to cause the control module to turn it on.

1. The ignition must be on (input).
2. The air conditioning is commanded on.
3. The engine coolant temperature is within a predetermined limit.

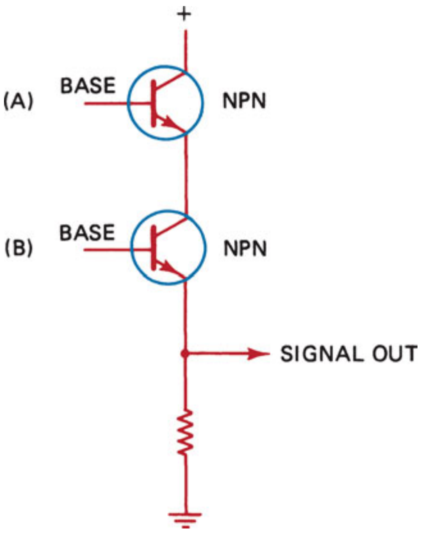


FIGURE 12–28 Typical transistor AND gate circuit using two transistors. The emitter is always the line with the arrow. Notice that both transistors must be turned on before there will be voltage present at the point labeled "signal out."

FREQUENTLY ASKED QUESTION

What Are Logic Highs and Lows?

All computer circuits and most electronic circuits (such as gates) use various combinations of high and low voltages. High voltages are typically those above 5 volts, and low is generally considered zero (ground). However, high voltages do not *have* to begin at 5 volts. *High, or the number 1, to a computer is the presence of voltage above a certain level.* For example, a circuit could be constructed where any voltage higher than 3.8 volts would be considered high. *Low, or the number 0, to a computer is the absence of voltage or a voltage lower than a certain value.* For example, a voltage of 0.62 may be considered low. Various associated names and terms can be summarized.

- Logic low = Low voltage = Number 0 = Reference low
- Logic high = Higher voltage = Number 1 = Reference high

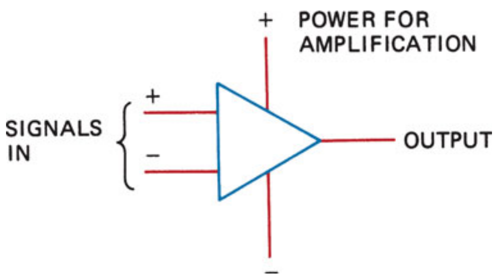


FIGURE 12–29 Symbol for an operational amplifier (op-amp).

If all of these conditions are met, then the control module will command the blower motor on. If any of the input signals are incorrect, the control module will not be able to perform the correct command.

OPERATIONAL AMPLIFIERS

Operational amplifiers (op-amps) are used in circuits to control and amplify digital signals. Op-amps are frequently used for motor control in climate control systems (heating and air conditioning) airflow control door operation. Op-amps can provide the proper voltage polarity and current (amperes) to control the direction of permanent magnetic (PM) motors. The symbol for an op-amp is shown in ● **FIGURE 12–29.**

ELECTRONIC COMPONENT FAILURE CAUSES

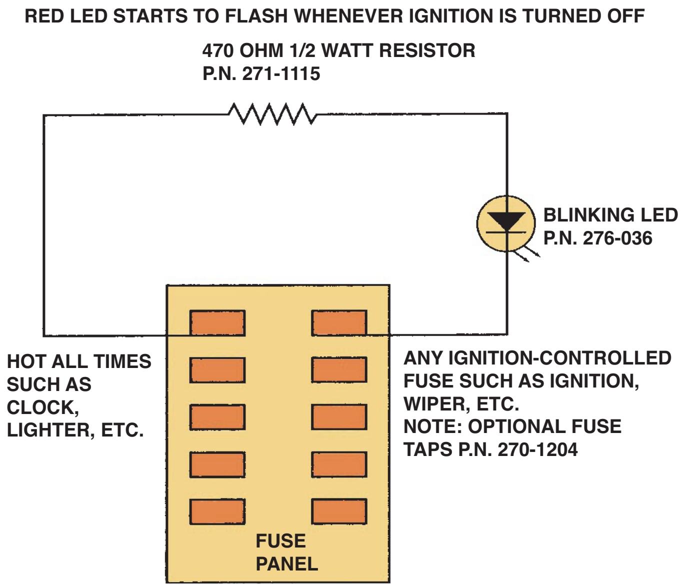
Electronic components such as electronic ignition modules, electronic voltage regulators, onboard computers, and any other electronic circuit are generally quite reliable; however, failure can occur. Frequent causes of premature failure include the following:

- **Poor connections.** It has been estimated that most engine computers returned as defective have simply had poor connections at the wiring harness terminal ends. These faults are often intermittent and hard to find.

  NOTE: When cleaning electronic contacts, use a pencil eraser. This cleans the contacts without harming the thin, protective coating used on most electronic terminals.

- **Heat.** The operation and resistance of electronic components and circuits are affected by heat. Electronic components should be kept as cool as possible and never hotter than 260°F (127°C).
- **Voltage spikes.** A high-voltage spike can literally burn a hole through semiconductor material. The source of these high-voltage spikes is often the discharge of a coil without proper (or with defective) despiking protection. A poor electrical connection at the battery or other major electrical connection can cause high-voltage spikes to occur, because the *entire wiring harness creates its own magnetic field*, similar to that formed around a coil. If the connection is loose and momentary loss of contact occurs, a high-voltage surge can occur through the entire electrical system. To help prevent this type of damage,

BLINKING LED THEFT DETERRENT*



*ALL PART NUMBERS ARE FROM RADIO SHACK

FIGURE 12–30 Schematic for a blinking LED theft deterrent.

> **TECH TIP**
>
> **Blinking LED Theft Deterrent**
>
> A blinking (flashing) LED consumes only about 5 milliamperes (5/1,000 of 1 ampere or 0.005 A). Most alarm systems use a blinking red LED to indicate that the system is armed. A fake alarm indicator is easy to make and install.
>
> A 470 ohm, 0.5 watt resistor limits current flow to prevent battery drain. The positive terminal (anode) of the diode is connected to a fuse that is hot at all times, such as the cigarette lighter. The negative terminal (cathode) of the LED is connected to any ignition-controlled fuse. ● **SEE FIGURE 12–30.**
>
> When the ignition is turned off, the power flows through the LED to ground and the LED flashes. To prevent distraction during driving, the LED goes out when the ignition is on. Therefore, this fake theft deterrent is "auto setting" and no other action is required to activate it when you leave your vehicle except to turn off the ignition and remove the key as usual.

ensure that all electrical connections, including grounds, are properly clean and tight.

CAUTION: One of the major causes of electronic failure occurs during jump starting a vehicle. Always check that the ignition switch is off on both vehicles when making the connection. Always double check that the correct battery polarity (+ to + and − to −) is being performed.

- **Excessive current.** All electronic circuits are designed to operate within a designated range of current (amperes). If a solenoid or relay is controlled by a computer circuit, the resistance of that solenoid or relay becomes part of that control circuit. If a coil winding inside the solenoid or relay becomes shorted, the resulting lower resistance will increase the current through the circuit. Even though individual components are used with current-limiting resistors in series, the coil winding resistance is also used as a current-control component in the circuit. If a computer fails, always measure the resistance across all computer-controlled relays and solenoids. The resistance should be within specifications (generally *over* 20 ohms) for each component that is computer controlled.

NOTE: Some computer-controlled solenoids are pulsed on and off rapidly. This type of solenoid is used in many electronically shifted transmissions. Their resistance is usually about half of the resistance of a simple on-off solenoid—usually between 10 and 15 ohms. Because the computer controls the on-time of the solenoid, the solenoid and its circuit control are called pulse-width modulated (PWM).

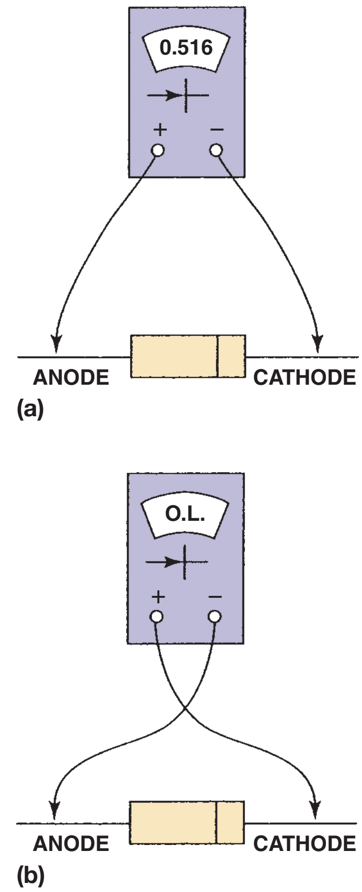


FIGURE 12–31 To check a diode, select "diode check" on a digital multimeter. The display will indicate the voltage drop (difference) between the meter leads. The meter itself applies a low-voltage signal (usually about 3 volts) and displays the difference on the display. (a) When the diode is forward biased, the meter should display a voltage between 0.500 and 0.700 V (500 to 700 mV). (b) When the meter leads are reversed, the meter should read OL (over limit) because the diode is reverse biased and blocking current flow.

HOW TO TEST DIODES AND TRANSISTORS

TESTERS Diodes and transistors can be tested with an ohmmeter. The diode or transistor being tested must be disconnected from the circuit for the results to be meaningful.

- Use the *diode-check* position on a digital multimeter.
- In the diode-check position on a digital multimeter, the meter applies a higher voltage than when the ohms test function is selected.
- This slightly higher voltage (about 2 to 3 volts) is enough to forward bias a diode or the P-N junction of transistors.

DIODES Using the diode test position, the meter applies a voltage. The display will show the voltage drop across the diode P-N junction. A good diode should give an over limit (OL) reading with the test leads attached to each lead of the diode in one way, and a voltage reading of 0.400 to 0.600 V when the leads are reversed. This reading is the voltage drop or the barrier voltage across the P-N junction of the diode.

1. A low-voltage reading with the meter leads attached both ways across a diode means that the diode is *shorted* and must be replaced.
2. An OL reading with the meter leads attached both ways across a diode means that the diode is *open* and must be replaced.

● **SEE FIGURE 12–31.**

TRANSISTORS Using a digital meter set to the diode-check position, a good transistor should show a voltage drop of 0.400 to 0.600 volt between the following:

- The emitter (*E*) and the base (*B*) and between the base (*B*) and the collector (*C*) with a meter connected one way, and OL when the meter test leads are reversed.
- An OL reading (no continuity) in both directions when a transistor is tested between the emitter (*E*) and the collector (*C*) (A transistor tester can also be used if available.).

● **SEE FIGURE 12–32.**

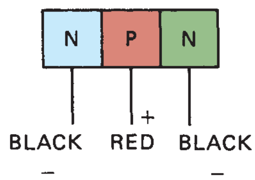


FIGURE 12–32 If the red (positive) lead of the ohmmeter (or a multimeter set to diode check) is touched to the center and the black (negative lead) touched to either end of the electrode, the meter should forward bias the P-N junction and indicate on the meter as low resistance. If the meter reads high resistance, reverse the meter leads, putting the black on the center lead and the red on either end lead. If the meter indicates low resistance, the transistor is a good PNP type. Check all P-N junctions in the same way.

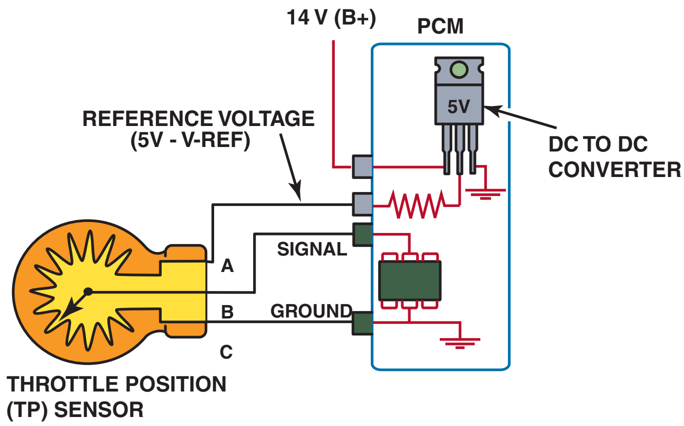


FIGURE 12–33 A DC to DC converter is built into most powertrain control modules (PCMs) and is used to supply the 5 volt reference called V-ref to many sensors used to control the internal combustion engine.

CONVERTERS AND INVERTERS

CONVERTERS DC to DC converters (usually written as DC-DC converter) are electronic devices used to transform DC voltage from one level of DC voltage to another higher or lower level. They are used to distribute various levels of DC voltage throughout a vehicle from a single power bus (or voltage source).

EXAMPLES OF USE One example of a DC-DC converter circuit is the circuit the PCM uses to convert 14 V to 5 V. The 5 volts is called the reference voltage, abbreviated V-ref, and is used to power many sensors in a computer-controlled engine management system. The schematic of a typical 5 volt V-ref interfacing with the TP sensor circuit is shown in ● **FIGURE 12–33.**

The PCM operates on 14 volts, using the principle of DC conversion to provide a constant 5 volts of sensor reference voltage to the TP sensor and others. The TP sensor demands little current, so the V-ref circuit is a low-power DC voltage converter in the range of 1 watt. The PCM uses a DC-DC converter, which is a small semiconductor device called a voltage regulator, and is designed to convert battery voltage to a constant 5 volts regardless of changes in the charging voltage.

Hybrid electric vehicles use DC-DC converters to provide higher or lower DC voltage levels and current requirements.

A high-power DC-DC converter schematic is shown in ● **FIGURE 12–34** and represents how a nonelectronic DC-DC converter works.

The central component of a converter is a transformer that physically isolates the input (42 V) from the output (14 V). The power transistor pulses the high-voltage coil of the transformer, and the resulting changing magnetic field induces a voltage in the coil windings of the lower voltage side of the transformer. The diodes and capacitors help control and limit the voltage and frequency of the circuit.

DC-DC CONVERTER CIRCUIT TESTING Usually a DC control voltage is used, which is supplied by a digital logic circuit to shift the voltage level to control the converter. A voltage test can indicate if the correct voltages are present when the converter is on and off.

Voltage measurements are usually specified to diagnose a DC-DC converter system. A digital multimeter (DMM) that is CAT III rated should be used.

1. Always follow the manufacturer's safety precautions when working with high-voltage circuits. These circuits are usually indicated by orange wiring.
2. Never tap into wires in a DC-DC converter circuit to access power for another circuit.
3. Never tap into wires in a DC-DC converter circuit to access a ground for another circuit.

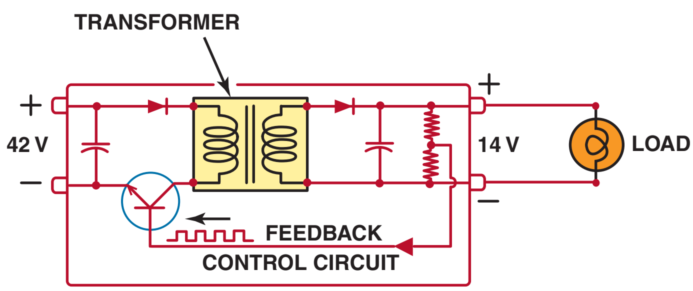


FIGURE 12–34 This DC-DC converter is designed to convert 42 volts to 14 volts, to provide 14 V power to accessories on a hybrid electric vehicle operating with a 42 volt electrical system.

WARNING

Always follow the manufacturer's safety precautions for discharging capacitors in DC-DC converter circuits.

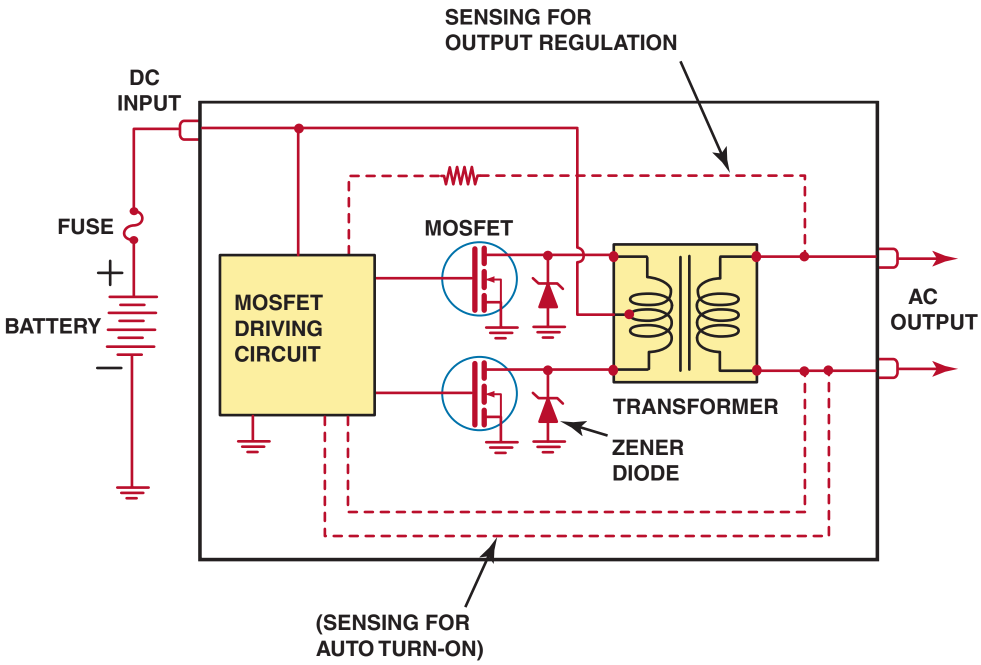


FIGURE 12–35 A typical circuit for an inverter designed to change direct current from a battery to alternating current for use by the electric motors used in a hybrid electric vehicle.

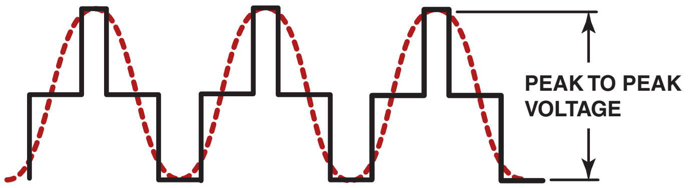


FIGURE 12–36 The switching (pulsing) MOSFETs create a waveform called a modified sine wave (solid lines) compared to a true sine wave (dotted lines).

4. Never block airflow to a DC-DC converter heat sink.
5. Never use a heat sink for a ground connection for a meter, scope, or accessory connection.
6. Never connect or disconnect a DC-DC converter while the converter is powered up.
7. Never connect a DC-DC converter to a larger voltage source than specified.

INVERTERS An **inverter** is an electronic circuit that changes direct current (DC) into alternating current (AC). In most DC-AC inverters, the switching transistors, which are usually MOSFETs, are turned on alternately for short pulses. As a result, the transformer produces a modified sine wave output, rather than a true sine wave. ● **SEE FIGURE 12–35.**

The waveform produced by an inverter is not the perfect sine wave of household AC, but is rather more like a pulsing DC that reacts similar to sine wave AC in transformers and in induction motors. ● **SEE FIGURE 12–36.**

Inverters power AC motors. An inverter converts DC power to AC power at the required frequency and amplitude. The inverter consists of three half-bridge units, and the output voltage is mostly created by a pulse-width modulation (PWM) technique. The three-phase voltage waves are shifted 120 degrees to each other, to power each of the three phases.

WARNING

Do not touch the terminals of a battery that are being used to power an inverter. There is always a risk that those battery terminals could deliver a much greater shock than from batteries alone, if a motor or inverter should develop a fault.

ELECTROSTATIC DISCHARGE

DEFINITION **Electrostatic discharge (ESD)** is created when static charges build up on the human body when movement occurs. The friction of the clothing and the movement of shoes against carpet or vinyl floors cause a high voltage to build. Then when we touch a conductive material, such as a doorknob, the static charge is rapidly discharged. These charges, although just slightly painful to us, can cause severe damage to delicate electronic components. The following are typical static voltages.

- If you can feel it, it is at least 3,000 volts.
- If you can hear it, it is at least 5,000 volts.
- If you can see it, it is at least 10,000 volts.

Although these voltages seem high, the current, in amperes, is extremely low. However, sensitive electronic components such as vehicle computers, radios, and instrument panel clusters can be ruined if exposed to as little as 30 volts. This is a problem, because harm can occur to components at voltages lower than we can feel.

AVOIDING ESD To help prevent damage to components, follow these easy steps.

1. Keep the replacement electronic component in the protective wrapping until just before installation.
2. Before handling any electronic component, ground yourself by touching a metal surface to drain away any static charge.
3. Do not touch the terminals of electronic components.
4. If working in an area where touching terminals may occur, wear a static electrically grounding wrist strap available at most electronic parts stores, such as Radio Shack.

If these precautions are observed, ESD damage can be eliminated or reduced. Remember, just because the component works after being touched does not mean that damage has not occurred. Often, a section of the electronic component may be damaged, yet will not fail until several days or weeks later.

SUMMARY

1. Semiconductors are constructed by doping semiconductor materials such as silicon.
2. N-type and P-type materials can be combined to form diodes, transistors, SCRs, and computer chips.
3. Diodes can be used to direct and control current flow in circuits and to provide despiking protection.
4. Transistors are electronic relays that can also amplify signals.
5. All semiconductors can be damaged if subjected to excessive voltage, current, or heat.
6. Never touch the terminals of a computer or electronic device; static electricity can damage electronic components.

REVIEW QUESTIONS

1. What is the difference between P-type material and N-type material?
2. How can a diode be used to suppress high-voltage surges in automotive components or circuits containing a coil?
3. How does a transistor work?
4. To what precautions should all service technicians adhere, to avoid damage to electronic and computer circuits?

CHAPTER QUIZ

1. A semiconductor is a material ________.
   - **a.** With fewer than four electrons in the outer orbit of its atoms
   - **b.** With more than four electrons in the outer orbit of its atoms
   - **c.** With exactly four electrons in the outer orbit of its atoms
   - **d.** Determined by other factors besides the number of electrons
2. The arrow in a symbol for a semiconductor device ________.
   - **a.** Points toward the negative
   - **b.** Points away from the negative
   - **c.** Is attached to the emitter on a transistor
   - **d.** Both a and c
3. A diode installed across a coil with the cathode toward the battery positive is called a(n) ________.
   - **a.** Clamping diode
   - **b.** Forward-bias diode
   - **c.** SCR
   - **d.** Transistor
4. A transistor is controlled by the polarity and current at the ________.
   - **a.** Collector
   - **b.** Emitter
   - **c.** Base
   - **d.** Both a and b
5. A transistor can ________.
   - **a.** Switch on and off
   - **b.** Amplify
   - **c.** Throttle
   - **d.** All of the above
6. Clamping diodes ________.
   - **a.** Are connected into a circuit with the positive (+) voltage source to the cathode and the negative (−) voltage to the anode
   - **b.** Are also called despiking diodes
   - **c.** Can suppress transient voltages
   - **d.** All of the above
7. A zener diode is normally used for voltage regulation. A zener diode, however, can also be used for high-voltage spike protection if connected ________.
   - **a.** Positive to anode, negative to cathode
   - **b.** Positive to cathode, ground to anode
   - **c.** Negative to anode, cathode to a resistor then to a lower voltage terminal
   - **d.** Both a and c
8. The forward-bias voltage required for an LED is ________.
   - **a.** 0.3 to 0.5 volt
   - **b.** 0.5 to 0.7 volt
   - **c.** 1.5 to 2.2 volts
   - **d.** 4.5 to 5.1 volts
9. An LED can be used in a ________.
   - **a.** Headlight
   - **b.** Taillight
   - **c.** Brake light
   - **d.** All of the above
10. Another name for a ground is ________.
    - **a.** Logic low
    - **b.** Zero
    - **c.** Reference low
    - **d.** All of the above

chapter 13

COMPUTER FUNDAMENTALS

OBJECTIVES: After studying Chapter 13, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the purpose and function of onboard computers. • List the various parts of an automotive computer. • List input sensors. • List output devices (actuators) controlled by the computer.

KEY TERMS: Actuator 171 • Analog-to-digital (AD) converter 170 • Baud rate 172 • Binary system 173 • Clock generator 172 • Controller 169 • CPU 171 • Digital computer 171 • Duty cycle 175 • E^2PROM 170 • ECA 169 • ECM 169 • ECU 169 • EEPROM 170 • Engine mapping 171 • Input 169 • Input conditioning 170 • KAM 170 • Nonvolatile RAM 170 • Output drivers 174 • Powertrain control module (PCM) 169 • PROM 170 • PWM 174 • RAM 170 • ROM 170 • SAE 169

COMPUTER FUNDAMENTALS

PURPOSE AND FUNCTION Modern automotive control systems consist of a network of electronic sensors, actuators, and computer modules designed to regulate the powertrain and vehicle support systems. The onboard automotive computer has many names. It may be called an **electronic control unit (ECU), electronic control module (ECM), electronic control assembly (ECA),** or a **controller,** depending on the manufacturer and the computer application. The **Society of Automotive Engineers (SAE)** bulletin J1930 standardizes the name as a **powertrain control module (PCM).** The PCM coordinates engine and transmission operation, processes data, maintains communications, and makes the control decisions needed to keep the vehicle operating. Not only is it capable of operating the engine and transmission, but it is also able to perform the following:

- Undergo self-tests (40% of the computing power is devoted to diagnosis)
- Set and store diagnostic trouble codes (DTCs)
- Communicate with the technician using a scan tool

VOLTAGE SIGNALS Automotive computers use voltage to send and receive information. Voltage is electrical pressure and does not flow through circuits, but voltage can be used as a signal. A computer converts input information or data into voltage signal combinations that represent number combinations.

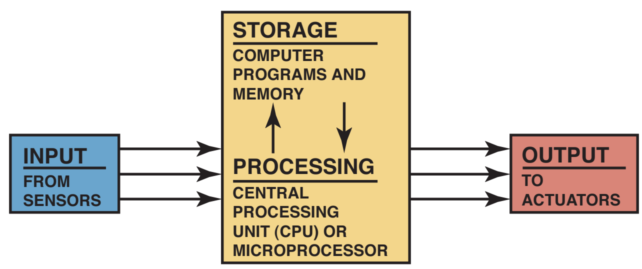


FIGURE 13–1 All computer systems perform four basic functions: input, processing, storage, and output.

A computer processes the input voltage signals it receives by computing what they represent, and then delivering the data in computed or processed form.

COMPUTER FUNCTIONS

BASIC FUNCTIONS The operation of every computer can be divided into four basic functions. ● **SEE FIGURE 13–1.**

- **Input.** Receives voltage signals from sensors
- **Processing.** Performs mathematical calculations
- **Storage.** Includes short-term and long-term memory
- **Output.** Controls an output device by either turning it on or off

INPUT FUNCTIONS First, the computer receives a voltage signal (input) from an input device. **Input** is a signal from a device that can be as simple as a button or a switch on an

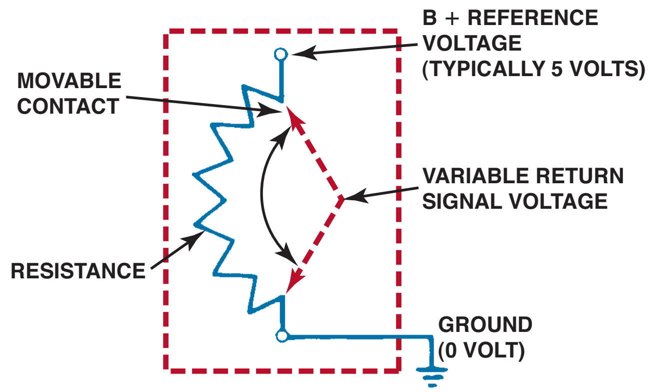


FIGURE 13–2 A potentiometer uses a movable contact to vary resistance and send an analog voltage right to the PCM.

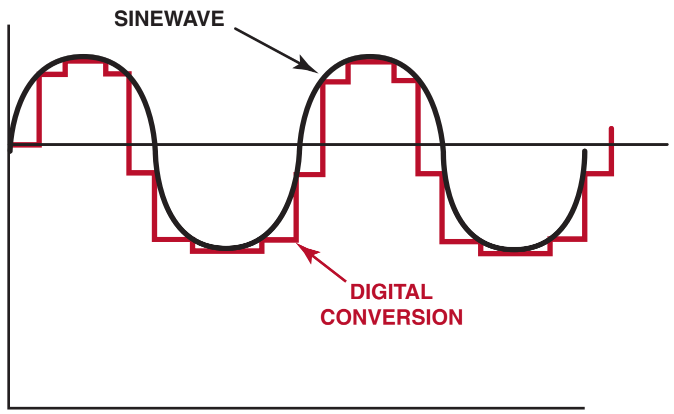


FIGURE 13–3 An AD converter changes analog (variable) voltage signals into digital signals that the PCM can process.

instrument panel, or a sensor on an automotive engine. ● **SEE FIGURE 13–2** for a typical type of automotive sensor.

Vehicles use various mechanical, electrical, and magnetic sensors to measure factors such as vehicle speed, throttle position, engine RPM, air pressure, oxygen content of exhaust gas, airflow, engine coolant temperature, and status of electrical circuits (on-off). Each sensor transmits its information in the form of voltage signals. The computer receives these voltage signals, but before it can use them, the signals must undergo a process called **input conditioning.** This process includes amplifying voltage signals that are too small for the computer circuitry to handle. Input conditioners generally are located inside the computer, but a few sensors have their own input conditioning circuitry.

A digital computer changes the analog input signals (voltage) to digital bits (*bi*nary digi*ts*) of information through an **analog-to-digital (AD) converter** circuit. The binary digital number is used by the computer in its calculations or logic networks. ● **SEE FIGURE 13–3.**

PROCESSING

The term *processing* is used to describe how input voltage signals received by a computer are handled through a series of electronic logic circuits maintained in its programmed instructions. These logic circuits change the input voltage signals, or data, into output voltage signals or commands.

STORAGE

Storage is the place where the program instructions for a computer are stored in electronic memory. Some programs may require that certain input data be stored for later reference or future processing. In others, output commands may be delayed or stored before they are transmitted to devices elsewhere in the system.

Computers have two types of memory.

1. Permanent memory is called **read-only memory (ROM)** because the computer can only read the contents; it cannot change the data stored in it. This data is retained even when power to the computer is shut off. Part of the ROM is built into the computer, and the rest is located in an integrated circuit (IC) chip called a **programmable read-only memory (PROM)** or calibration assembly. Many chips are erasable, meaning that the program can be changed. These chips are called erasable programmable read-only memory, or EPROM. Since the early 1990s, most programmable memory has been electronically erasable, meaning that the program in the chip can be reprogrammed by using a scan tool and the proper software. This computer reprogramming is usually called *reflashing*. These chips are electrically erasable programmable read-only memory, abbreviated **EEPROM** or **E^2PROM.**

   All vehicles equipped with onboard diagnosis second generation, called OBD-II, are equipped with EEPROMs.

2. Temporary memory is called **random-access memory (RAM),** because the computer can write or store new data into it as directed by the computer program, as well as read the data already in it. Automotive computers use two types of RAM memory.
   - Volatile RAM memory is lost whenever the ignition is turned off. However, a type of volatile RAM called **keep-alive memory (KAM)** can be wired directly to battery power. This prevents its data from being erased when the ignition is turned off. One example of RAM and KAM is the loss of station settings in a programmable radio when the battery is disconnected. Because all the settings are stored in RAM, they have to be reset when the battery is reconnected. System trouble codes are commonly stored in RAM and can be erased by disconnecting the battery.
   - **Nonvolatile RAM** memory can retain its information even when the battery is disconnected. One use for this type of RAM is the storage of odometer information in an electronic speedometer. The memory chip retains the mileage accumulated by the vehicle. When speedometer replacement is necessary, the odometer chip is removed and installed in the new speedometer unit. KAM is used primarily in conjunction with adaptive strategies.

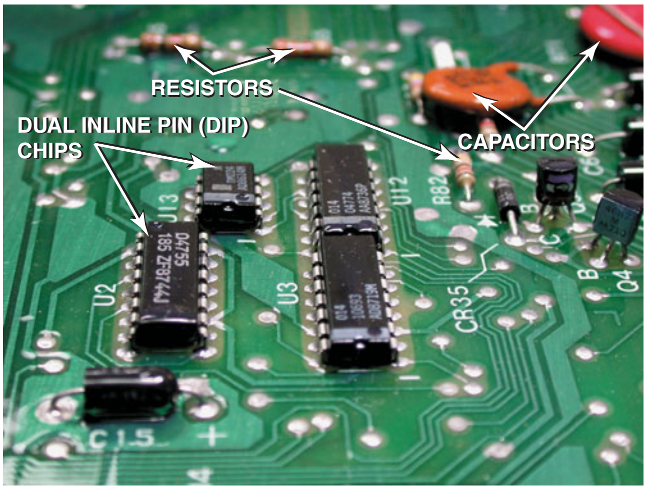


FIGURE 13–4 Many electronic components are used to construct a typical vehicle computer including chips, resistors, and capacitors.

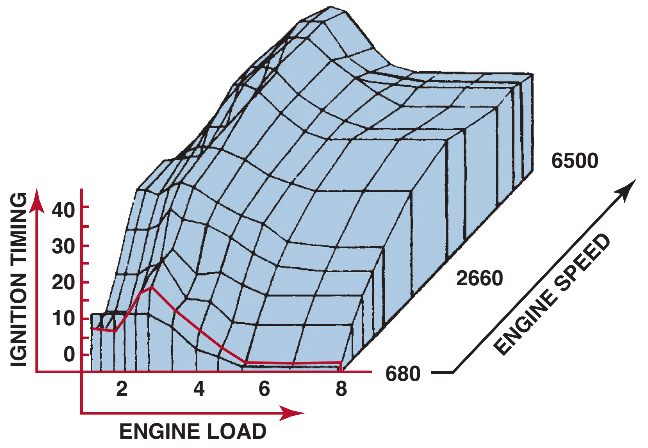


FIGURE 13–5 Typical engine map developed from testing and used by the vehicle computer to provide the optimum ignition timing for all engine speeds and load combinations.

OUTPUT FUNCTIONS After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system, such as system actuators. An **actuator** is an electrical or mechanical output device that converts electrical energy into a mechanical action, such as:

- Adjusting engine idle speed
- Operating fuel injectors
- Ignition timing control
- Altering suspension height

COMPUTER COMMUNICATION A typical vehicle can have many computers, also called modules or controllers. Computers also can communicate with, and control, each other through their output and input functions. This means that the output signal from one computer system can be the input signal for another computer system through a data network. See Chapter 14 for details on network communications.

DIGITAL COMPUTERS

PARTS OF A COMPUTER The software consists of the programs and logic functions stored in the computer's circuitry. The hardware is the mechanical and electronic parts of a computer.

- **Central processing unit.** The microprocessor is the **central processing unit (CPU)** of a computer. Because it performs the essential mathematical operations and logic decisions that make up its processing function, the CPU can be considered the brain of a computer. Some computers use more than one microprocessor, called a coprocessor. The digital computer can process thousands of digital signals per second because its circuits are able to switch voltage signals on and off in billionths of a second. It is called a **digital computer** because it processes zeros and ones (digits) and needs to have any variable input signals, called analog inputs, converted to digital form before it can function. ● **SEE FIGURE 13–4.**
- **Computer memory.** Other integrated circuit (IC) devices store the computer operating program, system sensor input data, and system actuator output data—information that is necessary for CPU operation.
- **Computer programs.** By operating a vehicle on a dynamometer and manually adjusting the variable factors such as speed, load, and spark timing, it is possible to determine the optimum output settings for the best driveability, economy, and emission control. This is called engine mapping. ● **SEE FIGURE 13–5.**

Engine mapping creates a three-dimensional performance graph that applies to a given vehicle and powertrain combination. Each combination is mapped in this manner to produce a PROM or EEPROM calibration. This allows an automaker to use one basic computer for all models.

Many older-vehicle computers used a single PROM that plugged into the computer.

NOTE: If the computer needs to be replaced, the PROM or calibration module must be removed from the defective unit and installed in the replacement computer. Since the mid-1990s, PCMs do not have removable calibration PROMs, and must be programmed or *flashed* using a scan tool before being put into service.

CLOCK RATES AND TIMING The microprocessor receives sensor input voltage signals, processes them by using information from other memory units, and then sends voltage signals to the appropriate actuators. The microprocessor communicates by transmitting long strings of 0s and 1s in a language

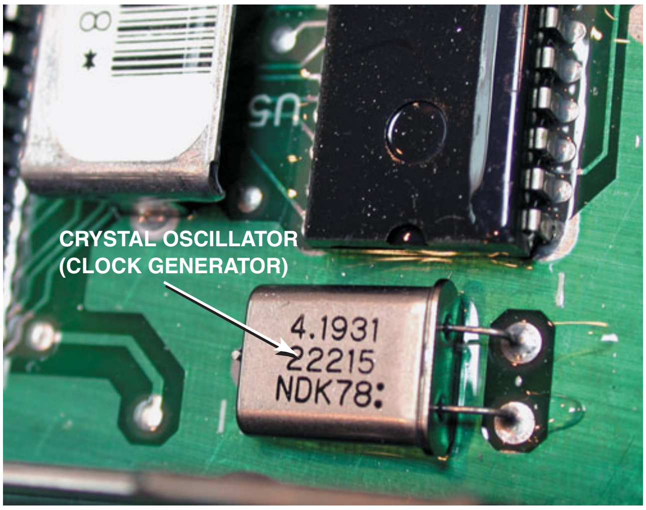


FIGURE 13–6 The clock generator produces a series of pulses that are used by the microprocessor and other components to stay in step with each other at a steady rate.

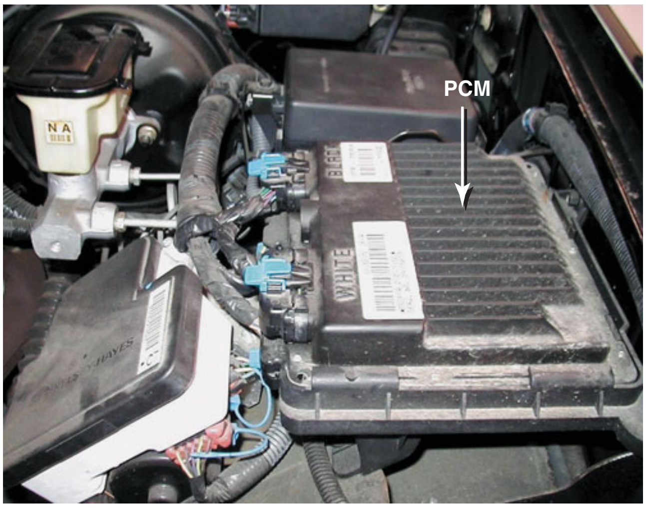


FIGURE 13–7 This powertrain control module (PCM) is located under the hood on this Chevrolet pickup truck.

called binary code; but the microprocessor must have some way of knowing when one signal ends and another begins. That is the job of a crystal oscillator called a **clock generator.** ● **SEE FIGURE 13–6.**

The computer's crystal oscillator generates a steady stream of one-bit-long voltage pulses. Both the microprocessor and the memories monitor the clock pulses while they are communicating. Because they know how long each voltage pulse should be, they can distinguish between a 01 and a 0011. To complete the process, the input and output circuits also watch the clock pulses.

COMPUTER SPEEDS Not all computers operate at the same speed; some are faster than others. The speed at which a computer operates is specified by the cycle time, or clock speed, required to perform certain measurements. Cycle time or clock speed is measured in megahertz (4.7 MHz, 8 MHz, 15 MHz, 18 MHz, and 32 Hz, which is the clock speed of most vehicle computers today).

BAUD RATE The computer transmits bits of a serial datastream at precise intervals. The computer's speed is called the **baud rate,** or bits per second. The term *baud* was named after J. M. Emile Baudot (1845–1903), a French telegraph operator who developed a five-bit-per-character code of telegraph. Just as mph helps in estimating the length of time required to travel a certain distance, the baud rate is useful in estimating how long a given computer will need to transmit a specified amount of data to another computer.

Automotive computers have evolved from a baud rate of 160 used in the early 1980s to a baud rate as high as 500,000 for some networks. The speed of data transmission is an important factor both in system operation and in system troubleshooting.

CONTROL MODULE LOCATIONS The computer hardware is all mounted on one or more circuit boards and installed in a metal case to help shield it from electromagnetic interference (EMI). The wiring harnesses that link the computer to sensors and actuators connect to multipin connectors or edge connectors on the circuit boards.

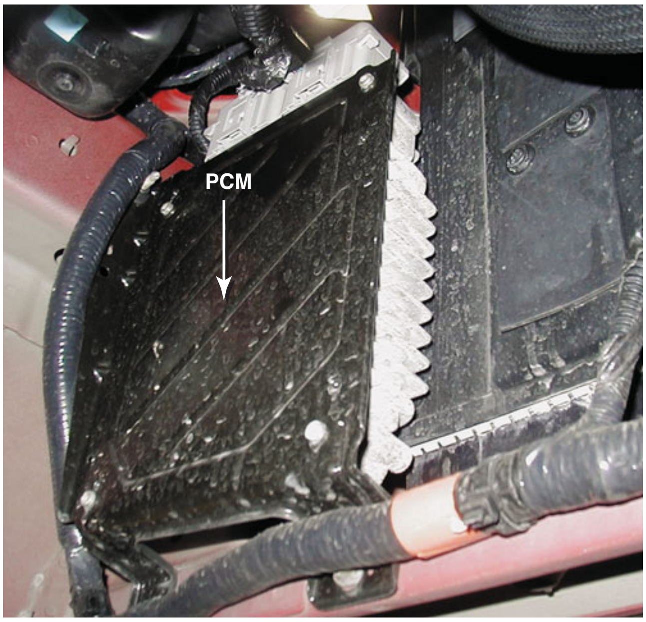


FIGURE 13–8 This PCM on a Chrysler vehicle can only be seen by hoisting the vehicle, because it is located next to the radiator and in the airflow to help keep it cool.

Onboard computers range from single-function units that control a single operation to multifunction units that manage all of the separate (but linked) electronic systems in the vehicle. They vary in size from a small module to a notebook-size box. Most other engine computers are installed in the passenger compartment either under the instrument panel or in a side kick panel where they can be shielded from physical damage caused by temperature extremes, dirt, and vibration, or interference by the high currents and voltages of various underhood systems. ● **SEE FIGURES 13–7 AND 13–8.**

? FREQUENTLY ASKED QUESTION

What Is a Binary System?

In a digital computer the signals are simple high-low, yes-no, on-off signals. The digital signal voltage is limited to two voltage levels: high voltage and low voltage. Since there is no stepped range of voltage or current in between, a digital binary signal is a "square wave." The signal is called "digital" because the on and off signals are processed by the computer as the digits or numbers 0 and 1. The number system containing only these two digits is called the **binary system.** Any number or letter from any number system or language alphabet can be translated into a combination of binary 0s and 1s for the digital computer. A digital computer changes the analog input signals (voltage) to digital bits (*bi*nary digi*ts*) of information through an analog-to-digital (AD) converter circuit. The binary digital number is used by the computer in its calculations or logic networks. Output signals usually are digital signals that turn system actuators on and off.

COMPUTER INPUT SENSORS

The vehicle computer uses signals (voltage levels) from the following sensors.

- **Engine speed (revolutions per minute, or RPM) sensor.** This signal comes from the primary ignition signal in the ignition control module (ICM) or directly from the crankshaft position (CKP) sensor.
- **Switches or buttons for accessory operation.** Many accessories use control buttons that signal the body computer to turn on or off an accessory such as the windshield wiper or heated seats.
- **Manifold absolute pressure (MAP) sensor.** This sensor detects engine load by using a signal from a sensor that measures the vacuum in the intake manifold.
- **Mass airflow (MAF) sensor.** This sensor measures the mass (weight and density) of the air flowing through the sensor and entering the engine.
- **Engine coolant temperature (ECT) sensor.** This sensor measures the temperature of the engine coolant. This is a sensor used for engine controls and for automatic air-conditioning control operation.
- **Oxygen sensor (O2S).** This sensor measures the oxygen in the exhaust stream. There are as many as four oxygen sensors in some vehicles.
- **Throttle position (TP) sensor.** This sensor measures the throttle opening and is used by the computer for engine control and the shift points of the automotive transmission/transaxle.
- **Vehicle speed (VS) sensor.** This sensor measures the vehicle speed using a sensor located at the output of the transmission/transaxle or by monitoring sensors at the wheel speed sensors. This sensor is used by the speedometer, cruise control, and airbag systems.

COMPUTER OUTPUTS

OUTPUT CONTROLS After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system, as follows:

- **Operate actuators.** An actuator is an electrical or mechanical device that converts electrical energy into heat, light, or motion to control engine idle speed, suspension height, ignition timing, and other output devices.
- **Network communication.** Computers also can communicate with another computer system through a network.

A vehicle computer can do only two things.

1. Turn a device on.
2. Turn a device off.

Typical output devices include the following:

- **Fuel injectors.** The computer can vary the amount of time in milliseconds the injectors are held open, thereby controlling the amount of fuel supplied to the engine.
- **Blower motor control.** Many blower motors are controlled by the body computer by pulsing the current on and off to maintain the desired speed.
- **Transmission shifting.** The computer provides a ground to the shift solenoids and torque converter clutch (TCC) solenoid. The operation of the automatic transmission/transaxle is optimized based on vehicle sensor information.
- **Idle speed control.** The computer can control the idle air control (IAC) or electronic throttle control (ETC) to maintain engine idle speed and to provide an increased idle speed as needed.
- **Evaporative emission control solenoids.** The computer can control the flow of gasoline fumes from the charcoal canister to the engine and seal off the system to perform a fuel system leak detection test as part of the OBD-II system requirements.

Most outputs work electrically in one of three ways:

1. Digital
2. Pulse-width modulated
3. Switched

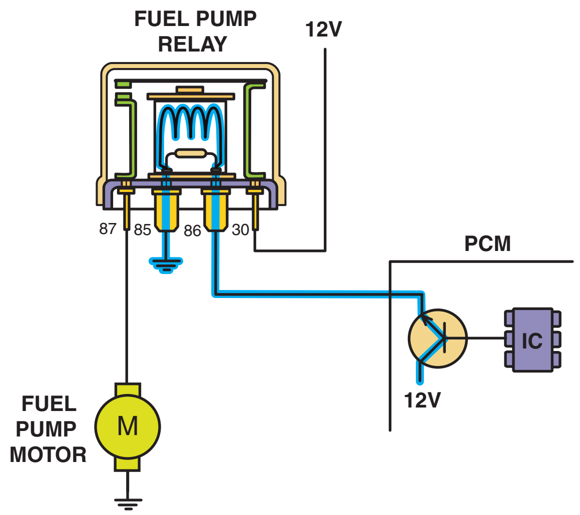


FIGURE 13–9 A typical output driver. In this case, the PCM applies voltage to the fuel pump relay coil to energize the fuel pump.

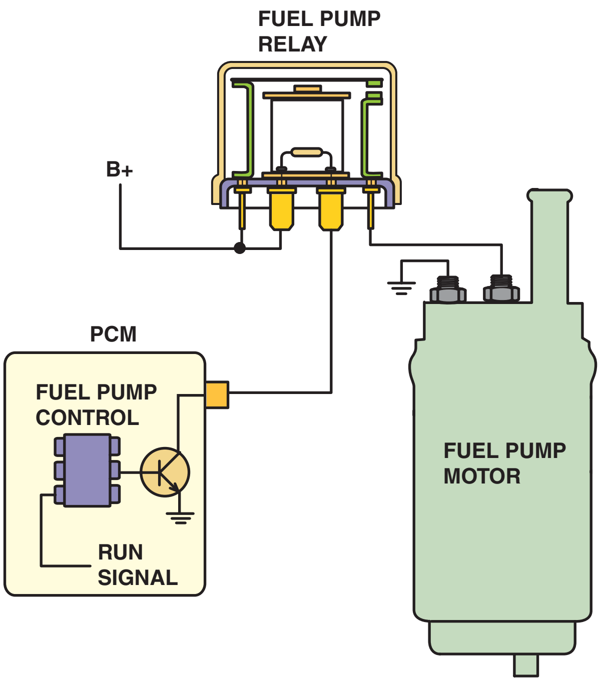


FIGURE 13–10 A typical low-side driver (LSD) which uses a control module to control the ground side of the relay coil.

Digital control is mostly used for computer communications and involves voltage signals that are transmitted and received in packets.

Pulse-width control allows a device, such as a blower motor, to be operated at variable speed by changing the amount of time electrical power is supplied to the device.

A switched output is an output that is either on or off. In many circuits, the PCM uses a relay to switch a device on or off, because the relay is a low-current device that can switch to a higher current device. Most computer circuits cannot handle high amounts of current. By using a relay circuit, the PCM provides the output control to the relay, which in turn provides the output control to the device.

The relay coil, which the PCM controls, typically draws less than 0.5 ampere. The device that the relay controls may draw 30 amperes or more. The PCM switches are actually transistors, and are often called **output drivers.** ● **SEE FIGURE 13–9.**

OUTPUT DRIVERS

There are two basic types of output drivers.

1. **Low-side drivers.** The low-side drivers (LSDs) are transistors inside the computer that complete the ground path of relay coil. Ignition (key-on) voltage and battery voltage are supplied to the relay. The ground side of the relay coil is connected to the transistor inside the computer. In the example of a fuel pump relay, when the transistor turns "on," it will complete the ground for the relay coil, and the relay will then complete the power circuit between the battery power and the fuel pump. A relatively low current flows through the relay coil and transistor that is inside the computer. This causes the relay to switch and provides the fuel pump with battery voltage. The majority of switched outputs have typically been low-side drivers. ● **SEE FIGURE 13–10.**

   Low-side drivers can often perform a diagnostic circuit check by monitoring the voltage from the relay to check that the control circuit for the relay is complete. A low-side driver, however, cannot detect a short-to-ground.

2. **High-side drivers.** The high-side drivers (HSDs) control the power side of the circuit. In these applications when the transistor is switched on, voltage is applied to the device. A ground has been provided to the device so when the high-side driver switches, the device will be energized. In some applications, high-side drivers are used instead of low-side drivers to provide better circuit protection. General Motors vehicles have used a high-side driver to control the fuel pump relay instead of a low-side driver. In the event of an accident, should the circuit to the fuel pump relay become grounded, a high-side driver would cause a short circuit, which would cause the fuel pump relay to de-energize. High-side drivers inside modules can detect electrical faults such as a lack of continuity when the circuit is not energized. ● **SEE FIGURE 13–11.**

PULSE-WIDTH MODULATION

Pulse-width modulation (PWM) is a method of controlling an output using a digital signal. Instead of just turning devices on or off, the computer can control the amount of on-time. For example, a solenoid could be a PWM device. If, for example, a vacuum solenoid is controlled by a switched driver, switching either on or off would mean that either full vacuum would flow through the solenoid or no vacuum would flow through the solenoid. However, to control the amount of vacuum that flows through the solenoid, pulse-width modulation could be used. A PWM signal is a digital signal,

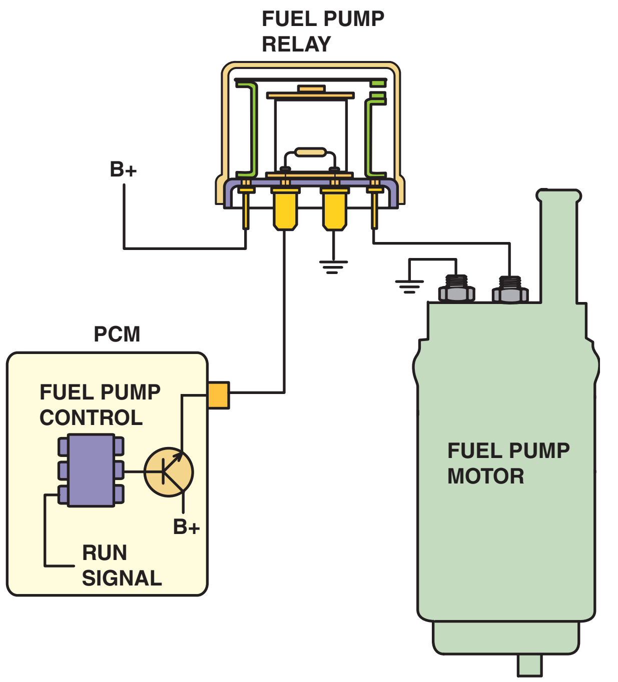


FIGURE 13–11 A typical module-controlled high-side driver (HSD) where the module itself supplies the electrical power to the device. The logic circuit inside the module can detect circuit faults including continuity of the circuit and if there is a short-to-ground in the circuit being controlled.

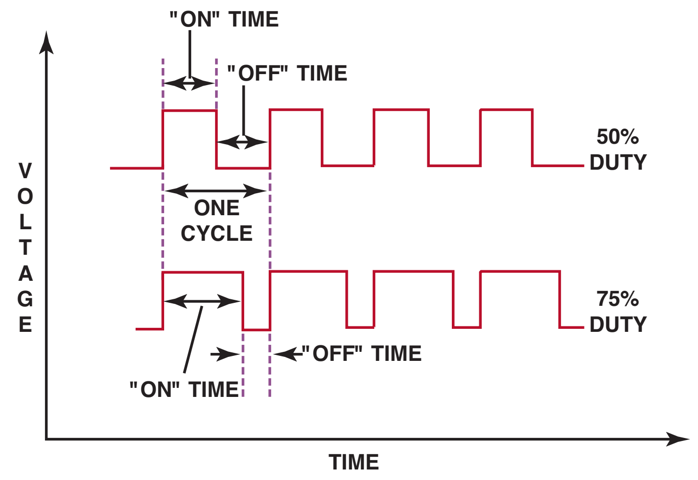


FIGURE 13–12 Both the top and bottom pattern have the same frequency. However, the amount of on-time varies. Duty cycle is the percentage of the time during a cycle that the signal is turned on.

usually 0 volt and 12 volts, which is cycling at a fixed frequency. Varying the length of time that the signal is on provides a signal that can vary the on- and off-time of an output. The ratio of on-time relative to the period of the cycle is referred to as **duty cycle.** ● **SEE FIGURE 13–12.**

Depending on the frequency of the signal, which is usually fixed, this signal would turn the device on and off a fixed number of times per second. When, for example, the voltage is high (12 volts) 90% of the time and low (0 volt) the other 10% of the time, the signal has a 90% duty cycle. In other words, if this signal were applied to the vacuum solenoid, the solenoid would be on 90% of the time. This would allow more vacuum to flow through the solenoid. The computer has the ability to vary this on- and off-time or pulse-width modulation at any rate between 0% and 100%. A good example of pulse-width modulation is the cooling fan speed control. The speed of the cooling fan is controlled by varying the amount of on-time that the battery voltage is applied to the cooling fan motor.

- 100% duty cycle: fan runs at full speed
- 75% duty cycle: fan runs at 3/4 speed
- 50% duty cycle: fan runs at 1/2 speed
- 25% duty cycle: fan runs at 1/4 speed

The use of PWM, therefore, results in precise control of an output device to achieve the amount of cooling needed and conserve electrical energy compared to simply timing the cooling fan on high when needed. PWM may be used to control vacuum through a solenoid, the amount of purge of the evaporative purge solenoid, the speed of a fuel pump motor, control of a linear motor, or even the intensity of a light bulb.

SUMMARY

1. The Society of Automotive Engineers (SAE) standard J1930 specifies that the term powertrain control module (PCM) be used for the computer that controls the engine and transmission in a vehicle.
2. The four basic computer functions are input, processing, storage, and output.
3. Types of memory include read-only memory (ROM) which can be programmable (PROM), erasable (EPROM), or electrically erasable (EEPROM); RAM; and KAM.
4. Computer input sensors include engine speed (RPM), MAP, MAF, ECT, O2S, TP, and VS.
5. A computer can only turn a device on or turn a device off, but it can do either operation rapidly.

REVIEW QUESTIONS

1. What part of the vehicle computer is considered to be the brain?
2. What is the difference between volatile and nonvolatile RAM?
3. What are the four input sensors?
4. What are the four output devices?

CHAPTER QUIZ

1. What unit of electricity is used as a signal for a computer?
   - **a.** Volt
   - **b.** Ohm
   - **c.** Ampere
   - **d.** Watt
2. The four basic computer functions include ___________.
   - **a.** Writing, processing, printing, and remembering
   - **b.** Input, processing, storage, and output
   - **c.** Data gathering, processing, output, and evaluation
   - **d.** Sensing, calculating, actuating, and processing
3. All OBD-II vehicles use what type of read-only memory?
   - **a.** ROM
   - **b.** PROM
   - **c.** EPROM
   - **d.** EEPROM
4. The "brain" of the computer is the ___________.
   - **a.** PROM
   - **b.** RAM
   - **c.** CPU
   - **d.** AD converter
5. Computer speed is measured in ___________.
   - **a.** Baud rate
   - **b.** Clock speed (Hz)
   - **c.** Voltage
   - **d.** Bytes
6. Which item is a computer input sensor?
   - **a.** RPM
   - **b.** Throttle position
   - **c.** Engine coolant temperature
   - **d.** All of the above
7. Which item is a computer output device?
   - **a.** Fuel injector
   - **b.** Transmission shift solenoid
   - **c.** Evaporative emission control solenoid
   - **d.** All of the above
8. The SAE term for the vehicle computer is ___________.
   - **a.** PCM
   - **b.** ECM
   - **c.** ECA
   - **d.** Controller
9. What two things can a vehicle computer actually perform (output)?
   - **a.** Store and process information
   - **b.** Turn something on or turn something off
   - **c.** Calculate and vary temperature
   - **d.** Control fuel and timing only
10. Analog signals from sensors are changed to digital signals for processing by the computer through which type of circuit?
    - **a.** Digital
    - **b.** Analog
    - **c.** Analog-to-digital converter
    - **d.** PROM

chapter 14 CAN AND NETWORK COMMUNICATIONS

OBJECTIVES: After studying Chapter 14, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Describe the types of networks and serial communications used on vehicles. • Discuss how the networks connect to the data link connector and to other modules. • Explain how to diagnose module communication faults.

KEY TERMS: Breakout box (BOB) 188 • BUS 180 • CAN 180 • Chrysler Collision Detection (CCD) 184 • Class 2 180 • E & C 180 • GMLAN 180 • Keyword 180 • Multiplexing 177 • Network 177 • Node 177 • Plastic optical fiber (POF) 188 • Programmable controller interface (PCI) 185 • Protocol 180 • Serial communications interface (SCI) 185 • Serial data 177 • Splice pack 178 • Standard corporate protocol (SCP) 183 • State of health (SOH) 189 • SWCAN 181 • Terminating resistors 189 • Twisted pair 177 • UART 180 • UART-based protocol (UBP) 183

MODULE COMMUNICATIONS AND NETWORKS

NEED FOR NETWORK Since the 1990s, vehicles have used modules to control the operation of most electrical components. A typical vehicle will have 10 or more modules and they communicate with each other over data lines or hard wiring, depending on the application.

ADVANTAGES Most modules are connected together in a network because of the following advantages.

- A decreased number of wires are needed, thereby saving weight and cost, as well as helping with installation at the factory and decreased complexity, making servicing easier.
- Common sensor data can be shared with those modules that may need the information, such as vehicle speed, outside air temperature, and engine coolant temperature.

  ● **SEE FIGURE 14–1.**

NETWORK FUNDAMENTALS

MODULES AND NODES Each module, also called a **node,** must communicate to other modules. For example, if the driver depresses the window-down switch, the power window switch sends a window-down message to the body control module. The body control module then sends the request to the driver's side window module. This module is responsible for actually performing the task by supplying power and ground to the window lift motor in the current polarity to cause the window to go down. The module also contains a circuit that monitors the current flow through the motor and will stop and/or reverse the window motor if an obstruction causes the window motor to draw more than the normal amount of current.

TYPES OF COMMUNICATION The types of communications include the following:

- **Differential.** In the differential form of module communication, a difference in voltage is applied to two wires, which are twisted to help reduce electromagnetic interference (EMI). These transfer wires are called a **twisted pair.**
- **Parallel.** In the parallel type of module communication, the send and receive signals are on different wires.
- **Serial data.** The **serial data** is data transmitted over one wire by a series of rapidly changing voltage signals pulsed from low to high or from high to low.
- **Multiplexing.** The process of **multiplexing** involves the sending of multiple signals of information at the same time over a signal wire and then separating the signals at the receiving end.

This system of intercommunication of computers or processors is referred to as a **network.** ● **SEE FIGURE 14–2.**

By connecting the computers together on a communications network, they can easily share information back and forth. This multiplexing has the following advantages.

- Elimination of redundant sensors and dedicated wiring for these multiple sensors
- Reduction of the number of wires, connectors, and circuits

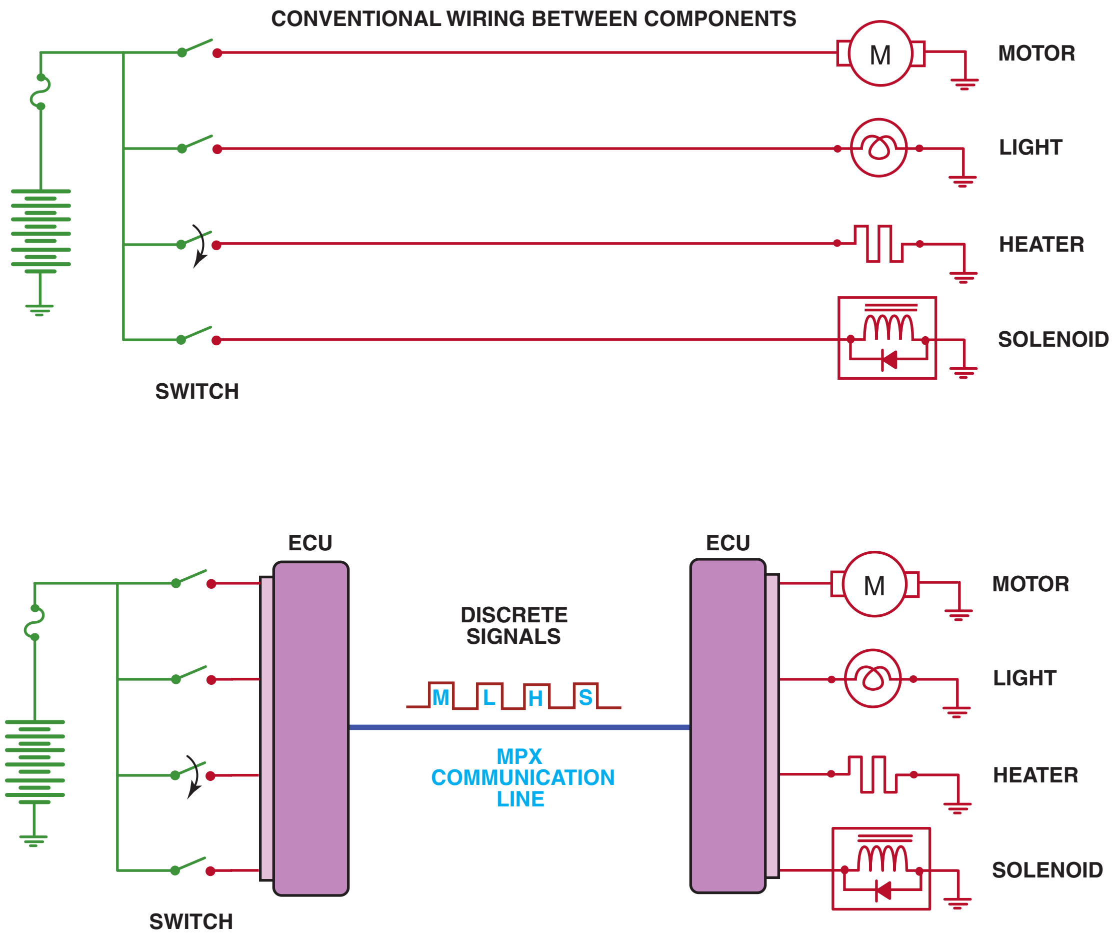


FIGURE 14–1 Module communications makes controlling multiple electrical devices and accessories easier by utilizing simple low-current switches to signal another module, which does the actual switching of the current to the device.

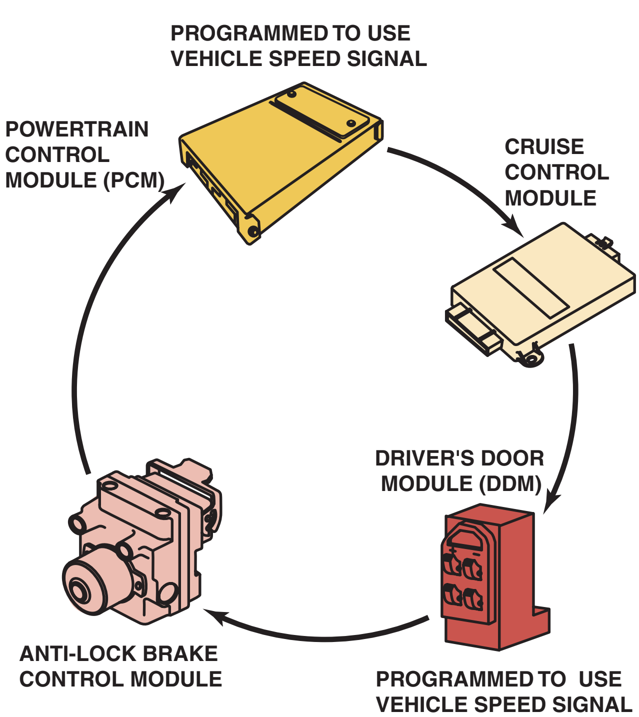


FIGURE 14–2 A network allows all modules to communicate with other modules.

- Addition of more features and option content to new vehicles
- Weight reduction due to fewer components, wires, and connectors, thereby increasing fuel economy
- Changeable features with software upgrades versus component replacement

MODULE COMMUNICATIONS CONFIGURATION

The three most common types of networks used on vehicles include:

1. **Ring link networks.** In a ring-type network, all modules are connected to each other by a serial data line (in a line) until all are connected in a ring. ● **SEE FIGURE 14–3.**
2. **Star link networks.** In a star link network, a serial data line attaches to each module and then each is connected to a central point. This central point is called a **splice pack**, abbreviated SP such as in "SP 306." The splice pack uses a bar to splice all of the serial lines together. Some GM vehicles use two or more splice packs to tie the modules

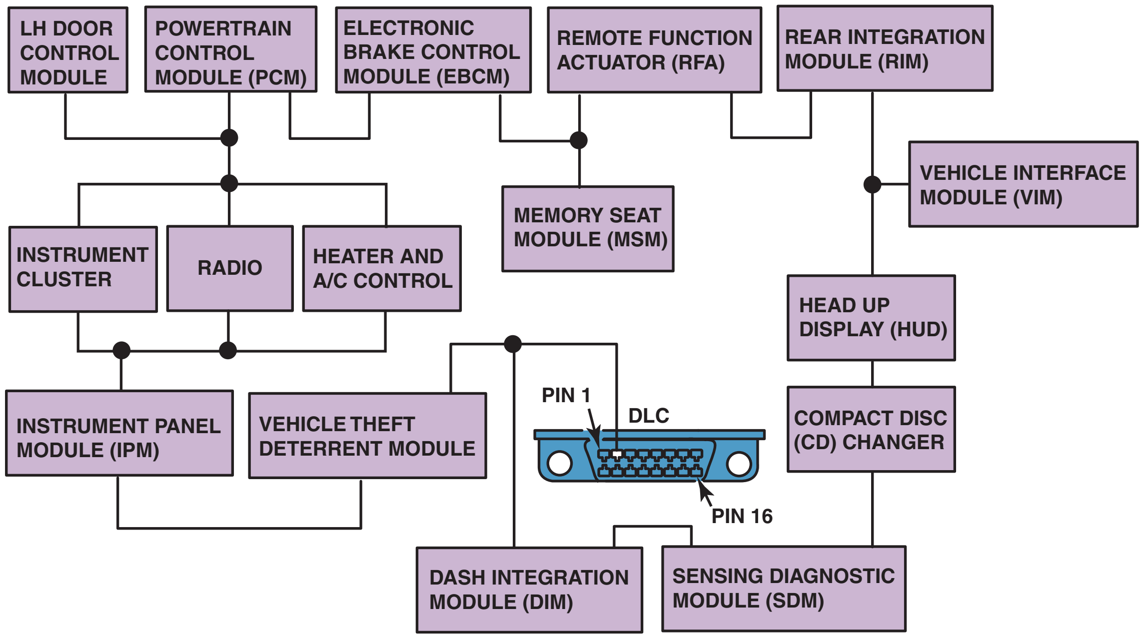


FIGURE 14–3 A ring link network reduces the number of wires it takes to interconnect all of the modules.

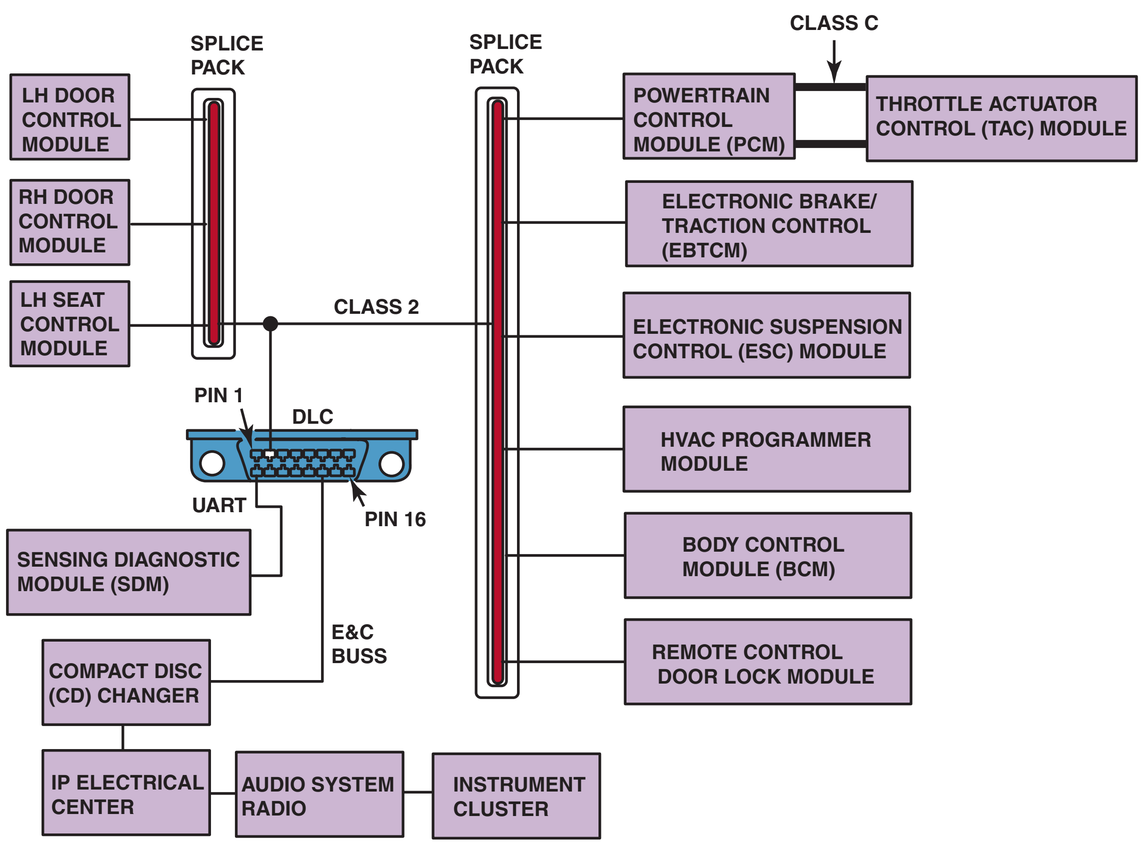


FIGURE 14–4 In a star link network, all of the modules are connected using splice packs.

together. When more than one splice pack is used, a serial data line connects one splice pack to the others. In most applications, the BUS bar used in each splice pack can be removed. When the BUS bar is removed, a special tool (J 42236) can be installed in place of the removed BUS bar. Using this tool, the serial data line for each module can be isolated and tested for a possible problem. Using the special tool at the splice pack makes diagnosing this type of network easier than many others. ● **SEE FIGURE 14–4.**

FREQUENTLY ASKED QUESTION

What Is a BUS?

A **BUS** is a term used to describe a communications network. Therefore, there are *connections to the BUS* and *BUS communications*, both of which refer to digital messages being transmitted among electronic modules or computers.

3. **Ring/star hybrid.** In a ring/star network, the modules are connected using both types of network configurations. Check service information (SI) for details on how this network is connected on the vehicle being diagnosed and always follow the recommended diagnostic steps.

NETWORK COMMUNICATIONS CLASSIFICATIONS

The Society of Automotive Engineers (SAE) standards include the following three categories of in-vehicle network communications.

CLASS A Low-speed networks, meaning less than 10,000 bits per second (bps, or 10 Kbs), are generally used for trip computers, entertainment, and other convenience features.

CLASS B Medium-speed networks, meaning 10,000 to 125,000 bps (10 to 125 Kbs), are generally used for information transfer among modules, such as instrument clusters, temperature sensor data, and other general uses.

CLASS C High-speed networks, meaning 125,000 to 1,000,000 bps, are generally used for real-time powertrain and vehicle dynamic control. High-speed BUS communication systems now use a **controller area network (CAN).** ● **SEE FIGURE 14–5.**

GENERAL MOTORS COMMUNICATIONS PROTOCOLS

UART General Motors and others use UART communications for some electronic modules or systems. **UART** is a serial data communications protocol that stands for **universal asynchronous receive and transmit.** UART uses a master control module connected to one or more remote modules. The master

FREQUENTLY ASKED QUESTION

What Is a Protocol?

A **protocol** is set of rules or a standard used between computers or electronic control modules. Protocols include the type of electrical connectors, voltage levels, and frequency of the transmitted messages. Protocols, therefore, include both the hardware and software needed to communicate between modules.

control module is used to control message traffic on the data line by poling all of the other UART modules. The remote modules send a response message back to the master module.

UART uses a fixed pulse-width switching between 0 and 5 V. The UART data BUS operates at a baud rate of 8,192 bps. ● **SEE FIGURE 14–6.**

ENTERTAINMENT AND COMFORT COMMUNICATION The GM **entertainment and comfort (E & C)** serial data is similar to UART, but uses a 0 to 12 V toggle. Like UART, the E & C serial data uses a master control module connected to other remote modules, which could include the following:

- Compact disc (CD) player
- Instrument panel (IP) electrical center
- Audio system (radio)
- Heating, ventilation, and air-conditioning (HVAC) programmer and control head
- Steering wheel controls

● **SEE FIGURE 14–7.**

CLASS 2 COMMUNICATIONS **Class 2** is a serial communications system that operates by toggling between 0 and 7 V at a transfer rate of 10.4 Kbs. Class 2 is used for most high-speed communications between the powertrain control module (PCM) and other control modules, plus to the scan tool. Class 2 is the primary high-speed serial communications system used by GMCAN (CAN). ● **SEE FIGURE 14–8.**

KEYWORD COMMUNICATION **Keyword** 81, 82, and 2000 serial data are also used for some module-to-module communication on GM vehicles. Keyword data BUS signals are toggled from 0 to 12 V when communicating. The voltage or the datastream is zero volts when not communicating. Keyword serial communication is used by the seat heater module and others, but is not connected to the data link connector (DLC). ● **SEE FIGURE 14–9.**

GMLAN General Motors, like all vehicle manufacturers, must use high-speed serial data to communicate with scan tools on all vehicles effective with the 2008 model year. As mentioned, the standard is called controller area network (CAN), which General Motors calls **GMLAN,** which stands for **GM local area network.**

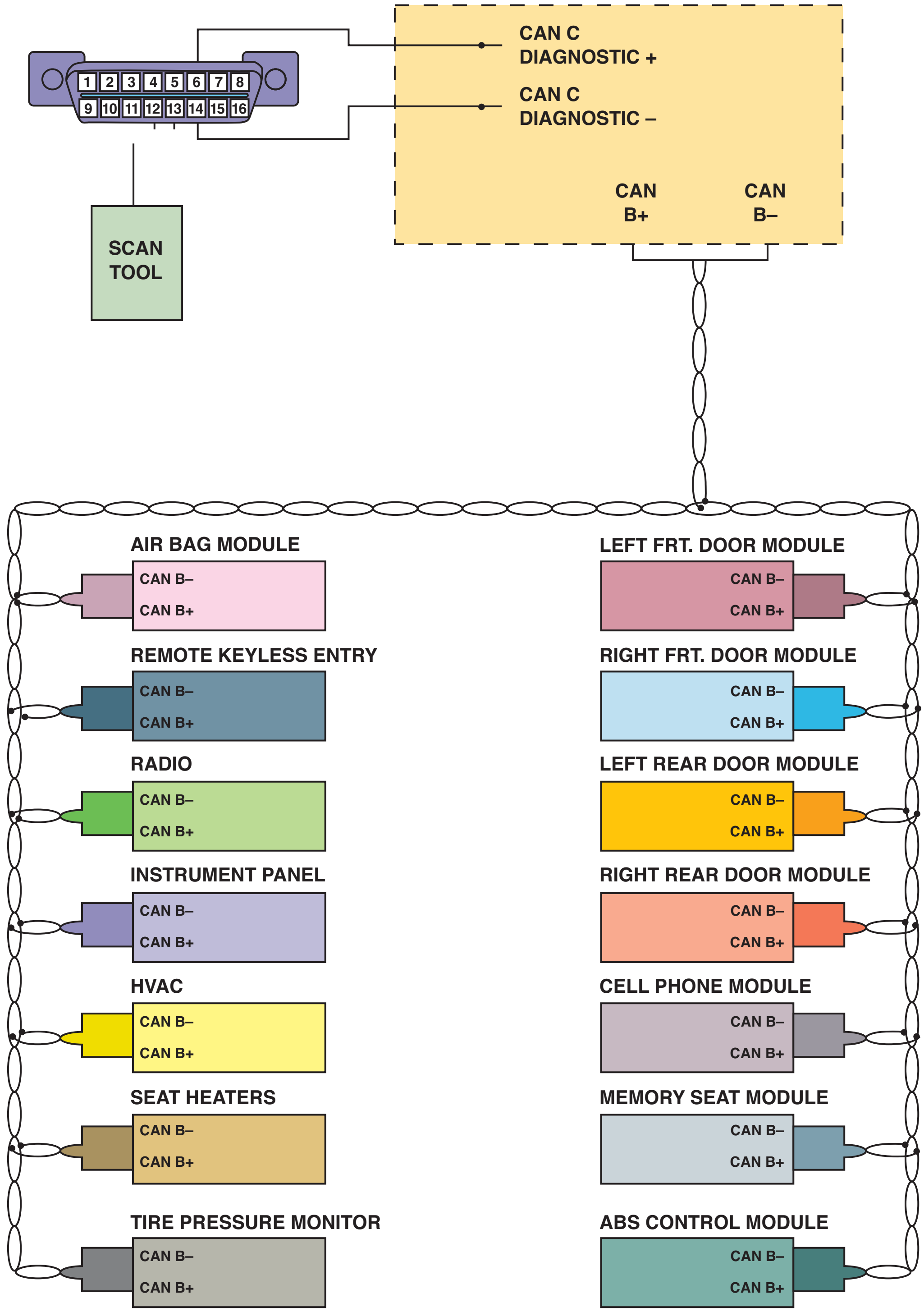


FIGURE 14–5 A typical BUS system showing module CAN communications and twisted pairs of wire.

General Motors uses two versions of GMLAN.

- **Low-speed GMLAN.** The low-speed version is used for driver-controlled functions such as power windows and door locks. The baud rate for low-speed GMLAN is 33,300 bps. The GMLAN low-speed serial data is not connected directly to the data link connector and uses one wire. The voltage toggles between 0 and 5 V after an initial 12 V spike, which indicates to the modules to turn on or wake up and listen for data on the line. Low-speed GMLAN is also known as **single-wire CAN,** or **SWCAN.**
- **High-speed GMLAN.** The baud rate is almost real time at 500 Kbs. This serial data method uses a two-twisted-wire circuit which is connected to the data link connector on pins 6 and 14. ● SEE FIGURE 14–10.

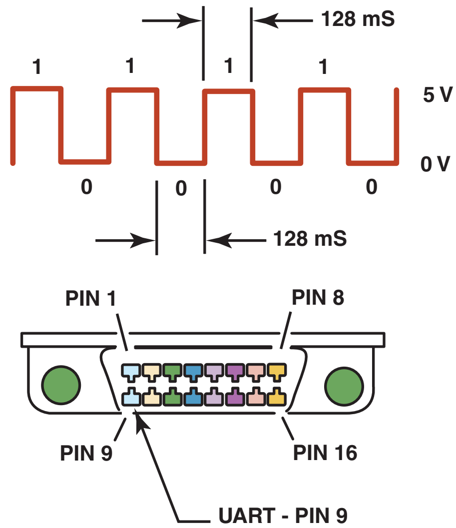


FIGURE 14–6 UART serial data master control module is connected to the data link connector at pin 9.

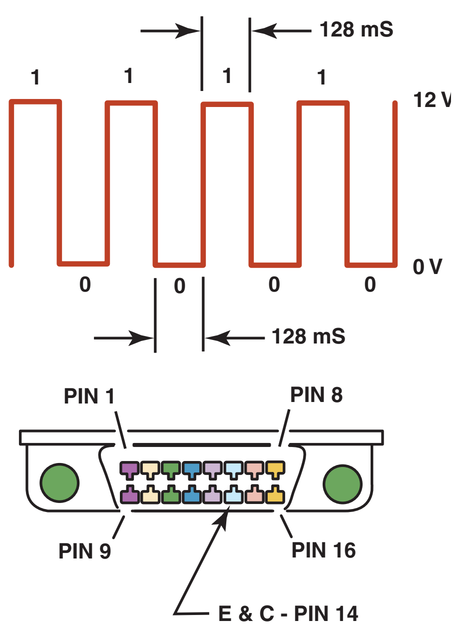


FIGURE 14–7 The E & C serial data is connected to the data link connector (DLC) at pin 14.

? FREQUENTLY ASKED QUESTION

Why Is a Twisted Pair Used?

A twisted pair is where two wires are twisted to prevent electromagnetic radiation from affecting the signals passing through the wires. By twisting the two wires about once every inch (9 to 16 times per foot), the interference is canceled by the adjacent wire.
● **SEE FIGURE 14–11.**

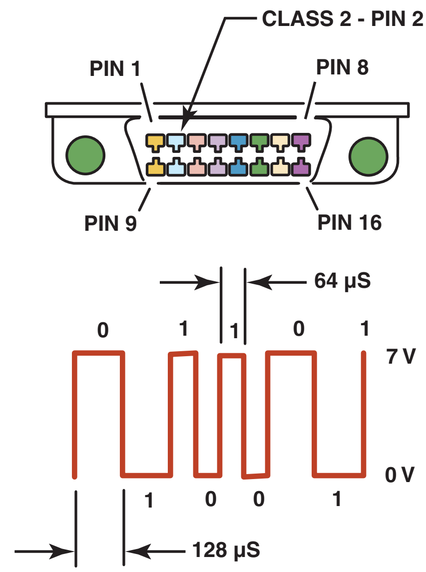


FIGURE 14–8 Class 2 serial data communication is accessible at the data link connector (DLC) at pin 2.

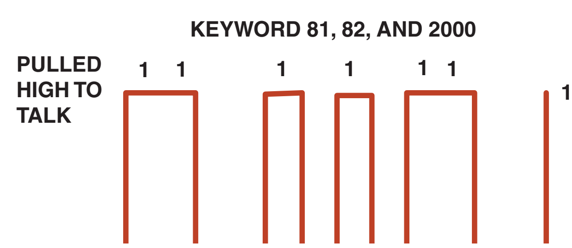


FIGURE 14–9 Keyword 82 operates at a rate of 8,192 bps, similar to UART, and keyword 2000 operates at a baud rate of 10,400 bps (the same as a Class 2 communicator).

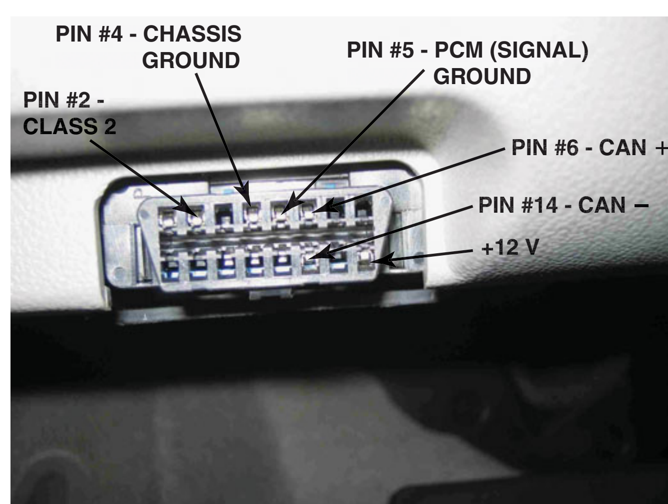


FIGURE 14–10 GMLAN uses pins at terminals 6 and 14.

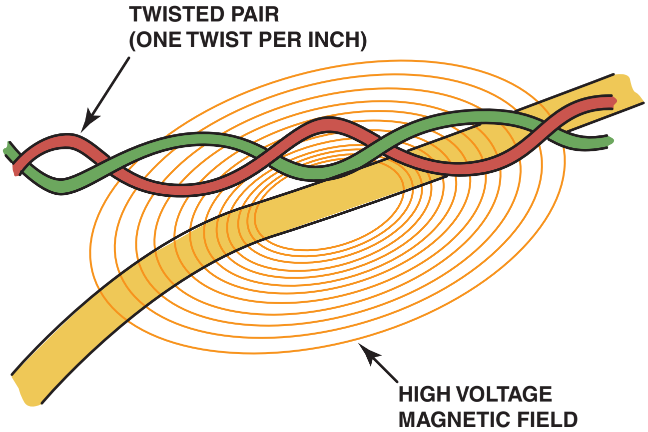


FIGURE 14–11 A twisted pair is used by several different network communications protocols to reduce interference that can be induced in the wiring from nearby electromagnetic sources.

FIGURE 14–12 A CANDi module will flash the green LED rapidly if communication is detected.

A CANDi (CAN diagnostic interface) module is required to be used with the Tech 2 to be able to connect a GM vehicle equipped with GMLAN. ● **SEE FIGURE 14–12.**

FORD NETWORK COMMUNICATIONS PROTOCOLS

STANDARD CORPORATE PROTOCOL Only a few Fords had scan tool data accessible through the OBD-I data link connector. To identify an OBD-I (1988–1995) on a Ford vehicle that is equipped with **standard corporate protocol (SCP)** and be able to communicate through a scan tool, look for terminals in cavities 1 and 3 of the DLC. ● **SEE FIGURE 14–13.**

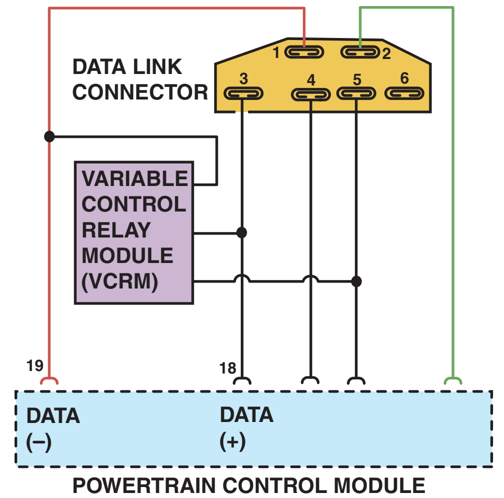


FIGURE 14–13 A Ford OBD-I diagnostic link connector showing that SCP communication uses terminals in cavities 1 (upper left) and 3 (lower left).

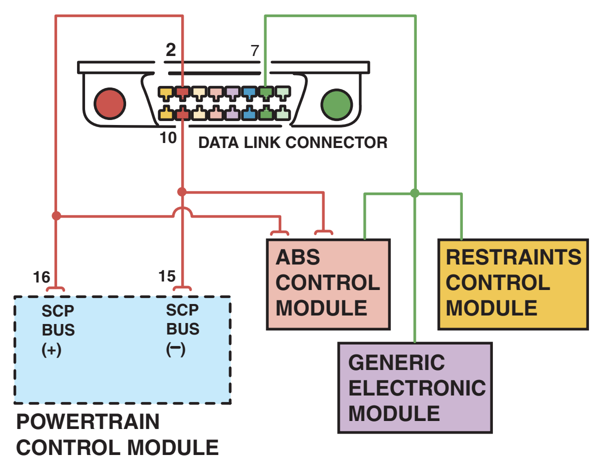


FIGURE 14–14 A scan tool can be used to check communications with the SCP BUS through terminals 2 and 10 and to the other modules connected to terminal 7 of the data link connector (DLC).

SCP uses the J-1850 protocol and is active with the key on. The SCP signal is from 4 V negative to 4.3 V positive, and a scan tool does not have to be connected for the signal to be detected on the terminals. OBD-II (EECV) Ford vehicles use terminals 2 (positive) and 10 (negative) of the 16 pin data link connector (DLC) for network communication, using the SCP module communications.

UART-BASED PROTOCOL Newer Fords use the CAN for scan tool diagnosis, but still retain SCP and **UART-based protocol (UBP)** for some modules. ● **SEE FIGURES 14–14 AND 14–15.**

? FREQUENTLY ASKED QUESTION

What Are U Codes?

The U diagnostic trouble codes were at first "undefined" but are now network-related codes. Use the network codes to help pinpoint the circuit or module that is not working correctly.

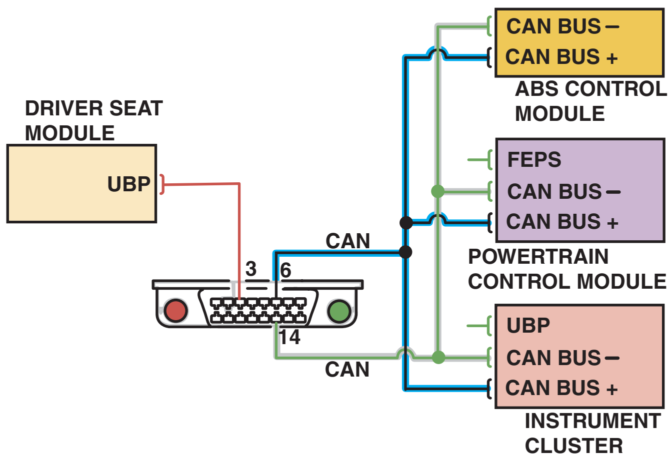


FIGURE 14–15 Many Fords use UBP module communications along with CAN.

CHRYSLER COMMUNICATIONS PROTOCOLS

CCD Since the late 1980s, the **Chrysler Collision Detection (CCD)** multiplex network is used for scan tool and module communications. It is a differential-type communication and uses a twisted pair of wires. The modules connected to the network apply a bias voltage on each wire. CCD signals are divided into plus and minus (CCD+ and CCD−) and the voltage difference does not exceed 0.02 V. The baud rate is 7,812.5 bps.

NOTE: The "collision" in the Chrysler Collision detection BUS communications refers to the program that avoids conflicts of information exchange within the BUS, and does not refer to airbags or other accident-related circuits of the vehicle.

The circuit is active without a scan tool command. ● **SEE FIGURE 14–16.**

The modules on the CCD BUS apply a bias voltage on each wire by using termination resistors. ● **SEE FIGURE 14–17.**

The difference in voltage between CCD+ and CCD− is less than 20 mV. For example, using a digital meter with the

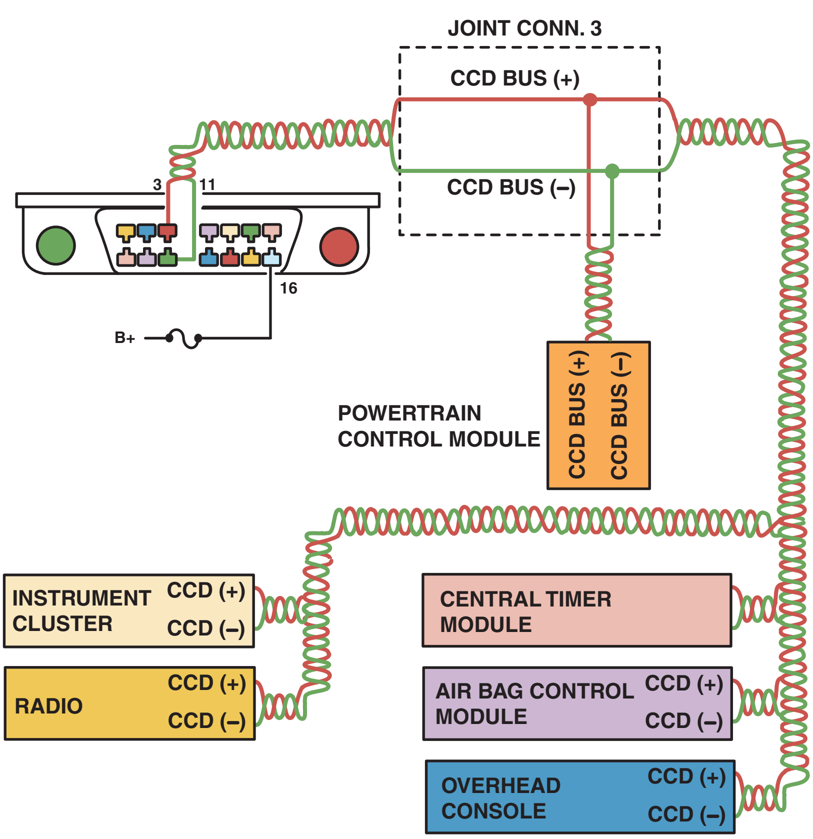


FIGURE 14–16 CCD signals are labeled plus and minus and use a twisted pair of wires. Notice that terminals 3 and 11 of the data link connector are used to access the CCD BUS from a scan tool. Pin 16 is used to supply 12 volts to the scan tool.

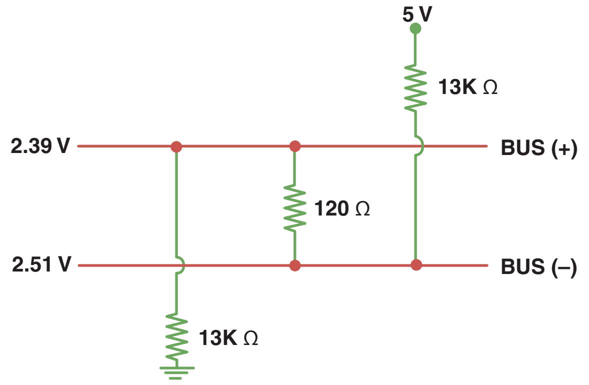


FIGURE 14–17 The differential voltage for the CCD BUS is created by using resistors in a module.

black meter lead attached to ground and the red meter lead attached at the data link connector (DLC), a normal reading could include:

- Terminal 3 = 2.45 volts
- Terminal 11 = 2.47 volts

This is an acceptable reading because the readings are 20 mV (0.020 volt) of each other. If both had been exactly 2.5 volts, then this could indicate that the two data lines are shorted together. The module providing the bias voltage is usually the body control module on passenger cars and the front control module on Jeeps and trucks.

PROGRAMMABLE CONTROLLER INTERFACE

The Chrysler **programmable controller interface (PCI)** is a one-wire communication protocol that connects at the OBD-II DLC at terminal 2. The PCI BUS is connected to all modules on the BUS in a star configuration and operates at a baud rate of 10,200 bps. The voltage signal toggles between 7.5 and 0 V. If this voltage is checked at terminal 2 of the OBD-II DLC, a voltage of about 1 V indicates the average voltage and means that the BUS is functioning and is not shorted-to-ground. PCI and CCD are often used in the same vehicle. ● **SEE FIGURE 14–18.**

SERIAL COMMUNICATIONS INTERFACE

Chrysler used **serial communications interface (SCI)** for most scan tool and flash reprogramming functions until it was replaced with CAN. SCI is connected at the OBD-II diagnostic link connector (DLC) at terminals 6 (SCI receive) and 7 (SCI transmit). A scan tool must be connected to test the circuit.

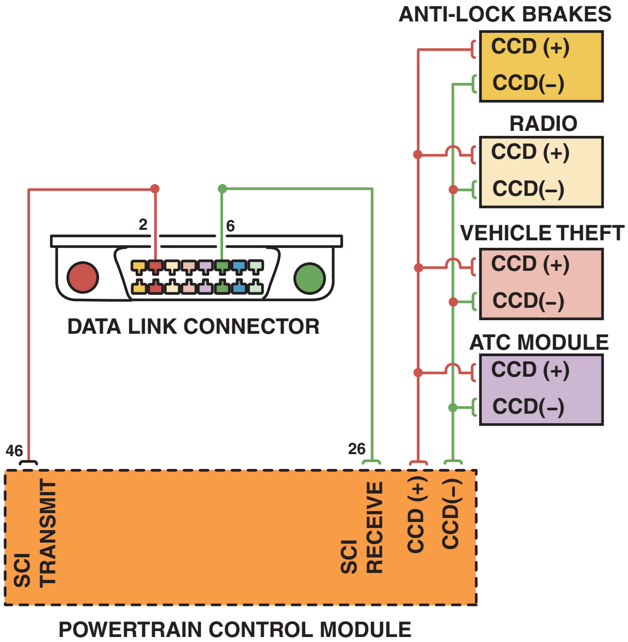


FIGURE 14–18 Many Chrysler vehicles use both SCI and CCD for module communication.

CONTROLLER AREA NETWORK

BACKGROUND

Robert Bosch Corporation developed the CAN protocol, which was called CAN 1.2, in 1993. The CAN protocol was approved by the Environmental Protection Agency (EPA) for 2003 and newer vehicle diagnostics, and a legal requirement for all vehicles by 2008. The CAN diagnostic systems use pins 6 and 14 in the standard 16 pin OBD-II (J-1962) connector. Before CAN, the scan tool protocol had been manufacturer specific.

CAN FEATURES

The CAN protocol offers the following features.

- Faster than other BUS communication protocols
- Cost effective because it is an easier system than others to use
- Less effected by electromagnetic interference (Data is transferred on two wires that are twisted together, called twisted pair, to help reduce EMI interference.)
- Message based rather than address based which makes it easier to expand
- No wakeup needed because it is a two-wire system
- Supports up to15 modules plus a scan tool
- Uses a 120 ohm resistor at the ends of each pair to reduce electrical noise
- Applies 2.5 volts on both wires:

  H (high) goes to 3.5 volts when active

  L (low) goes to 1.5 volts when active

  ● **SEE FIGURE 14–19.**

CAN CLASS A, B, AND C

There are three classes of CAN and they operate at different speeds. The CAN A, B, and C networks can all be linked using a gateway within the same vehicle. The gateway is usually one of the many modules in the vehicle.

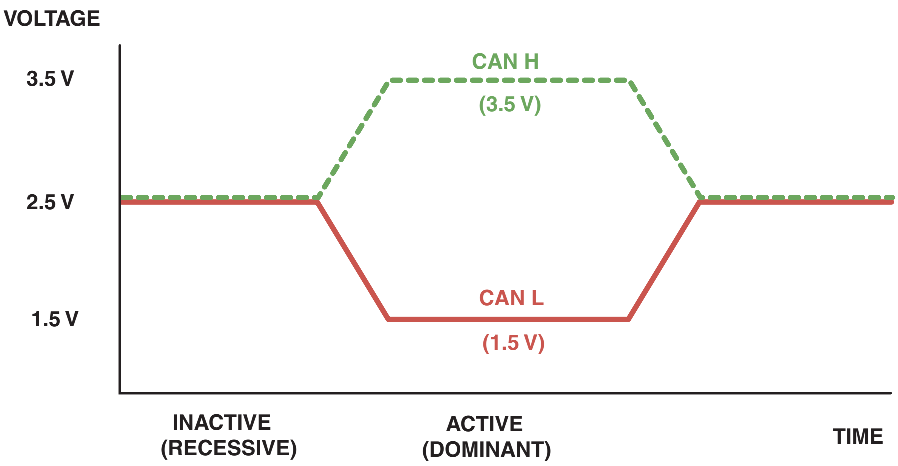


FIGURE 14–19 CAN uses a differential type of module communication where the voltage on one wire is the equal but opposite voltage on the other wire. When no communication is occurring, both wires have 2.5 volts applied. When communication is occurring, CAN H (high) goes up 1 volt to 3.5 volts and CAN L (low) goes down 1 volt to 1.5 volts.

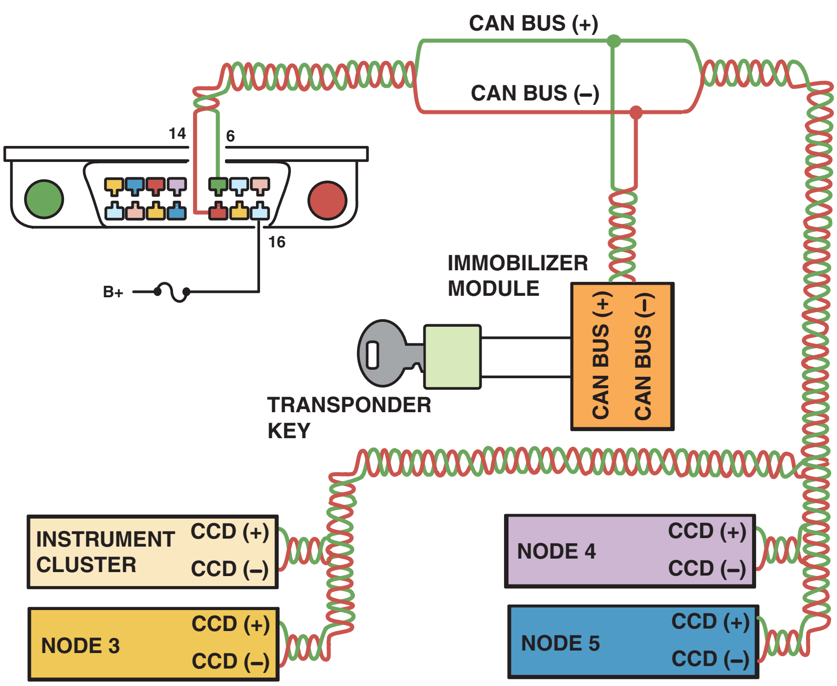


FIGURE 14–20 A typical (generic) system showing how the CAN BUS is connected to various electrical accessories and systems in the vehicle.

- **CAN A.** This class operates on only one wire at slow speeds and is therefore less expensive to build. CAN A operates a data transfer rate of 33.33 Kbs in normal mode and up to 83.33 Kbs during reprogramming mode. CAN A uses the vehicle ground as the signal return circuit.
- **CAN B.** This class operates on a two-wire network and does not use the vehicle ground as the signal return circuit. CAN B uses a data transfer rate of 95.2 Kbs. Instead, CAN B (and CAN C) uses two network wires for differential signaling. This means that the two data signal voltages are opposite to each other and used for error detection by constantly being compared. In this case, when the signal voltage at one of the CAN data wires goes high (CAN H), the other one goes low (CAN L), hence the name *differential signaling*. Differential signaling is also used for redundancy, in case one of the signal wires shorts out.
- **CAN C.** This class is the highest speed CAN protocol with speeds up to 500 Kbs. Beginning with 2008 models, all vehicles sold in the United States must use CAN BUS for scan tool communications. Most vehicle manufacturers started using CAN in older models; and it is easy to determine if a vehicle is equipped with CAN. The CAN BUS communicates to the scan tool through terminals 6 and 14 of the DLC indicating that the vehicle is equipped with CAN. ● **SEE FIGURE 14–20.**

The total voltage remains constant at all times and the electromagnetic field effects of the two data BUS lines cancel each other out. The data BUS line is protected against received radiation and is virtually neutral in sending radiation.

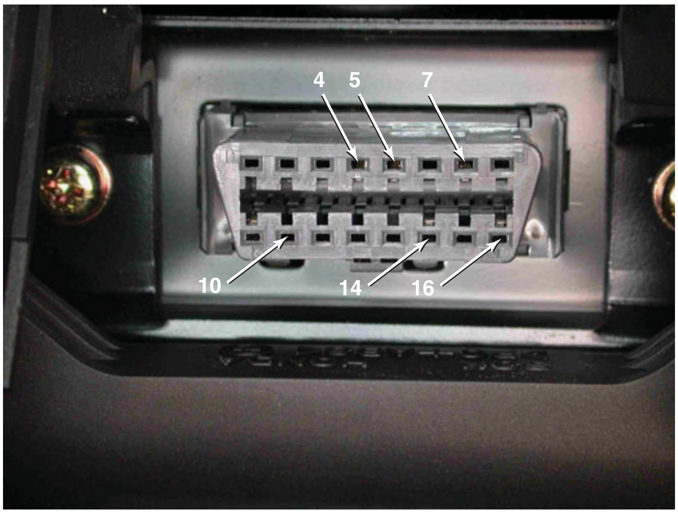


FIGURE 14–21 A DLC from a pre-CAN Acura. It shows terminals in cavities 4, 5 (grounds), 7, 10, 14, and 16 (B+).

FIGURE 14–22 A Honda scan display showing a B and two U codes, all indicating a BUS-related problem(s).

HONDA/TOYOTA COMMUNICATIONS

The primary BUS communications on pre-CAN-equipped vehicles is ISO 9141-2 using terminals 7 and 15 at the OBD-II DLC. ● **SEE FIGURE 14–21.**

A factory scan tool or an aftermarket scan tool equipped with enhanced original equipment (OE) software is needed to access many of the BUS messages. ● **SEE FIGURE 14–22.**

EUROPEAN BUS COMMUNICATIONS

UNIQUE DIAGNOSTIC CONNECTOR Many different types of module communications protocols are used on European vehicles such as Mercedes and BMW.

Most of these communication BUS messages cannot be accessed through the data link connector (DLC). To check the operation of the individual modules, a scan tool equipped with factory-type software will be needed to communicate with the module through the gateway module. ● **SEE FIGURE 14–23** for an alternative access method to the modules.

MEDIA ORIENTED SYSTEM TRANSPORT BUS The media oriented system transport (MOST) BUS uses fiber optics for module-to-module communications in a ring or star configuration. This BUS system is currently being used for entertainment equipment data communications for videos, CDs, and other media systems in the vehicle.

FIGURE 14–23 A typical 38-cavity diagnostic connector as found on many BMW and Mercedes vehicles under the hood. The use of a breakout box (BOB) connected to this connector can often be used to gain access to module BUS information.

MOTOROLA INTERCONNECT BUS Motorola interconnect (MI) is a single-wire serial communications protocol, using one master control module and many slave modules. Typical application of the MI BUS protocol is with power and memory mirrors, seats, windows, and headlight levelers.

DISTRIBUTED SYSTEM INTERFACE BUS Distributed system interface (DSI) BUS protocol was developed by Motorola and uses a two-wire serial BUS. This BUS protocol is currently being used for safety-related sensors and components.

BOSCH-SIEMANS-TEMIC BUS The Bosch-Siemans-Temic (BST) BUS is another system that is used for safety-related components and sensors in a vehicle, such as airbags. The BST BUS is a two-wire system and operates up to 250,000 bps.

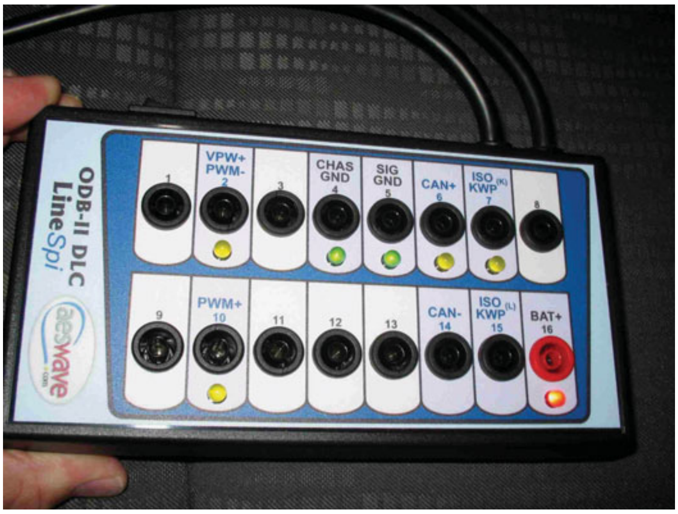


FIGURE 14–24 A breakout box (BOB) used to access the BUS terminals while using a scan tool to activate the modules. This breakout box is equipped with LEDs that light when circuits are active.

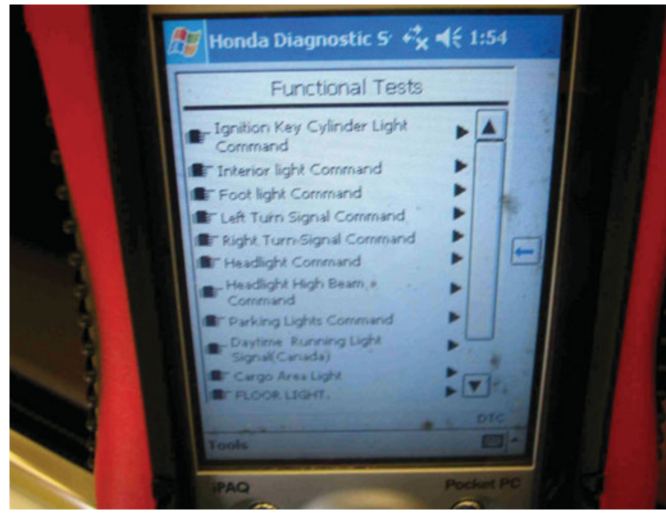


FIGURE 14–25 This Honda scan tool allows the technician to turn on individual lights and operate individual power windows and other accessories that are connected to the BUS system.

? FREQUENTLY ASKED QUESTION

How Do You Know What System Is Used?

Use service information to determine which network communication protocol is used. However, due to the various systems on some vehicles, it may be easier to look at the data link connection to determine the system. All OBD-II vehicles have terminals in the following cavities.

Terminal 4: chassis ground

Terminal 5: computer (signal) ground

Terminal 16: 12 V positive

The terminals in cavities 6 and 14 mean that this vehicle is equipped with CAN as the only module communication protocol available at the DLC. To perform a test of the BUS, use a **breakout box (BOB)** to gain access to the terminals while connecting to the vehicle, using a scan tool. ● **SEE FIGURE 14–24** or a typical OBD-II connector breakout box.

BYTEFLIGHT BUS The byteflight BUS is used in safety critical systems, such as airbags, and uses the time division multiple access (TDMA) protocol, which operates at 10 million bps using a **plastic optical fiber (POF).**

FLEXRAY BUS FlexRay BUS is a version of byteflight, and is a high-speed serial communication system for in-vehicle networks. FlexRay is commonly used for steer-by-wire and brake-by-wire systems.

DOMESTIC DIGITAL BUS The domestic digital BUS, commonly designated D2B, is an optical BUS system connecting audio, video, computer, and telephone components in a single-ring structure with a speed of up to 5,600,000 bps.

LOCAL INTERCONNECT NETWORK BUS Local interconnect network (LIN) is a BUS protocol used between intelligent sensors and actuators, and has a BUS speed of 19,200 bps.

NETWORK COMMUNICATIONS DIAGNOSIS

STEPS TO FINDING A FAULT When a network communications fault is suspected, perform the following steps.

STEP 1 **Check everything that does and does not work.** Often accessories that do not seem to be connected can help identify which module or BUS circuit is at fault.

STEP 2 **Perform module status test.** Use a factory level scan tool or an aftermarket scan tool equipped with enhanced software that allows OE-like functions. Check if the components or systems can be operated through the scan tool. ● **SEE FIGURE 14–25.**

- **Ping modules.** Start the Class 2 diagnosis by using a scan tool and select *diagnostic circuit check*. If no diagnostic trouble codes (DTCs) are shown, there could be a communication problem. Select

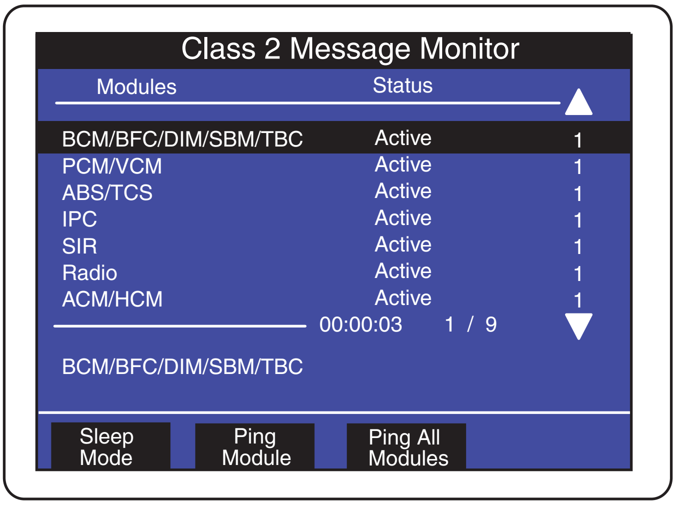


FIGURE 14–26 Modules used in a General Motors vehicle can be "pinged" using a Tech 2 scan tool.

TECH TIP

No Communication? Try Bypass Mode.

If a Tech 2 scan tool shows "no communication," try using the bypass mode to see what should be on the data display. To enter bypass mode, perform the following steps.

STEP 1 Select tool option (F3).

STEP 2 Set communications to bypass (F5).

STEP 3 Select enable.

STEP 4 Input make/model and year of vehicle.

STEP 5 Note all parameters that should be included, as shown. The values will not be shown.

message monitor, which will display the status of all of the modules on the Class 2 BUS circuit. The modules that are awake will be shown as active and the scan tool can be used to ping individual modules or command all modules. The ping command should change the status from "active" to "inactive." ● **SEE FIGURE 14–26.**

NOTE: If an excessive parasitic draw is being diagnosed, use a scan tool to ping the modules in one way to determine if one of the modules is not going to sleep and causing the excessive battery drain.

- **Check state of health.** All modules on the Class 2 BUS circuit have at least one other module responsible for reporting **state of health (SOH).** If a module fails to send a state of health message within five seconds, the companion module will set a diagnostic trouble code for the module that did not respond. The defective module is not capable of sending this message.

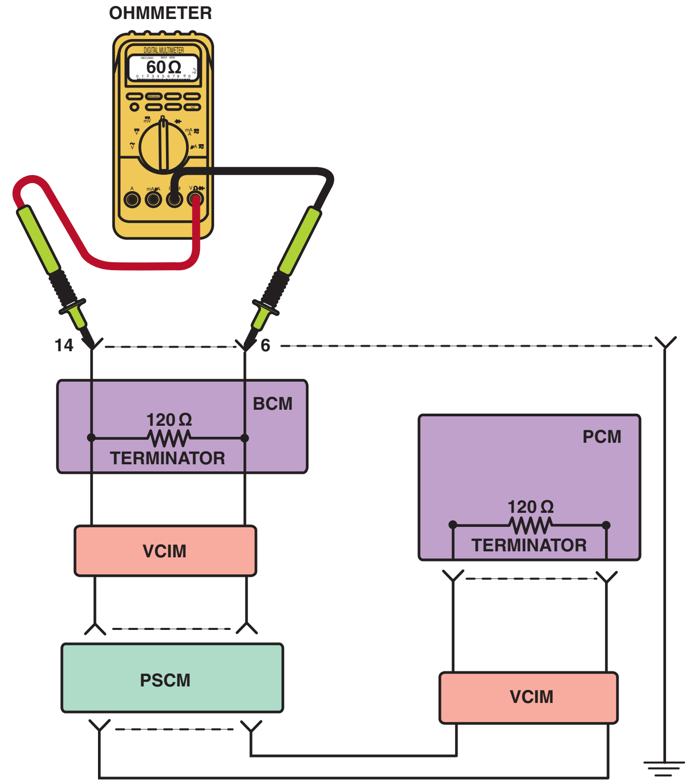


FIGURE 14–27 Checking the terminating resistors using an ohmmeter at the DLC.

STEP 3 **Check the resistance of the terminating resistors.** Most high-speed BUS systems use resistors at each end, called **terminating resistors.** These resistors are used to help reduce interference into other systems in the vehicle. Usually two 120 ohm resistors are installed at each end and are therefore connected electrically in parallel. Two 120 ohm resistors connected in parallel would measure 60 ohms if being tested using an ohmmeter. ● **SEE FIGURE 14–27.**

STEP 4 **Check data BUS for voltages.** Use a digital multimeter set to DC volts, to monitor communications and check the BUS for proper operation. Some BUS conditions and possible causes include:

- **Signal is zero volt all of the time.** Check for short-to-ground by unplugging modules one at a time to check if one module is causing the problem.
- **Signal is high or 12 volts all of the time.** The BUS circuit could be shorted to 12 V. Check with the customer to see if any service or body repair work was done recently. Try unplugging each module one at a time to pin down which module is causing the communications problem.
- **A variable voltage usually indicates that messages are being sent and received.** CAN and Class 2 can be identified by looking at the data link connector (DLC) for a terminal in cavity number 2. Class 2 is active all of the time the ignition is on, and therefore voltage variation between 0 and 7 V can be measured using a DMM set to read DC volts. ● **SEE FIGURE 14–28.**

FIGURE 14–28 Use front-probe terminals to access the data link connector. Always follow the specified back-probe and front-probe procedures as found in service information.

STEP 5 **Use a digital storage oscilloscope to monitor the waveforms of the BUS circuit.** Using a scope on the data line terminals can show if communication is being transmitted. Typical faults and their causes include:

- **Normal operation.** Normal operation shows variable voltage signals on the data lines. It is impossible to know what information is being transmitted, but if there is activity with short sections of inactivity, this indicates normal data line transmission activity. ● **SEE FIGURE 14–29.**
- **High voltage.** If there is a constant high-voltage signal without any change, this indicates that the data line is shorted to voltage.
- **Zero or low voltage.** If the data line voltage is zero or almost zero and not showing any higher voltage signals, then the data line is short-to-ground.

STEP 6 **Follow factory service information instructions to isolate the cause of the fault.** This step often involves disconnecting one module at a time to see if it is the cause of a short-to-ground or an open in the BUS circuit.

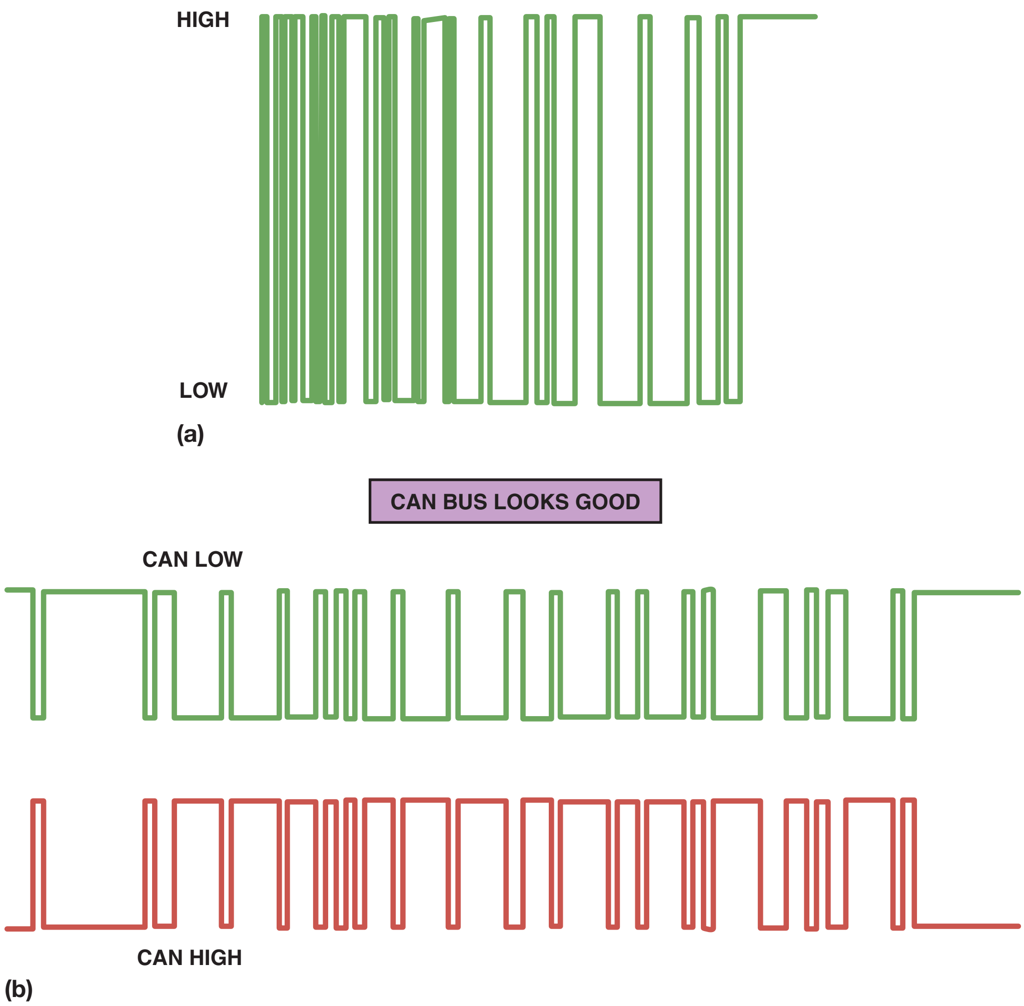


FIGURE 14–29 (a) Data is sent in packets, so it is normal to see activity then a flat line between messages. (b) A CAN BUS should show voltages that are opposite when there is normal communications. CAN H (high) circuit should go from 2.5 volts at rest to 3.5 volts when active. The CAN L (low) circuit goes from 2.5 volts at rest to 1.5 volts when active.

REAL WORLD FIX

The Radio Caused No-Start Story

A 2005 Chevrolet Cobalt did not start. A technician checked with a subscription-based helpline service and discovered that a fault with the Class 2 data circuit could prevent the engine from starting. The advisor suggested that a module should be disconnected one at a time to see if one of them was taking the data line to ground. The two most common components on the Class 2 serial data line that have been known to cause a lack of communication and become shorted-to-ground are the radio and electronic brake control module (EBCM). The first one the technician disconnected was the radio. The engine started and ran. Apparently the Class 2 serial data line was shorted-to-ground inside the radio, which took the entire BUS down. When BUS communication is lost, the PCM is not able to energize the fuel pump, ignition, or fuel injectors so the engine would not start. The radio was replaced to solve the no-start condition.

FREQUENTLY ASKED QUESTION

Which Module Is the Gateway Module?

The gateway module is responsible for communicating with other modules and acts as the main communications module for scan tool data. Most General Motors vehicles use the body control module (BCM) or the instrument panel control (IPC) module as the gateway. To verify which module is the gateway, check the schematic and look for one that has voltage applied during all of the following conditions.

- Key on, engine off
- Engine cranking
- Engine running

OBD-II DATA LINK CONNECTOR

All OBD-II vehicles use a 16 pin connector that includes:

Pin 4 = chassis ground

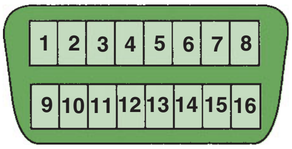
Pin 5 = signal ground

Pin 16 = battery power (4 A max)

● **SEE FIGURE 14–30.**

GENERAL MOTORS VEHICLES

- SAE J-1850 (VPW, Class 2, 10.4 Kbs) standard, which uses pins 2, 4, 5, and 16, but not 10



OBD-II DLC

PIN NO.	ASSIGNMENTS
1.	MANUFACTURER'S DISCRETION
2.	BUS + LINE, SAE J1850
3.	MANUFACTURER'S DISCRETION
4.	CHASSIS GROUND
5.	SIGNAL GROUND
6.	MANUFACTURER'S DISCRETION
7.	K LINE, ISO 9141
8.	MANUFACTURER'S DISCRETION
9.	MANUFACTURER'S DISCRETION
10.	BUS – LINE, SAE J1850
11.	MANUFACTURER'S DISCRETION
12.	MANUFACTURER'S DISCRETION
13.	MANUFACTURER'S DISCRETION
14.	MANUFACTURER'S DISCRETION
15.	L LINE, ISO 9141
16.	VEHICLE BATTERY POSITIVE (4A MAX)

FIGURE 14–30 A 16 pin OBD-II DLC with terminals identified. Scan tools use the power pin (16) and ground pin (4) for power so that a separate cigarette lighter plug is not necessary on OBD-II vehicles.

TECH TIP

Check Computer Data Line Circuit Schematic

Many General Motors vehicles use more than one type of BUS communications protocol. Check service information (SI) and look at the schematic for computer data line circuits which should show all of the data BUSes and their connectors to the diagnostic link connector (DLC). ● **SEE FIGURE 14–31.**

- GM Domestic OBD-II

  Pin 1 and 9: CCM (comprehensive component monitor) slow baud rate, 8,192 UART

  Pins 2 and 10: OEM enhanced, fast rate, 40,500 baud rate

  Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

  Pins 6 and 14: GMLAN

ASIAN, CHRYSLER, AND EUROPEAN VEHICLES

- ISO 9141-2 standard, which uses pins 4, 5, 7, 15, and 16
- Chrysler Domestic Group OBD-II

  Pins 2 and 10: CCM

  Pins 3 and 14: OEM enhanced, 60,500 baud rate

  Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

FORD VEHICLES

- SAE J-1850 (PWM, 41.6 Kbs) standard, which uses pins 2, 4, 5, 10, and 16
- Ford Domestic OBD-II

  Pins 2 and 10: CCM

  Pins 6 and 14: OEM enhanced, Class C, 40,500 baud rate

  Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

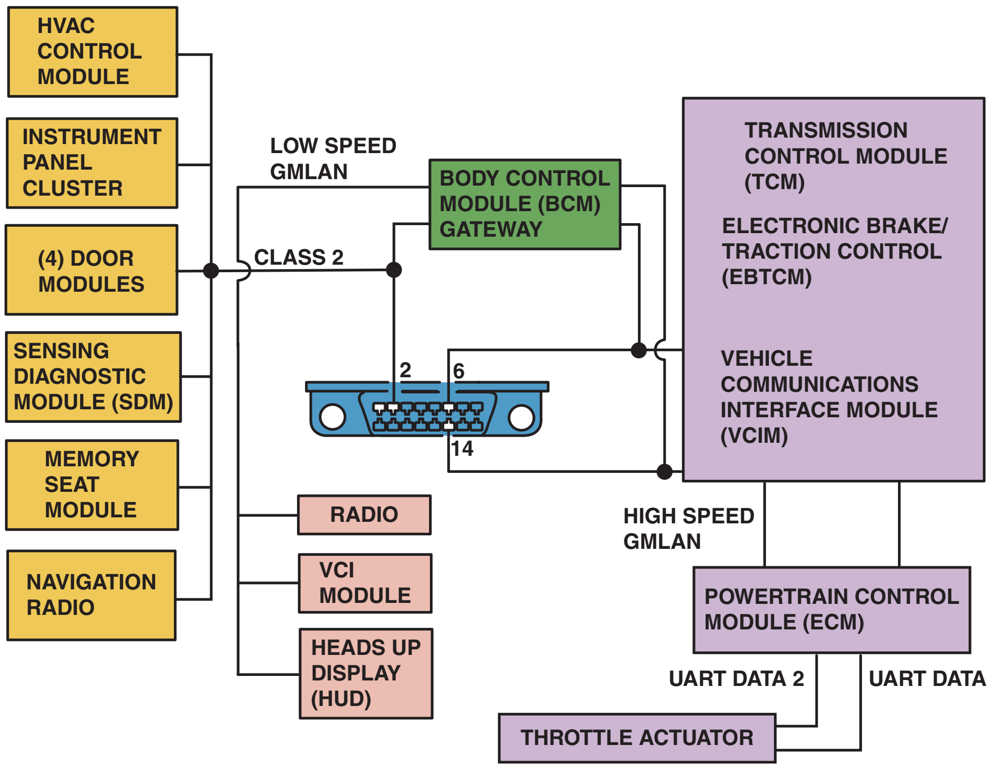


FIGURE 14–31 This schematic of a Chevrolet Equinox shows that the vehicle uses a GMLAN BUS (DLC pins 6 and 14), plus a Class 2 (pin 2) and UART.

SUMMARY

1. The use of a network for module communications reduces the number of wires and connections needed.
2. Module communication configurations include ring link, star link, and ring/star hybrid systems.
3. The SAE communication classifications for vehicle communications systems include Class A (low speed), Class B (medium speed), and Class C (high speed).
4. Various module communications used on General Motors vehicles include UART, E & C, Class 2, keyword communications, and GMLAN (CAN).
5. Types of module communications used on Ford vehicles include SCP, UBP, and CAN.
6. Chrysler brand vehicles use SCI, CCD, PCI, and CAN communications protocols.
7. Many European vehicles use an underhood electrical connector that can be used to access electrical components and modules using a breakout box (BOB) or special tester.
8. Diagnosis of network communications includes checking the terminating resistors and checking for changing voltage signals at the DLC.

REVIEW QUESTIONS

1. Why is a communication network used?
2. Why are the two wires twisted if used for network communications?
3. Why is a gateway module used?
4. What are U codes?

CHAPTER QUIZ

1. Technician A says that module communications networks are used to reduce the number of wires in a vehicle. Technician B says that a communications network is used to share data from sensors, which can be used by many different modules. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A module is also known as a ________.
   - **a.** BUS
   - **b.** Node
   - **c.** Terminator
   - **d.** Resistor pack
3. A high-speed CAN BUS communicates with a scan tool through which terminal(s)?
   - **a.** 6 and 14
   - **b.** 2
   - **c.** 7 and 15
   - **d.** 4 and 16
4. UART uses a ________ signal that toggles 0 V.
   - **a.** 5 V
   - **b.** 7 V
   - **c.** 8 V
   - **d.** 12 V
5. GM Class 2 communication toggles between ________.
   - **a.** 5 and 7 V
   - **b.** 0 and 12 V
   - **c.** 7 and 12 V
   - **d.** 0 and 7 V
6. Which terminal of the data link connector does General Motors use for Class 2 communication?
   - **a.** 1
   - **b.** 2
   - **c.** 3
   - **d.** 4
7. GMLAN is the General Motors term for which type of module communication?
   - **a.** UART
   - **b.** Class 2
   - **c.** High-speed CAN
   - **d.** Keyword 2000
8. CAN H and CAN L operate how?
   - **a.** CAN H is at 2.5 volts when not transmitting.
   - **b.** CAN L is at 2.5 volts when not transmitting.
   - **c.** CAN H goes to 3.5 volts when transmitting.
   - **d.** All of the above
9. Which terminal of the OBD-II data link connector is the signal ground for all vehicles?
   - **a.** 1
   - **b.** 3
   - **c.** 4
   - **d.** 5
10. Terminal 16 of the OBD-II data link connector is used for what?
    - **a.** Chassis ground
    - **b.** 12 V positive
    - **c.** Module (signal ground)
    - **d.** Manufacturer's discretion

chapter 15

BATTERIES

OBJECTIVES: After studying Chapter 15, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "B" (Battery Diagnosis and Service). • Describe how a battery works. • List battery ratings. • Describe deep cycling. • Discuss how charge indicators work.

KEY TERMS: AGM 198 • Ampere hour 200 • Battery Council International (BCI) 200 • CA 199 • CCA 199 • Cells 195 • Deep cycling 200 • Electrolyte 196 • Element 195 • Flooded cell battery 198 • Gassing 195 • Gel battery 198 • Grid 194 • Low-water-loss battery 194 • Maintenance-free battery 194 • MCA 199 • Partitions 196 • Porous lead 195 • Recombinant battery 198 • Reserve capacity 199 • Sediment chamber 194 • SLA 197 • SLI 194 • Specific gravity 197 • Sponge lead 195 • SVR 197 • VRLA 197

INTRODUCTION

PURPOSE AND FUNCTION Everything electrical in a vehicle is supplied current from the battery. The battery is one of the most important parts of a vehicle because it is the heart or foundation of the electrical system. The primary purpose of an automotive battery is to provide a source of electrical power for starting and for electrical demands that exceed alternator output.

WHY BATTERIES ARE IMPORTANT The battery also acts as a stabilizer to the voltage for the entire electrical system. The battery is a voltage stabilizer because it acts as a reservoir where large amounts of current (amperes) can be removed quickly during starting and replaced gradually by the alternator during charging.

- The battery *must* be in good (serviceable) condition before the charging system and the cranking system can be tested. For example, if a battery is discharged, the cranking circuit (starter motor) could test as being defective because the battery voltage might drop below specifications.
- The charging circuit could also test as being defective because of a weak or discharged battery. It is important to test the vehicle battery before further testing of the cranking or charging system.

> ? FREQUENTLY ASKED QUESTION
>
> **What Is an SLI Battery?**
>
> Sometimes the term *SLI* is used to describe a type of battery. **SLI** means **starting, lighting, and ignition,** and describes the use of a typical automotive battery. Other types of batteries used in industry are usually batteries designed to be deep cycled and are usually not as suitable for automotive needs.

BATTERY CONSTRUCTION

CASE Most automotive battery cases (container or covers) are constructed of polypropylene, a thin (approximately 0.08 in., or 0.02 mm, thick), strong, and lightweight plastic. In contrast, containers for industrial batteries and some truck batteries are constructed of a hard, thick rubber material.

Inside the case are six cells (for a 12 volt battery). ● **SEE FIGURE 15–1.** Each cell has positive and negative plates. Built into the bottom of many batteries are ribs that support the lead-alloy plates and provide a space for sediment to settle, called the **sediment chamber.** This space prevents spent active material from causing a short circuit between the plates at the bottom of the battery.

A **maintenance-free battery** uses little water during normal service because of the alloy material used to construct the battery plate grids. Maintenance-free batteries are also called **low-water-loss batteries.**

GRIDS Each positive and negative plate in a battery is constructed on a framework, or **grid,** made primarily of lead. Lead is a soft material and must be strengthened for use in an automotive battery grid. Adding antimony or calcium to the pure lead adds strength to the lead grids. ● **SEE FIGURE 15–2.**

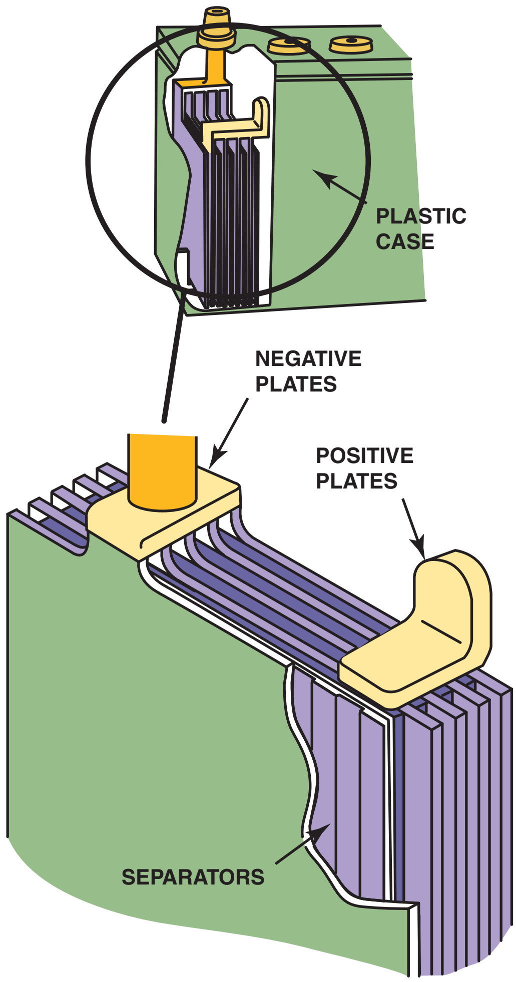


FIGURE 15–1 Batteries are constructed of plates grouped into cells and installed in a plastic case.

Battery grids hold the active material and provide the electrical pathways for the current created in the plate.

Maintenance-free batteries use calcium instead of antimony, because 0.2% calcium has the same strength as 6% antimony. A typical lead-calcium grid uses only 0.09% to 0.12% calcium. Using low amounts of calcium instead of higher amounts of antimony reduces **gassing.** Gassing is the release of hydrogen and oxygen from the battery that occurs during charging and results in water usage.

Low-maintenance batteries use a low percentage of antimony (about 2% to 3%), or use antimony only in the positive grids and calcium for the negative grids. *The percentages that make up the alloy of the plate grids constitute the major difference between standard and maintenance-free batteries.* The chemical reactions that occur inside each battery are identical regardless of the type of material used to construct the grid plates.

POSITIVE PLATES The positive plates have *lead dioxide (peroxide)*, in paste form placed onto the grid framework. This process is called *pasting*. This active material can react with the sulfuric acid of the battery and is dark brown in color.

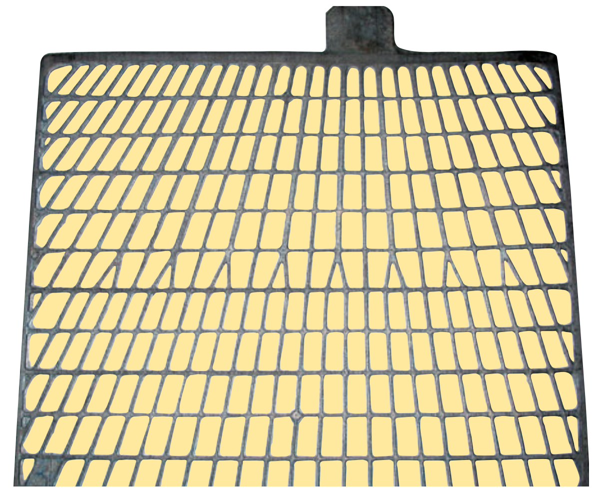


FIGURE 15–2 A grid from a battery used in both positive and negative plates.

NEGATIVE PLATES The negative plates are pasted to the grid with a pure **porous lead,** called **sponge lead,** and are gray in color.

SEPARATORS The positive and the negative plates must be installed alternately next to each other without touching. Nonconducting *separators* are used, which allow room for the reaction of the acid with both plate materials, yet insulate the plates to prevent shorts. These separators are porous (with many small holes) and have ribs facing the positive plate. Separators can be made from resin-coated paper, porous rubber, fiberglass, or expanded plastic. Many batteries use envelope-type separators that encase the entire plate and help prevent any material that may shed from the plates from causing a short circuit between plates at the bottom of the battery.

CELLS **Cells** are constructed of positive and negative plates with insulating separators between each plate. Most batteries use one more negative plate than positive plate in each cell; however, many newer batteries use the same number of positive and negative plates. A cell is also called an **element.** Each cell is actually a 2.1 volt battery, regardless of the number of positive or negative plates used. The greater the number of plates used in each cell, the greater the amount of *current* that can be produced. Typical batteries contain four positive plates and five negative plates per cell. A 12 volt battery contains six cells connected in series, which produce 12.6 volts ($6 \times 2.1 = 12.6$) and contain 54 plates (9 plates per cell $\times$ 6 cells). If the same 12 volt battery had five positive plates and six negative plates, for a total of 11 plates per cell ($5 + 6$), or 66 plates (11 plates $\times$ 6 cells), then it would have the same voltage, but the amount of current that the battery could produce would be increased. ● **SEE FIGURE 15–3.**

The amperage capacity of a battery is determined by the amount of active plate material in the battery and the area of the plate material exposed to the electrolyte in the battery.

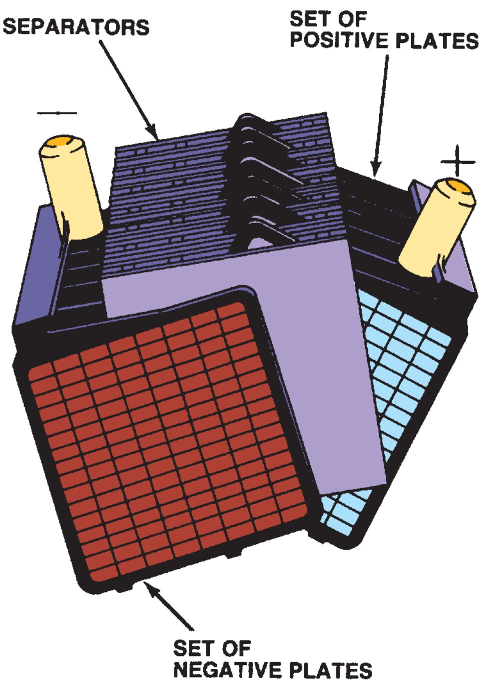


FIGURE 15–3 Two groups of plates are combined to form a battery element.

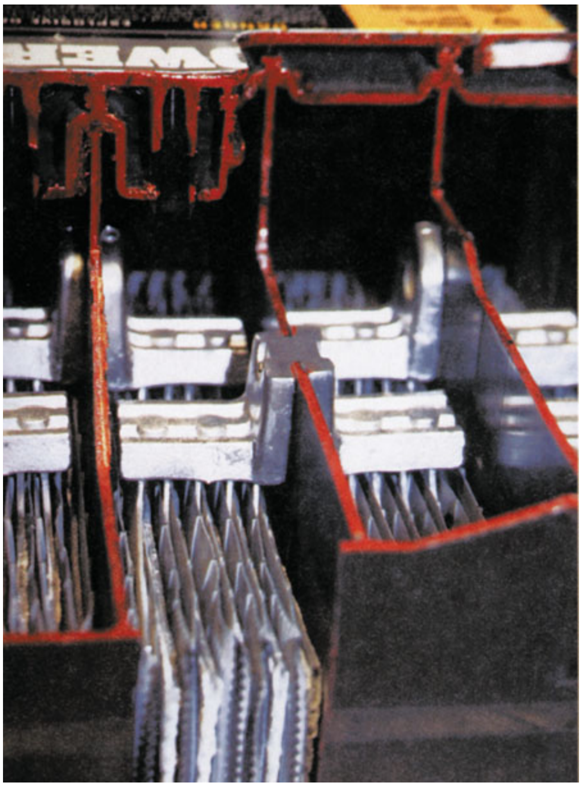


FIGURE 15–4 A cutaway battery showing the connection of the cells to each other through the partition.

PARTITIONS Each cell is separated from the other cells by **partitions,** which are made of the same material as that used for the outside case of the battery. Electrical connections between cells are provided by lead connectors that loop over the top of the partition and connect the plates of the cells together. Many batteries connect the cells directly through the partition connectors, which provide the shortest path for the current and the lowest resistance. ● **SEE FIGURE 15–4.**

ELECTROLYTE **Electrolyte** is the term used to describe the acid solution in a battery. The electrolyte used in automotive batteries is a solution (liquid combination) of 36% sulfuric acid and 64% water. This electrolyte is used for both lead-antimony and lead-calcium (maintenance-free) batteries. The chemical symbol for this sulfuric acid solution is H_2SO_4.

H_2 = Symbol for hydrogen (the subscript 2 means that there are two atoms of hydrogen)

S = Symbol for sulfur

O_4 = Symbol for oxygen (the subscript 4 indicates that there are four atoms of oxygen)

Electrolyte is sold premixed in the proper proportion and is factory installed or added to the battery when the battery is sold. Additional electrolyte must *never* be added to any battery after the original electrolyte fill. It is normal for some water (H_2O) in the form of hydrogen and oxygen gases to escape during charging as a result of the chemical reactions. The escape of gases from a battery during charging or discharging is called gassing. Only pure distilled water should be added to a battery. If distilled water is not available, clean drinking water can be used.

HOW A BATTERY WORKS

PRINCIPLE INVOLVED The principle of how a battery works is based on a scientific principle discovered years ago that states:

- When two dissimilar metals are placed in an acid, electrons flow between the metals if a circuit is connected between them.
- This can be demonstrated by pushing a steel nail and a piece of solid copper wire into a lemon. Connect a voltmeter to the ends of the copper wire and nail, and voltage will be displayed.

A fully charged lead-acid battery has a positive plate of lead dioxide (peroxide) and a negative plate of lead surrounded by a sulfuric acid solution (electrolyte). The difference in potential (voltage) between lead peroxide and lead in acid is approximately 2.1 volts.

DURING DISCHARGING The positive plate lead dioxide (PbO_2) combines with the SO_4, forming $PbSO_4$ from the electrolyte and releases its O_2 into the electrolyte, forming H_2O. The negative plate also combines with the SO_4 from the electrolyte and becomes lead sulfate ($PbSO_4$). ● **SEE FIGURE 15–5.**

FULLY DISCHARGED STATE When the battery is fully discharged, both the positive and the negative plates are $PbSO_4$ (lead sulfate) and the electrolyte has become water

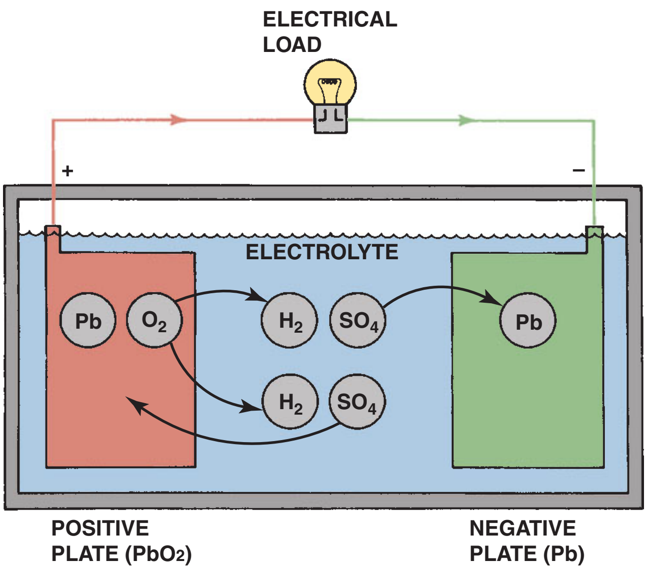


FIGURE 15–5 Chemical reaction for a lead-acid battery that is fully charged being discharged by the attached electrical load.

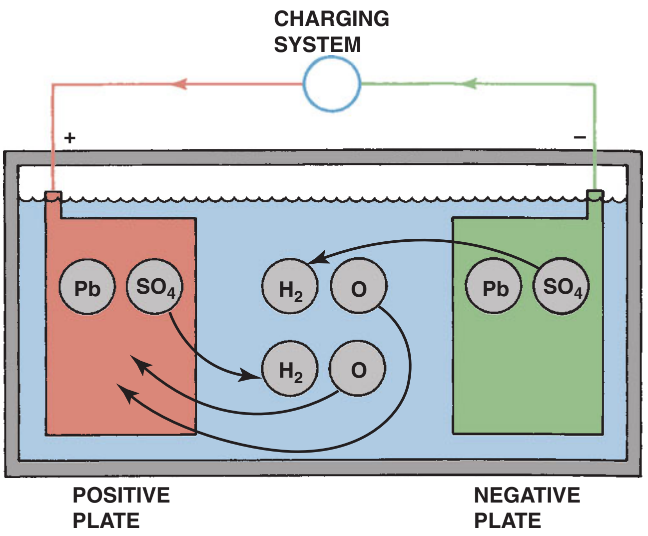


FIGURE 15–6 Chemical reaction for a lead-acid battery that is fully discharged being charged by the attached generator.

(H_2O). As the battery is being discharged, the plates and electrolyte approach the completely discharged state. There is also the danger of freezing when a battery is discharged, because the electrolyte is mostly water.

CAUTION: Never charge or jump start a frozen battery because the hydrogen gas can get trapped in the ice and ignite if a spark is caused during the charging process. The result can be an explosion.

DURING CHARGING During charging, the sulfate from the acid leaves both the positive and the negative plates and returns to the electrolyte, where it becomes normal-strength sulfuric acid solution. The positive plate returns to lead dioxide (PbO_2), the negative plate is again pure lead (Pb), and the electrolyte becomes H_2SO_4. ● **SEE FIGURE 15–6.**

SPECIFIC GRAVITY

DEFINITION The amount of sulfate in the electrolyte is determined by the electrolyte's **specific gravity,** which is the ratio of the weight of a given volume of a liquid to the weight of an equal volume of water. In other words, the more dense the liquid is, the higher its specific gravity. Pure water is the basis for this measurement and is given a specific gravity of 1.000 at 80°F (27°C). Pure sulfuric acid has a specific gravity of 1.835; the *correct* concentration of water and sulfuric acid (called electrolyte—64% water, 36% acid) is 1.260 to 1.280 at 80°F. The higher the battery's specific gravity, the more fully it is charged. ● **SEE FIGURE 15–7.**

CHARGE INDICATORS Some batteries are equipped with a built-in state-of-charge indicator, commonly called *green eyes*. This indicator is simply a small, ball-type hydrometer that is installed in one cell. This hydrometer uses a plastic ball that floats if the electrolyte density is sufficient (which it is when the battery is about 65% charged). When the ball floats, it appears in the hydrometer's sight glass, changing its color. ● **SEE FIGURE 15–8.**

Because the hydrometer is only testing one cell (out of six on a 12 volt battery), and because the hydrometer ball can easily stick in one position, do not trust that this is accurate information about a state of charge (SOC) of the battery.

Values of specific gravity, state of charge, and battery voltage at 80°F (27°C) are given in ● **CHART 15–1.**

> ? **FREQUENTLY ASKED QUESTION**
>
> **Is There an Easy Way to Remember How a Battery Works?**
>
> Yes. Think of the sulfuric acid solution in the electrolyte being deposited, then removed from the plates.
>
> - **During discharge.** The acid (SO_4) is leaving the electrolyte and getting onto both plates.
> - **During charging.** The acid (SO_4) is being forced from both plates and enters the electrolyte.

VALVE REGULATED LEAD-ACID BATTERIES

TERMINOLOGY There are two basic types of **valve regulated lead-acid (VRLA),** also called **sealed valve-regulated (SVR)** or **sealed lead-acid (SLA),** batteries. These batteries

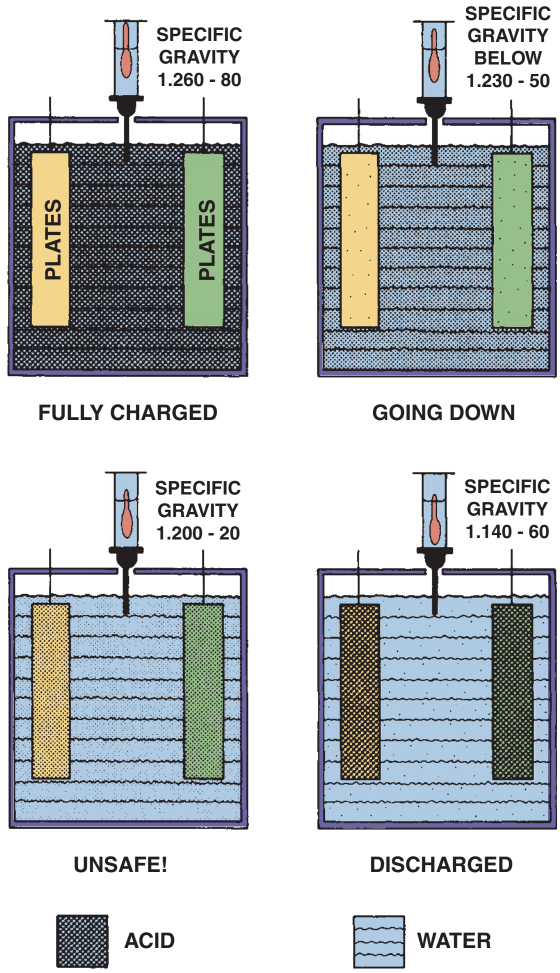


FIGURE 15–7 As the battery becomes discharged, the specific gravity of the battery acid decreases.

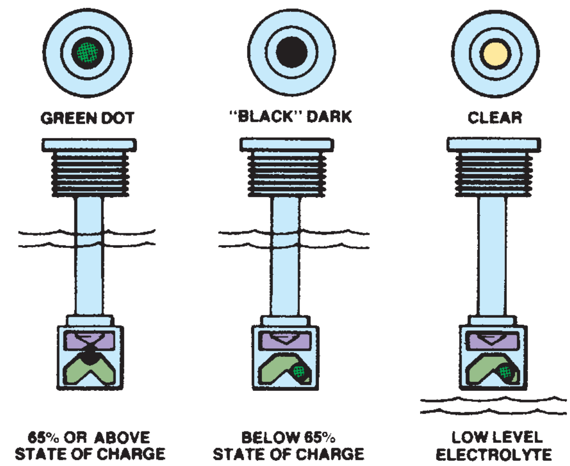


FIGURE 15–8 Typical battery charge indicator. If the specific gravity is low (battery discharged), the ball drops away from the reflective prism. When the battery is charged enough, the ball floats and reflects the color of the ball (usually green) back up through the sight glass and the sight glass is dark.

SPECIFIC GRAVITY	STATE OF CHARGE	BATTERY VOLTAGE (V)
1.265	Fully charged	12.6 or higher
1.225	75% charged	12.4
1.190	50% charged	12.2
1.155	25% charged	12.0
Lower than 1.120	Discharged	11.9 or lower

CHART 15–1

A comparison showing the relationship among specific gravity, battery voltage, and state of charge.

use a low-pressure venting system that releases excess gas and automatically reseals if a buildup of gas is created due to overcharging. The two types include the following:

- **Absorbed glass mat.** The acid used in an **absorbed glass mat (AGM)** battery is totally absorbed into the separator, making the battery leakproof and spillproof. The battery is assembled by compressing the cell about 20%, then inserting it into the container. The compressed cell helps reduce damage caused by vibration and helps keep the acid tightly against the plates. The sealed maintenance-free design uses a pressure release valve in each cell. Unlike conventional batteries that use a liquid electrolyte, called **flooded cell batteries,** most of the hydrogen and oxygen given off during charging remains inside the battery. The separator or mat is only 90% to 95% saturated with electrolyte, thereby allowing a portion of the mat to be filled with gas. The gas spaces provide channels to allow the hydrogen and oxygen gases to recombine rapidly and safely. Because the acid is totally absorbed into the glass mat separator, an AGM battery can be mounted in any direction. AGM batteries also have a longer service life, often lasting 7 to 10 years. Absorbed glass mat batteries are used as standard equipment in some vehicles such as the Chevrolet Corvette and in most Toyota hybrid electric vehicles. ● **SEE FIGURE 15–9.**
- **Gelled electrolyte batteries.** In a gelled electrolyte battery, silica is added to the electrolyte, which turns the electrolyte into a substance similar to gelatin. This type of battery is also called a **gel battery.**

Both types of valve-regulated, lead-acid batteries are also called **recombinant battery** design. A recombinant-type battery means that the oxygen gas generated at the positive plate travels through the dense electrolyte to the negative plate. When the oxygen reaches the negative plate, it reacts with the lead, which consumes the oxygen gas and prevents the formation of hydrogen gas. It is because of this oxygen recombination that VRLA batteries do not use water.

FIGURE 15–9 An absorbed glass mat battery is totally sealed and is more vibration resistant than conventional lead-acid batteries.

FIGURE 15–10 A typical battery hold-down bracket. All batteries should use a bracket to prevent battery damage due to vibration and shock.

CAUSES AND TYPES OF BATTERY FAILURE

NORMAL LIFE Most automotive batteries have a useful service life of three to seven years; however, proper care can help increase the life of a battery, but abuse can shorten it. The major cause of premature battery failure is overcharging.

CHARGING VOLTAGE The automotive charging circuit, consisting of an alternator and connecting wires, must be operating correctly to prevent damage to the battery.

- Charging voltages higher than 15.5 volts can damage a battery by warping the plates as a result of the heat of overcharging.
- AGM batteries can be damaged if charged at a voltage higher than 14.5 volts.

Overcharging also causes the active plate material to disintegrate and fall out of the supporting grid framework. Vibration or bumping can also cause internal damage similar to that caused by overcharging. It is important, therefore, to ensure that all automotive batteries are securely clamped down in the vehicle. The shorting of cell plates can occur without notice. If one of the six cells of a 12 volt battery is shorted, the resulting voltage of the battery is only 10 volts ($12 - 2 = 10$). With only 10 volts available, the starter *usually* will not be able to start the engine.

BATTERY HOLD-DOWNS All batteries must be attached securely to the vehicle to prevent battery damage. Normal vehicle vibrations can cause the active materials inside the battery to shed. Battery hold-down clamps or brackets help reduce vibration, which can greatly reduce the capacity and life of any battery. ● **SEE FIGURE 15–10.**

BATTERY RATINGS

Batteries are rated according to the amount of current they can produce under specific conditions.

COLD-CRANKING AMPERES Every automotive battery must be able to supply electrical power to crank the engine in cold weather and still provide battery voltage high enough to operate the ignition system for starting. The cold-cranking ampere rating of a battery is the number of amperes that can be supplied by a battery at 0°F (−18°C) for 30 seconds while the battery still maintains a voltage of 1.2 volts per cell or higher. This means that the battery voltage would be 7.2 volts for a 12 volt battery and 3.6 volts for a 6 volt battery. The cold-cranking performance rating is called **cold-cranking amperes (CCA).** Try to purchase a battery with the highest CCA for the money. See the vehicle manufacturer's specifications for recommended battery capacity.

CRANKING AMPERES The designation **CA** refers to the number of amperes that can be supplied by a battery at 32°F (0°C). This rating results in a higher number than the more stringent CCA rating. ● **SEE FIGURE 15–11.**

MARINE CRANKING AMPERES **Marine cranking amperes (MCA)** is similar to cranking amperes and is tested at 32°F (0°C).

RESERVE CAPACITY The **reserve capacity** rating for batteries is *the number of minutes* for which the battery can produce 25 amperes and still have a battery voltage of 1.75 volts per cell (10.5 volts for a 12 volt battery). This rating is actually a measurement of the time for which a vehicle can be driven in the event of a charging system failure.

FIGURE 15–11 This battery has a cranking amperes (CA) rating of 1,000. This means that this battery is capable of cranking an engine for 30 seconds at a temperature of 32°F (0°C) at a minimum of 1.2 volts per cell (7.2 volts for a 12 volt battery).

? FREQUENTLY ASKED QUESTION

What Determines Battery Capacity?

The capacity of any battery is determined by the amount of active plate material in the battery. A battery with a large number of thin plates can produce high current for a short period. If a few thick plates are used, the battery can produce low current for a long period. A trolling motor battery used for fishing must supply a low current for a long period of time. An automotive battery is required to produce a high current for a short period for cranking. Therefore, every battery is designed for a specific application.

AMPERE HOUR **Ampere hour** is an older battery rating system that measures how many amperes of current the battery can produce over a period of time. For example, a battery that has a 50 amp-hour (A-H) rating can deliver 50 amperes for one hour or 1 ampere for 50 hours or any combination that equals 50 amp-hours.

? FREQUENTLY ASKED QUESTION

What Is Deep Cycling?

Deep cycling is almost fully discharging a battery and then completely recharging it. Golf cart batteries are an example of lead-acid batteries that must be designed to be deep cycled. A golf cart must be able to cover two 18-hole rounds of golf and then be fully recharged overnight. Charging is hard on batteries because the internal heat generated can cause plate warpage, so these specially designed batteries use thicker plate grids that resist warpage. Normal automotive batteries are not designed for repeated deep cycling.

BATTERY SIZES

BCI GROUP SIZES Battery sizes are standardized by the **Battery Council International (BCI).** When selecting a replacement battery, check the specified group number in service information, battery application charts at parts stores, or the owner's manual.

TYPICAL GROUP SIZE APPLICATIONS

- **24/24F (top terminals).** Fits many Honda, Acura, Infinity, Lexus, Nissan, and Toyota vehicles.
- **34/78 (dual terminals, both side and top posts).** Fits many General Motors pickups and SUVs, as well as midsize and larger GM sedans and large Chrysler/Dodge vehicles.
- **35 (top terminals).** Fits many Japanese brand vehicles.
- **65 (top terminals).** Fits most large Ford/Mercury passenger cars, trucks, and SUVs.
- **75 (side terminals).** Fits some General Motors small and midsize cars and some Chrysler/ Dodge vehicles.
- **78 (side terminals).** Fits many General Motors pickups and SUVs, as well as midsize and larger GM sedans.

Exact dimensions can be found on the Internet by searching for BCI battery sizes.

SUMMARY

1. Maintenance-free batteries use lead-calcium grids instead of lead-antimony grids to reduce gassing.
2. When a battery is being discharged, the acid (SO_4) is leaving the electrolyte and being deposited on the plates. When the battery is being charged, the acid (SO_4) is forced off the plates and back into the electrolyte.
3. All batteries give off hydrogen and oxygen when being charged.
4. Batteries are rated according to CCA and reserve capacity.

REVIEW QUESTIONS

1. Why can discharged batteries freeze?
2. What are the battery-rating methods?
3. Why can a battery explode if it is exposed to an open flame or spark?

CHAPTER QUIZ

1. When a battery becomes completely discharged, both positive and negative plates become ________ and the electrolyte becomes ________.
   a. H_2SO_4 / Pb
   b. $PbSO_4$ / H_2O
   c. PbO_2 / H_2SO_4
   d. $PbSO_4$ / H_2SO_4
2. A fully charged 12 volt battery should indicate ________.
   a. 12.6 volts or higher
   b. A specific gravity of 1.265 or higher
   c. 12 volts
   d. Both a and b
3. Deep cycling means ________.
   a. Overcharging the battery
   b. Overfilling or underfilling the battery with water
   c. The battery is fully discharged and then recharged
   d. The battery is overfilled with acid (H_2SO_4)
4. What makes a battery “low maintenance” or “maintenance free”?
   a. Material is used to construct the grids.
   b. The plates are constructed of different metals.
   c. The electrolyte is hydrochloric acid solution.
   d. The battery plates are smaller, making more room for additional electrolytes.
5. The positive battery plate is ________.
   a. Lead dioxide
   b. Brown in color
   c. Sometimes called lead peroxide
   d. All of the above
6. Which battery rating is tested at 0°F (−18°C)?
   a. Cold-cranking amperes (CCA)
   b. Cranking amperes (CA)
   c. Reserve capacity
   d. Battery voltage test
7. Which battery rating is expressed in minutes?
   a. Cold-cranking amperes (CCA)
   b. Cranking amperes (CA)
   c. Reserve capacity
   d. Battery voltage test
8. What battery rating is tested at 32°F (0°C)?
   a. Cold-cranking amperes (CCA)
   b. Cranking amperes (CA)
   c. Reserve capacity
   d. Battery voltage test
9. What gases are released from a battery when it is being charged?
   a. Oxygen
   b. Hydrogen
   c. Nitrogen and oxygen
   d. Hydrogen and oxygen
10. A charge indicator (eye) operates by showing green or red when the battery is charged and dark if the battery is discharged. This charge indicator detects ________.
   a. Battery voltage
   b. Specific gravity
   c. Electrolyte water pH
   d. Internal resistance of the cells

chapter 16

BATTERY TESTING AND SERVICE

OBJECTIVES: After studying Chapter 16, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "B" (Battery Diagnosis and Service). • List the precautions necessary when working with batteries. • Explain how to safely charge a battery. • Discuss how to perform a battery drain test. • Describe how to perform a battery load test. • Explain how to conduct a conductance test. • Discuss how to test batteries for open-circuit voltage and specific gravity.

KEY TERMS: Battery electrical drain test 211 • Dynamic voltage 203 • Hydrometer 205 • IOD 211 • Load test 205 • Open circuit voltage 203 • Parasitic load test 211 • Three-minute charge test 205

BATTERY SERVICE SAFETY CONSIDERATIONS

HAZARDS Batteries contain acid and release explosive gases (hydrogen and oxygen) during normal charging and discharging cycles.

SAFETY PROCEDURES To help prevent physical injury or damage to the vehicle, always adhere to the following safety procedures.

1. When working on any electrical component on a vehicle, disconnect the negative battery cable from the battery. When the negative cable is disconnected, all electrical circuits in the vehicle will be open, which will prevent accidental electrical contact between an electrical component and ground. Any electrical spark has the potential to cause explosion and personal injury.
2. Wear eye protection (goggles preferred) when working around any battery.
3. Wear protective clothing to avoid skin contact with battery acid.
4. Always adhere to all safety precautions as stated in the service procedures for the equipment used for battery service and testing.
5. Never smoke or use an open flame around any battery.

SYMPTOMS OF A WEAK OR DEFECTIVE BATTERY

The following warning signs indicate that a battery is near the end of its useful life.

- **Uses water in one or more cells.** This indicates that the plates are sulfated and that during the charging process, the water in the electrolyte is being turned into separate hydrogen and oxygen gases. ● **SEE FIGURE 16–1.**
- **Excessive corrosion on battery cables or connections.** Corrosion is more likely to occur if the battery is sulfated, creating hot spots on the plates. When the battery is being charged, the acid fumes are forced

FIGURE 16–1 A visual inspection on this battery shows the electrolyte level was below the plates in all cells.

FIGURE 16–2 Corrosion on a battery cable could be an indication that the battery itself is either being overcharged or is sulfated, creating a lot of gassing of the electrolyte.

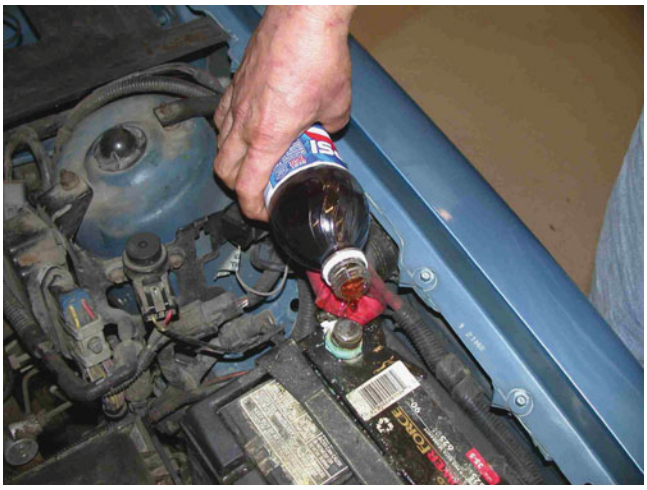


FIGURE 16–3 Besides baking soda and water, a sugar-free diet soft drink can also be used to neutralize the battery acid.

TECH TIP

Dynamic versus Open Circuit Voltage

Open circuit voltage is the voltage (usually of a battery) that exists *without* a load being applied. **Dynamic voltage** is the voltage of the power source (battery) with the circuit in operation. A vehicle battery, for example, may indicate that it has 12.6 volts or more, but that voltage will drop when the battery is put under a load such as cranking the engine. If the battery voltage drops too much, the starter motor will rotate more slowly and the engine may not start.

If the dynamic voltage is lower than specified, the battery may be weak or defective or the circuit may be defective.

out of the vent holes and onto the battery cables, connections, and even on the battery tray underneath the battery. ● **SEE FIGURE 16–2.**

- **Slower than normal engine cranking.** When the capacity of the battery is reduced due to damage or age, it is less likely to be able to supply the necessary current for starting the engine, especially during cold weather.

BATTERY MAINTENANCE

NEED FOR MAINTENANCE Most new-style batteries are of a maintenance-free design that uses lead-calcium instead of lead-antimony plate grid construction. Because lead-calcium batteries do not release as much gas as the older-style, lead-antimony batteries, there is less consumption of water during normal service. Also, with less gassing, less corrosion is observed on the battery terminals, wiring, and support trays. If the electrolyte level can be checked, and if it is low, add only distilled water. Distilled water is recommended by all battery manufacturers, but if distilled water is not available, clean ordinary drinking water, low in mineral content, can be used.

Battery maintenance includes making certain that the battery case is clean and checking that the battery cables and hold-down fasteners are clean and tight.

BATTERY TERMINAL CLEANING Many battery-related faults are caused by poor electrical connections at the battery. Battery cable connections should be checked and cleaned to prevent voltage drop at the connections. One common reason for an engine to not start is loose or corroded battery cable connections. Perform an inspection and check for the following conditions.

- Loose or corroded connections at the battery terminals (should not be able to be moved by hand)
- Loose or corroded connections at the ground connector on the engine block
- Wiring that has been modified to add auxiliary power for a sound system, or other electrical accessory

If the connections are loose or corroded, use 1 tablespoon of baking soda in 1 quart (liter) of water and brush this mixture onto the battery and housing to neutralize the acid. Mechanically clean the connections and wash the area with water. ● **SEE FIGURE 16–3.**

BATTERY HOLD-DOWN The battery should also be secured with a hold-down bracket to prevent vibration from damaging the plates inside the battery. The hold-down bracket should be snug enough to prevent battery movement, yet not so tight as to cause the case to crack. Factory-original hold-down brackets are often available through local automobile dealers, and universal hold-down units are available through local automotive parts stores.

(a) (b)

FIGURE 16–4 (a) A voltage reading of 12.28 volts indicates that the battery is not fully charged and should be charged before testing. (b) A battery that measures 12.6 volts or higher after the surface charge has been removed is 100% charged.

BATTERY VOLTAGE TEST

STATE OF CHARGE Testing the battery voltage with a voltmeter is a simple method for determining the state of charge of any battery. ● **SEE FIGURE 16–4.**

The voltage of a battery does not necessarily indicate whether the battery can perform satisfactorily, but it does indicate to the technician more about the battery's condition than a simple visual inspection. A battery that "looks good" may not be good. This test is commonly called an *open circuit battery voltage test* because it is conducted with an open circuit, no current flowing, and no load applied to the battery.

1. If the battery has just been charged or the vehicle has recently been driven, it is necessary to remove the surface charge from the battery before testing. A surface charge is a charge of higher-than-normal voltage that is just on the surface of the battery plates. The surface charge is quickly removed when the battery is loaded and therefore does not accurately represent the true state of charge of the battery.
2. To remove the surface charge, turn the headlights on high beam (brights) for one minute, then turn the headlights off and wait two minutes.
3. With the engine and all electrical accessories off, and the doors shut (to turn off the interior lights), connect a voltmeter to the battery posts. Connect the red positive lead to the positive post and the black negative lead to the negative post.

NOTE: If the meter reads negative (−), the battery has been reverse charged (has reversed polarity) and should be replaced, or the meter has been connected incorrectly.

4. Read the voltmeter and compare the results with the state of charge. The voltages shown are for a battery at or near room temperature (70°F to 80°F, or 21°C to 27°C). ● **SEE CHART 16–1.**

BATTERY VOLTAGE (V)	STATE OF CHARGE
12.6 or higher	100% charged
12.4	75% charged
12.2	50% charged
12.0	25% charged
11.9 or lower	Discharged

CHART 16–1

The estimated state of charge of a 12 volt battery after the surface charge has been removed.

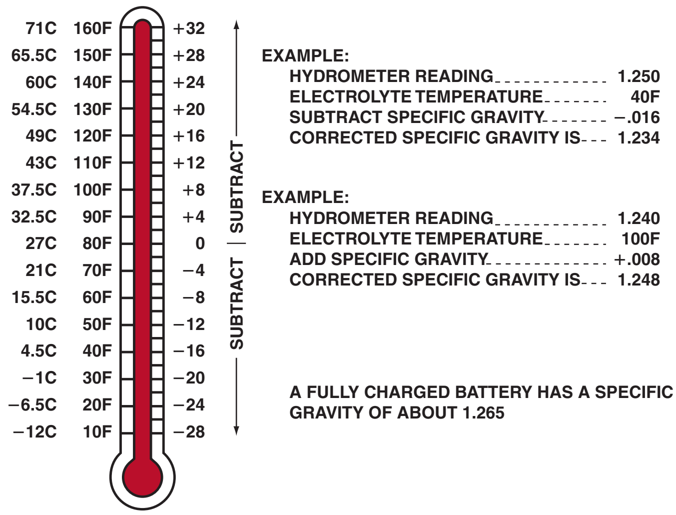


FIGURE 16–5 When testing a battery using a hydrometer, the reading must be corrected if the temperature is above or below 80°F (27°C).

HYDROMETER TESTING

If the battery has removable filler caps, the specific gravity of the electrolyte can also be checked. A **hydrometer** is a tester that measures the specific gravity. ● **SEE FIGURE 16–5.**

This test can also be performed on most maintenance-free batteries because their filler caps are removable, except for those produced by Delco (Delphi) Battery. The specific gravity test indicates the state of battery charge and can indicate a defective battery if the specific gravity of one or more cells varies by more than 0.050 from the value of the highest-reading cell. ● **SEE CHART 16–2.**

SPECIFIC GRAVITY	BATTERY VOLTAGE (V)	STATE OF CHARGE
1.265	12.6 or higher	100% charged
1.225	12.4	75% charged
1.190	12.2	50% charged
1.155	12.0	25% charged
Lower than 1.120	11.9 or lower	Discharged

CHART 16–2

Measuring the specific gravity can detect a defective battery. A battery should be at least 75% charged before being load tested.

FREQUENTLY ASKED QUESTION

What Is the Three-Minute Charge Test?

A **three-minute charge test** is used to check if a battery is sulfated, and is performed as follows:

- Connect a battery charger and a voltmeter to the battery terminals.
- Charge the battery at a rate of 40 amperes for three minutes.
- At the end of three minutes, read the voltmeter.

Results: If the voltage is above 15.5 volts, replace the battery. If the voltage is below 15.5 volts, the battery is not sulfated and should be charged and retested.

This is *not* a valid test of many maintenance-free batteries, such as the Delphi Freedom. Due to the high internal resistance, a discharged Delphi Freedom battery may not start to accept a charge for several hours. Always use another alternative battery test before discarding a battery based on the results of the three-minute charge test.

BATTERY LOAD TESTING

TERMINOLOGY One test to determine the condition of any battery is the **load test.** Most automotive starting and charging testers use a carbon pile to create an electrical load on the battery. The amount of the load is determined by the original CCA rating of the battery, which should be at least 75% charged before performing a load test. The capacity is measured in cold-cranking amperes, which is the number of amperes that a battery can supply at 0°F (−18°C) for 30 seconds.

TEST PROCEDURE To perform a battery load test, take the following steps.

STEP 1 **Determine the CCA rating of the battery.** The proper electrical load used to test a battery is half of the CCA rating or three times the ampere-hour rating, with a minimum 150 ampere load. ● **SEE FIGURE 16–6.**

STEP 2 **Connect the load tester to the battery.** Follow the instructions for the tester being used.

STEP 3 **Apply the load for a full 15 seconds.** Observe the voltmeter during the load testing and check the voltage at the end of the 15 sec. period while the battery is still under load. A good battery should indicate above 9.6 V.

STEP 4 **Repeat the test.** Many battery manufacturers recommend performing the load test twice, using the first load period to remove the surface charge on the battery and the second test to provide a truer indication of the condition of the battery. Wait 30 seconds between tests to allow time for the battery to recover. ● **SEE FIGURE 16–7.**

Results: If the battery fails the load test, recharge the battery and retest. If the load test is failed again, replacement of the battery is required.

FIGURE 16–6 This battery has cold-cranking amperes (CCA) of 550 A, cranking amperes (CA) of 680 A, and load test amperes of 270 A listed on the top label. Not all batteries have this complete information.

FIGURE 16–7 An alternator regulator battery starter tester (ARBST) automatically loads the battery with a fixed load for 15 sec. to remove the surface charge, then removes the load for 30 sec. to allow the battery to recover, and then reapplies the load for another 15 sec. The results of the test are then displayed.

? FREQUENTLY ASKED QUESTION

How Should You Test a Vehicle Equipped with Two Batteries?

Many vehicles equipped with a diesel engine use two batteries. These batteries are usually electrically connected in parallel to provide additional current (amperes) at the same voltage. ● **SEE FIGURE 16–8.**

Some heavy-duty trucks and buses connect two batteries in series to provide about the same current as one battery, but with twice the voltage, as shown in ● **FIGURE 16–9.**

To successfully test the batteries, they should be disconnected and tested separately. If just one battery is found to be defective, most experts recommend that both be replaced to help prevent future problems. Because the two batteries are electrically connected, a fault in one battery can cause the good battery to discharge into the defective battery, thereby affecting both even if just one battery is at fault.

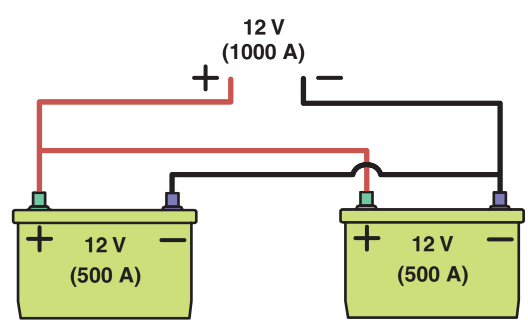


FIGURE 16–8 Most light-duty vehicles equipped with two batteries are connected in parallel as shown. Two 500 A, 12 volt batteries are capable of supplying 1,000 A at 12 volts, which is needed to start many diesel engines.

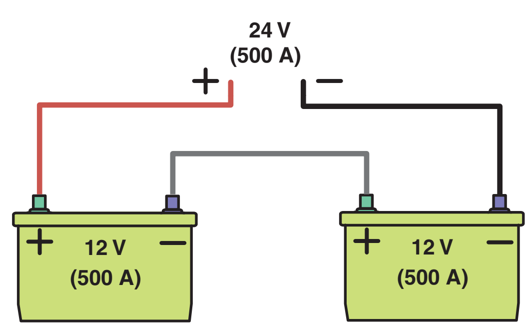


FIGURE 16–9 Many heavy-duty trucks and buses use two 12 volt batteries connected in series to provide 24 volts.

ELECTRONIC CONDUCTANCE TESTING

TERMINOLOGY General Motors Corporation, Chrysler Corporation, and Ford specify that an electronic conductance tester be used to test batteries in vehicles still under factory warranty. Conductance is a measure of how well a battery can create current. This tester sends a small signal through the battery and then measures a part of the AC response. As a battery ages, the plates can become sulfated and shed active materials from the grids, reducing the battery capacity. Conductance testers can be used to test flooded or absorbed glass (AGM) type batteries. The unit can determine the following information about a battery.

- CCA
- State of charge
- Voltage of the battery
- Defects such as shorts and opens

FIGURE 16–10 A conductance tester is very easy to use and has proved to accurately determine battery condition if the connections are properly made. Follow the instructions on the display exactly for best results.

However, a conductance tester is not designed to accurately determine the state of charge or CCA rating of a new battery. Unlike a battery load test, a conductance tester can be used on a battery that is discharged. This type of tester should only be used to test batteries that have been in service. ● **SEE FIGURE 16–10.**

TEST PROCEDURE

STEP 1 Connect the unit to the positive and negative terminals of the battery. If testing a side post battery, always use the lead adapters and *never* use steel bolts as these can cause an incorrect reading.

NOTE: Test results can be incorrectly reported on the display if proper, clean connections to the battery are not made. Also be sure that all accessories and the ignition switch are in the off position.

STEP 2 Enter the CCA rating (if known) and push the arrow keys.

STEP 3 The tester determines and displays one of the following:

- **Good battery.** The battery can return to service.
- **Charge and retest.** Fully recharge the battery and return it to service.
- **Replace the battery.** The battery is not serviceable and should be replaced.
- **Bad cell—replace.** The battery is not serviceable and should be replaced.

Some conductance testers can check the charging and cranking circuits, too.

SAFETY TIP

Never Charge or Jump Start a Frozen Battery

A discharged battery can freeze because the electrolyte becomes mostly water. Never attempt to charge or jump start a vehicle that has a frozen battery. When the battery freezes, it often bulges at the sides because water expands about 9% when it freezes, forming ice crystals that occupy more space than liquid water. The crystals can trap bubbles of hydrogen and oxygen that are created during the chemical processes in a battery. When attempting to charge or jump start the frozen battery, these pockets of gases can explode. Because the electrolyte expands, the freezing action usually destroys the plates and can loosen the active material from the grids. It is rare for a frozen battery to be restored to useful service.

BATTERY CHARGING

CHARGING PROCEDURE If the state of charge of a battery is low, it must be recharged. It is best to slow charge any battery to prevent possible overheating damage to the battery. Perform the following steps.

STEP 1 **Determine the charge rate.** The charge rate is based on the current state of charge (SOC) and charging rate. ● **SEE CHART 16–3** for the recommended charging rate.

STEP 2 **Connect a battery charger to the battery.** Be sure the charger is not plugged in when connecting a charger to a battery. Always follow the battery charger's instructions for proper use.

STEP 3 **Set the charging rate.** The initial charge rate should be about 35 A for 30 minutes to help start the charging process. Fast charging a battery increases the temperature of the battery and can cause warping of the plates inside the battery. Fast charging also increases the amount of gassing (release of hydrogen and oxygen), which can create a health and fire hazard. The battery temperature should not exceed 125°F (hot to the touch).

- Fast charge: 15 A maximum
- Slow charge: 5 A maximum

● **SEE FIGURE 16–11.**

CHARGING AGM BATTERIES Charging an absorbed glass mat (AGM) battery requires a different charger than is used to recharge a flooded-type battery. The differences include:

- The AGM can be charged with high current, up to 75% of the ampere-hour rating due to lower internal resistance.
- The charging voltage has to be kept at or below 14.4 volts to prevent damage.

OPEN CIRCUIT VOLTAGE	BATTERY SPECIFIC GRAVITY*	STATE OF CHARGE	CHARGING TIME TO FULL CHARGE AT 80°F**					
			at 60 amps	at 50 amps	at 40 amps	at 30 amps	at 20 amps	at 10 amps
12.6	1.265	100%	FULL CHARGE					
12.4	1.225	75%	15 min.	20 min.	27 min.	35 min.	48 min.	90 min.
12.2	1.190	50%	35 min.	45 min.	55 min.	75 min.	95 min.	180 min.
12.0	1.155	25%	50 min.	65 min.	85 min.	115 min.	145 min.	260 min.
11.8	1.120	0%	65 min.	85 min.	110 min.	150 min.	195 min.	370 min.

CHART 16–3

Battery charging guideline showing the charging times that vary according to state of charge, temperature, and charging rate. It may take eight hours or more to charge a fully discharged battery.
*Correct for temperature
**If colder, it'll take longer

FIGURE 16–11 A typical industrial battery charger. Be sure that the ignition switch is in the off position before connecting any battery charger. Connect the cables of the charger to the battery before plugging the charger into the outlet. This helps prevent a voltage spike and spark that could occur if the charger happened to be accidentally left on. Always follow the battery charger manufacturer's instructions.

Because most conventional battery chargers use a charging voltage of 16 volts or higher, a charger specifically designed to charge AGM batteries must be used.

Absorbed glass mat batteries are often used as auxiliary batteries in hybrid electric vehicles when the battery is located inside the vehicle. ● **SEE CHART 16–4** for a summary of the locations of the 12 volt auxiliary battery and high-voltage battery and safety switch/plug.

TECH TIP

Charge Batteries at 1% of Their CCA Rating

Many batteries are damaged due to being overcharged. To help prevent damage such as warped plates and excessive release of sulfur smell gases, charge batteries at a rate equal to 1% of the battery's CCA rating. For example, a battery with a 700 CCA rating should be charged at 7 amperes ($700 \times 0.01 = 7$ amperes). No harm will occur to the battery at this charge rate even though it may take longer to achieve a full charge. This means that a battery may require eight or more hours to become fully charged depending on the battery capacity and state of charge (SOC).

BATTERY CHARGE TIME

The time needed to charge a completely discharged battery can be estimated by using the reserve capacity rating of the battery in minutes divided by the charging rate.

Hours needed to charge the battery = Reserve capacity ÷ Charge current

For example, if a 10 A charge rate is applied to a discharged battery that has a 90-minute reserve capacity, the time needed to charge the battery will be nine hours.

90 minutes ÷ 10 A = 9 hours

MAKE, MODEL (YEARS)	AUXILIARY 12 V BATTERY LOCATION	HV BATTERY PACK LOCATION (VOLTAGE)	TYPE OF 12 V BATTERY
Cadillac Escalade (2008+) (two mode)	Under the hood; driver's side	Under second row seat (300 volts)	Flooded lead-acid
Chevrolet Malibu (2008+)	Under the hood; driver's side	Mounted behind rear seat under vehicle floor (36 volts)	Flooded lead-acid
Chevrolet Silverado (2004–2008) (PHT)	Under the hood; driver's side	Under second row seat (42 volts)	Flooded lead-acid
Chevrolet Tahoe (two mode)	Under the hood; driver's side	Under second row seat (300 volts)	Flooded lead-acid
Chrysler Aspen (2009)	Under driver's side door, under vehicle	Under rear seat; driver's side (288 volts)	Flooded lead-acid
Dodge Durango (2009)	Under driver's side door, under vehicle	Under rear seat; driver's side (288 volts)	Flooded lead-acid
Ford Escape (2005+)	Under the hood; driver's side	Cargo area in the rear under carpet (300 volts)	Flooded lead-acid
GMC Sierra (2004–2008) (PHT)	Under the hood; driver's side	Under second row seat (42 volts)	Flooded lead-acid
GMC Yukon (2008+) (two mode)	Under the hood; driver's side	Under second row seat (300 volts)	Flooded lead-acid
Honda Accord (2005–2007)	Under the hood; driver's side	Behind rear seat (144 volts)	Flooded lead-acid
Honda Civic (2003+)	Under the hood; driver's side	Behind rear seat (144 to 158 volts, 2006+)	Flooded lead-acid
Honda Insight (1999–2005)	Under the hood; center under windshield	144 volts; under hatch floor in the rear	Flooded lead-acid
Honda Insight (2010+)	Under the hood; driver's side	144 volts; under floor behind rear seat	Flooded lead-acid
Lexus GS450h (2007+)	In the trunk; driver's side, behind interior panel	Trunk behind rear seat (288 volts)	Absorbed glass mat (AGM)
Lexus LS 600h (2006+)	In the trunk; driver's side, behind interior panel	Trunk behind rear seat (288 volts)	Absorbed glass mat (AGM)
Lexus RX400h (2006–2009)	Under the hood; passenger side	Under the second row seat (288 volts)	Flooded lead-acid
Mercury Mariner (2005+)	Under the hood; driver's side	Cargo area in the rear under carpet (300 volts)	Flooded lead-acid
Nissan Altima (2007+)	In the trunk; driver's side	Behind rear seat (245 volts)	Absorbed glass mat (AGM)
Saturn AURA Hybrid (2007+)	Under the hood; driver's side	Behind the rear seat; under the vehicle floor (36 volts)	Flooded lead-acid
Saturn VUE Hybrid (2007+)	Under the hood; driver's side	Behind the rear seat; under the vehicle floor (36 volts)	Flooded lead-acid
Toyota Camry Hybrid (2007+)	In the trunk; passenger side	Behind the rear seat; under the vehicle floor (245 volts)	Absorbed glass mat (AGM)
Toyota Highlander Hybrid (2006–2009)	Under the hood; passenger side	Under the second row seat (288 volts)	Flooded lead-acid
Toyota Prius (2001–2003)	In the trunk; driver's side	Behind rear seat (274 volts)	Absorbed glass mat (AGM)
Toyota Prius (2004–2009)	In the trunk; driver's side	Behind rear seat (201 volts)	Absorbed glass mat (AGM)
Toyota Prius (2010+)	In the trunk; driver's side	Behind rear seat (201.6 volts)	Absorbed glass mat (AGM)

CHART 16–4

A summary chart showing where the 12 volt and high-voltage batteries and shut-off switch/plugs are located. Only the auxiliary 12 volt batteries can be serviced or charged.

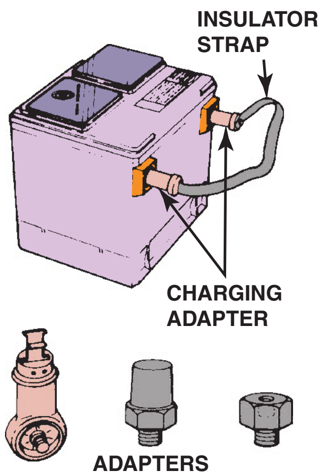


FIGURE 16–12 Adapters should be used on side terminal batteries whenever charging.

TECH TIP

Always Use Adapters on Side Post Batteries

Side post batteries require that an adapter be used when charging the battery, if it is removed from the vehicle. Do not use steel bolts. If a bolt is threaded into the terminal, only the parts of the threads that contact the battery terminal will be conducting all of the charging current. An adapter or a bolt with a nut attached is needed to achieve full contact with the battery terminals. ● **SEE FIGURE 16–12.**

FREQUENTLY ASKED QUESTION

Should Batteries Be Kept Off of Concrete Floors?

All batteries should be stored in a cool, dry place when not in use. Many technicians have been warned not to store or place a battery on concrete. According to battery experts, it is the temperature difference between the top and the bottom of the battery that causes a difference in the voltage potential between the top (warmer section) and the bottom (colder section). It is this difference in temperature that causes self-discharge to occur.

In fact, submarines cycle seawater around their batteries to keep all sections of the battery at the same temperature to help prevent self-discharge.

Therefore, always store or place batteries up off the floor and in a location where the entire battery can be kept at the same temperature, avoiding extreme heat and freezing temperatures. Concrete cannot drain the battery directly because the case of the battery is a very good electrical insulator.

FIGURE 16–13 A typical battery jump box used to jump start vehicles. These hand-portable units have almost made jumper cables obsolete.

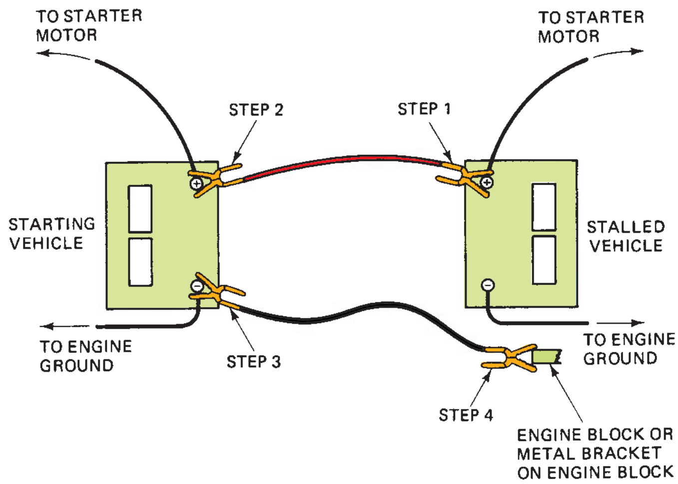


FIGURE 16–14 Jumper cable usage guide. Notice that the last connection should be the engine block of the disabled vehicle to help prevent the spark that normally occurs from igniting the gases from the battery.

JUMP STARTING

To jump start another vehicle with a dead battery, connect good-quality copper jumper cables or a jump box to the good battery and the dead battery, as shown in ● **FIGURE 16–13.**

When using jumper cables or a battery jump box, the last connection made should always be on the engine block or an engine bracket on the dead vehicle as far from the battery as possible. ● **SEE FIGURE 16–14.**

It is normal for a spark to be created when the jumper cables finally complete the jumping circuit, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground and/or positive power connections built away from the battery just for the purpose of jump starting. Check the owner's manual or service information for the exact location.

FIGURE 16–15 The code on the Delphi battery indicates that it was built in 2005 (5), in February (B), on the eleventh day (11), during third shift (C), and in the Canadian plant (Z).

TECH TIP

Look at the Battery Date Code

All major battery manufacturers stamp codes on the battery case that give the date of manufacture and other information. Most battery manufacturers use a number to indicate the year of manufacture and a letter to indicate the month of manufacture, except the letter I, because it can be confused with the number 1. For example:

A = January	G = July
B = February	H = August
C = March	J = September
D = April	K = October
E = May	L = November
F = June	M = December

The shipping date from the manufacturing plant is usually indicated by a *sticker* on the end of the battery. Almost every battery manufacturer uses just one letter and one number to indicate the month and year. ● **SEE FIGURE 16–15.**

BATTERY ELECTRICAL DRAIN TEST

TERMINOLOGY The **battery electrical drain test** determines if any component or circuit in a vehicle is causing a drain on the battery when everything is off. This test is also called the **ignition off draw (IOD)** or **parasitic load test.**

FIGURE 16–16 This mini clamp-on digital multimeter is being used to measure the amount of battery electrical drain that is present. In this case, a reading of 20 mA (displayed on the meter as 00.02 A) is within the normal range of 20 to 30 mA. Be sure to clamp around all of the positive battery cable or all of the negative battery cable, whichever is easiest to get the clamp around.

Many electronic components draw a continuous, slight amount of current from the battery when the ignition is off. These components include:

1. Electronically tuned radios for station memory and clock circuits
2. Computers and controllers, through slight diode leakage
3. The alternator, through slight diode leakage

These components may cause a voltmeter to read full battery voltage if it is connected between the negative battery terminal and the removed end of the negative battery cable. Because of this fact, voltmeters should not be used for battery drain testing. This test should be performed when one of the following conditions exists.

1. When a battery is being charged or replaced (a battery drain could have been the cause for charging or replacing the battery)
2. When the battery is suspected of being drained

PROCEDURE FOR BATTERY ELECTRICAL DRAIN TEST

- **Inductive DC ammeter.** The fastest and easiest method to measure battery electrical drain is to connect an inductive DC ammeter that is capable of measuring low current (10 mA). ● **SEE FIGURE 16–16** for an example of a clamp-on digital multimeter being used to measure battery drain.
- **DMM set to read milliamperes.** Following is the procedure for performing the battery electrical drain test using a DMM set to read DC amperes.

STEP 1 Make certain that all lights, accessories, and ignition are off.

STEP 2 Check all vehicle doors to be certain that the interior courtesy (dome) lights are off.

FIGURE 16–17 After connecting the shut-off tool, start the engine and operate all accessories. Stop the engine and turn off everything. Connect the ammeter across the shut-off switch in parallel. Wait 20 minutes. This time allows all electronic circuits to "time out" or shut down. Open the switch—all current now will flow through the ammeter. A reading greater than specified (usually greater than 50 mA, or 0.05 A) indicates a problem that should be corrected.

STEP 3 Disconnect the *negative* (−) battery cable and install a parasitic load tool, as shown in ● **FIGURE 16–17.**

STEP 4 Start the engine and drive the vehicle about 10 minutes, being sure to turn on all the lights and accessories including the radio.

STEP 5 Turn the engine and all accessories off including the underhood light.

STEP 6 Connect an ammeter across the parasitic load tool switch and wait 20 minutes for all computers and circuits to shut down.

STEP 7 Open the switch on the load tool and read the battery electrical drain on the meter display.

NOTE: Using a voltmeter or test light to measure battery drain is *not* recommended by most vehicle manufacturers. The high internal resistance of the voltmeter results in an irrelevant reading that does not provide the technician with adequate information about a problem.

SPECIFICATIONS Results:

- Normal = 20 to 30 mA (0.02 to 0.03 A)
- Maximum allowable = 50 mA (0.05 A)

RESET ALL MEMORY FUNCTIONS Be sure to reset the clock, "auto up" windows, and antitheft radio if equipped. ● **SEE FIGURE 16–18.**

BATTERY DRAIN AND RESERVE CAPACITY It is normal for a battery to self-discharge even if there is not an electrical load such as computer memory to drain the battery. According to General Motors, this self-discharge is about 13 mA (0.013 A).

FIGURE 16–18 The battery was replaced in this Acura and the radio displayed "code" when the replacement battery was installed. Thankfully, the owner had the five-digit code required to unlock the radio.

REAL WORLD FIX

The Chevrolet Battery Story

A 2005 Chevrolet Impala was being diagnosed for a dead battery. Testing for a battery drain (parasitic draw) showed 2.25 A, which was clearly over the acceptable value of 0.050 or less. At the suggestion of the shop foreman, the technician used a Tech 2 scan tool to check if all of the computers and modules went to sleep after the ignition was turned off. The scan tool display indicated that the instrument panel (IP) showed that it remained awake after all of the others had gone into sleep mode. The IP cluster was unplugged and the vehicle was tested for an electrical drain again. This time, it was only 32 mA (0.032 A), well within the normal range. Replacing the IP cluster solved the excessive battery drain.

Some vehicle manufacturers specify a maximum allowable parasitic draw or battery drain be based on the reserve capacity of the battery. The calculation used is the reserve capacity of the battery divided by 4; this equals the maximum allowable battery drain. For example, a battery rated at 120 minutes reserve capacity should have a maximum battery drain of 30 mA.

120 minutes reserve capacity ÷ 4 = 30 mA

FINDING THE SOURCE OF THE DRAIN If there is a drain, check and temporarily disconnect the following components.

1. Underhood light
2. Glove compartment light
3. Trunk light

If after disconnecting these three components the battery drain draws more than 50 mA (0.05 A), disconnect one

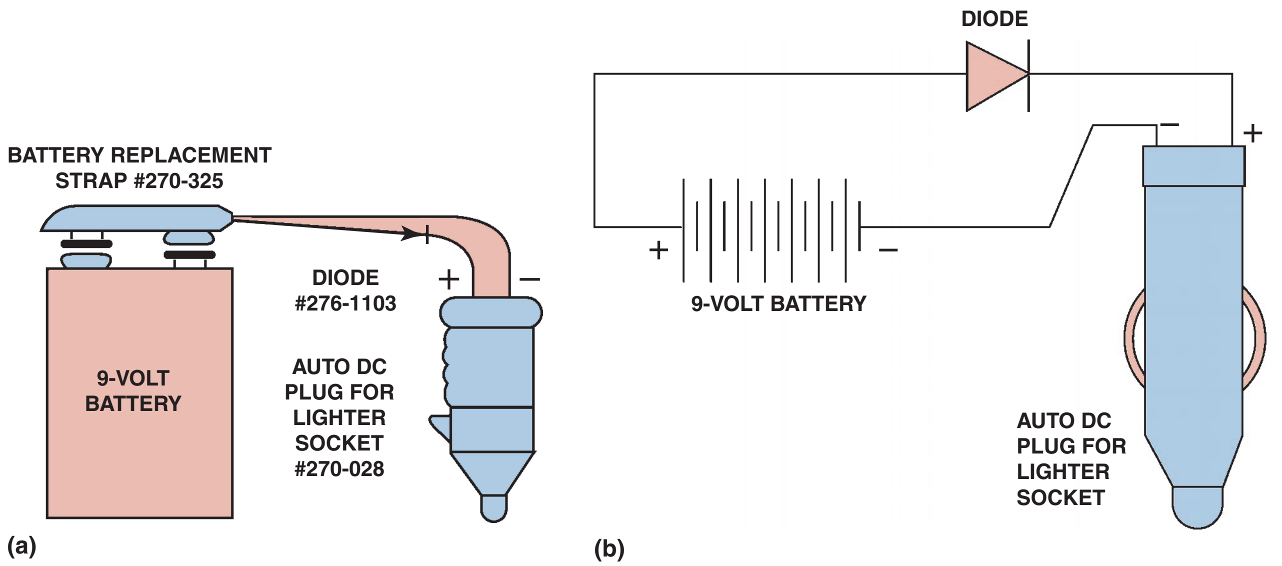


FIGURE 16–19 (a) Memory saver. The part numbers represent components from Radio Shack. (b) A schematic drawing of the same memory saver. Some experts recommend using a 12 volt lantern battery instead of a small 9 volt battery to help ensure that there will be enough voltage in the event that a door is opened while the vehicle battery is disconnected. Interior lights could quickly drain a small 9 volt battery.

TECH TIP

It Could Happen to You!

The owner of a Toyota replaced the battery. After doing so, the owner noted that the "airbag" amber warning lamp was lit and the radio was locked out. The owner had purchased the vehicle used and did not know the four-digit security code needed to unlock the radio. Determined to fix the problem, the owner tried three four-digit numbers, hoping that one of them would work. However, after three tries, the radio became permanently disabled.

Frustrated, the owner went to a dealer. It cost over $300 to fix the problem. A special tool was required to easily reset the airbag lamp. The radio had to be removed and sent out of state to an authorized radio service center and then reinstalled into the vehicle.

Therefore, before disconnecting the battery, check to be certain that the owner has the security code for a security-type radio. A "memory saver" may be needed to keep the radio powered up when the battery is being disconnected. ● **SEE FIGURE 16–19.**

fuse at a time from the fuse box until the excessive drain drops to normal.

NOTE: Do not reinsert fuses after they have been removed as this action can cause modules to "wake up," leading to an inconclusive test.

FIGURE 16–20 Many newer vehicles have batteries that are sometimes difficult to find. Some are located under plastic panels under the hood, under the front fender, or even under the rear seat as shown here. The jump-start instructions indicate that the spare tire hold-down bolt is to be used as the ground connection if jump starting is necessary.

FREQUENTLY ASKED QUESTION

Where Is the Battery?

Many vehicle manufacturers today place the battery under the backseat, under the front fender, or in the trunk. ● **SEE FIGURE 16–20.**

Often, the battery is not visible even if it is located under the hood. When testing or jump starting a vehicle, look for a battery access point.

If the excessive battery drain stops after one fuse is disconnected, the source of the drain is located in that particular circuit, as labeled on the fuse box. Continue to disconnect the *power-side* wire connectors from each component included in that particular circuit until the test light goes off. The source of the battery drain can then be traced to an individual component or part of one circuit.

WHAT TO DO IF A BATTERY DRAIN STILL EXISTS

If all the fuses have been disconnected and the drain still exists, the source of the drain has to be between the battery and the fuse box. The most common sources of drain under the hood include the following:

1. **The alternator.** Disconnect the alternator wires and retest. If the ammeter now reads a normal drain, the problem is a defective diode(s) in the alternator.
2. **The starter solenoid (relay) or wiring near its components.** These are also a common source of battery drain, due to high current flows and heat, which can damage the wire or insulation.

TECH TIP

Check the Battery Condition First

A discharged or defective battery has lower voltage potential than a good battery that is at least 75% charged. This lower battery voltage cannot properly power the starter motor. A weak battery could also prevent the charging voltage from reaching the voltage regulator cutoff point. This lower voltage could be interpreted as indicating a defective alternator and/or voltage regulator. If the vehicle continues to operate with low system voltage, the stator winding in the alternator can be overheated, causing alternator failure.

BATTERY SYMPTOM GUIDE

The following list will assist technicians in troubleshooting batteries.

Problem	Possible Causes and/or Solutions
1. Headlights are dimmer than normal.	1. Discharged battery or poor connections on the battery, engine, or body
2. Solenoid clicks.	2. Discharged battery or poor connections on the battery or an engine fault, such as coolant on top of the pistons, causing a hydrostatic lock
3. Engine is slow in cranking.	3. Discharged battery, high-resistance battery cables, or defective starter or solenoid
4. Battery will not accept a charge.	4. Possible loose battery cable connections (If the battery is a maintenance-free type, attempt to fast charge the battery for several hours. If the battery still will not accept a charge, replace the battery.)
5. Battery is using water.	5. Check charging system for too high a voltage (If the voltage is normal, the battery is showing signs of gradual failure. Load test and replace the battery, if necessary.)

SUMMARY

1. All batteries should be securely attached to the vehicle with hold-down brackets to prevent vibration damage.
2. Batteries can be tested with a voltmeter to determine the state of charge. A battery load test loads the battery to half of its CCA rating. A good battery should be able to maintain higher than 9.6 volts for the entire 15 sec. test period.
3. Batteries can be tested with a conductance tester even if discharged.
4. A battery drain test should be performed if the battery runs down.
5. Be sure that a battery charger is unplugged from a power outlet when making connections to a battery.

REVIEW QUESTIONS

1. What are the results of a voltmeter test of a battery and its state of charge?
2. What are the steps for performing a battery load test?
3. How is a battery drain test performed?
4. Why should a battery not be fast charged?

CHAPTER QUIZ

1. Technician A says that distilled or clean drinking water should be added to a battery when the electrolyte level is low. Technician B says that fresh electrolyte (solution of acid and water) should be added. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. All batteries should be in a secure bracket that is bolted to the vehicle to prevent physical damage to the battery.
   - **a.** True
   - **b.** False
3. A battery date code sticker indicates D6. What does this mean?
   - **a.** The date it was shipped from the factory was December 2006.
   - **b.** The date it was shipped from the factory was April 2006.
   - **c.** The battery expires in December 2002.
   - **d.** It was built the second day of the week (Tuesday).
4. Many vehicle manufacturers recommend that a special electrical connector be installed between the battery and the battery cable when testing for ________.
   - **a.** Battery drain (parasitic drain)
   - **b.** Specific gravity
   - **c.** Battery voltage
   - **d.** Battery charge rate
5. When load testing a battery, which battery rating is often used to determine how much load to apply to the battery?
   - **a.** CA
   - **b.** RC
   - **c.** MCA
   - **d.** CCA
6. When measuring the specific gravity of the electrolyte, the maximum allowable difference between the highest and lowest hydrometer reading is ________.
   - **a.** 0.010
   - **b.** 0.020
   - **c.** 0.050
   - **d.** 0.50
7. A battery high-rate discharge (load capacity) test is being performed on a 12 volt battery. Technician A says that a good battery should have a voltage reading of higher than 9.6 volts while under load at the end of the 15 sec. test. Technician B says that the battery should be discharged (loaded) to twice its CCA rating. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. When charging a lead-acid (flooded-type) battery, ________.
   - **a.** The initial charging rate should be about 35 amperes for 30 minutes
   - **b.** The battery may not accept a charge for several hours, yet may still be a good (serviceable) battery
   - **c.** The battery temperature should not exceed 125°F (hot to the touch)
   - **d.** All of the above
9. Normal battery drain (parasitic drain) in a vehicle with many computer and electronic circuits is ________.
   - **a.** 20 to 30 milliamperes
   - **b.** 2 to 3 amperes
   - **c.** 150 to 300 milliamperes
   - **d.** None of the above
10. When jump starting, ________.
    - **a.** The last connection should be the positive post of the dead battery
    - **b.** The last connection should be the engine block of the dead vehicle
    - **c.** The alternator must be disconnected on both vehicles
    - **d.** Both a and c

chapter 17

CRANKING SYSTEM

OBJECTIVES: After studying Chapter 17, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "C" (Starting System Diagnosis and Repair). • Describe how the cranking circuit works. • Discuss how a starter motor converts electrical power into mechanical power. • Describe the hold-in and pull-in windings of a starter solenoid.

KEY TERMS: Armature 221 • Brush-end housing 220 • Brushes 221 • CEMF 219 • Commutator-end housing 220 • Commutator segments 221 • Compression spring 224 • Drive-end housing 220 • Field coils 220 • Field housing 220 • Field poles 220 • Ground brushes 222 • Hold-in winding 225 • Insulated brushes 222 • Mesh spring 224 • Neutral safety switch 216 • Overrunning clutch 224 • PM starter 220 • Pole shoes 220 • Pull-in winding 225 • RVS 217 • Starter drive 223 • Starter solenoid 225 • Through bolts 220

CRANKING CIRCUIT

PARTS INVOLVED For any engine to start, it must first be rotated using an external power source. It is the purpose and function of the cranking circuit to create the necessary power and transfer it from the battery to the starter motor, which rotates the engine.

The cranking circuit includes those mechanical and electrical components required to crank the engine for starting. The cranking force in the early 1900s was the driver's arm, because the driver had to physically crank the engine until it started. Modern cranking circuits include the following:

1. **Starter motor.** The starter is normally a 0.5 to 2.6 horsepower (0.4 to 2 kilowatts) electric motor that can develop nearly 8 horsepower (6 kilowatts) for a very short time when first cranking a cold engine. ● **SEE FIGURE 17–1.**
2. **Battery.** The battery must be of the correct capacity and be at least 75% charged to provide the necessary current and voltage for correct starter operation.
3. **Starter solenoid or relay.** The high current required by the starter must be able to be turned on and off. A large switch would be required if the current were controlled by the driver directly. Instead, a small current switch (ignition switch) operates a solenoid or relay that controls the high current to the starter.
4. **Starter drive.** The starter drive uses a small pinion gear that contacts the engine flywheel gear teeth and transmits starter motor power to rotate the engine.
5. **Ignition switch.** The ignition switch and safety control switches control the starter motor operation. ● **SEE FIGURE 17–2.**

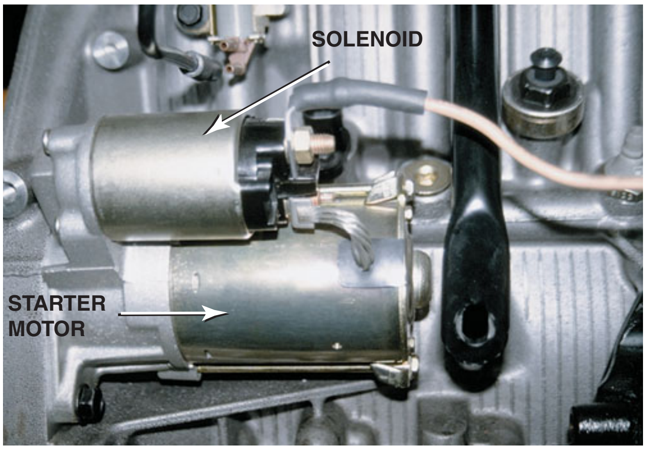


FIGURE 17–1 A typical solenoid-operated starter.

CONTROL CIRCUIT PARTS AND OPERATION The engine is cranked by an electric motor that is controlled by a key-operated ignition switch. The ignition switch will not operate the starter unless the automatic transmission is in neutral or park, or the clutch pedal is depressed on manual transmission/transaxle vehicles. This is to prevent an accident that might result from the vehicle moving forward or rearward when the engine is started. The types of controls that are used to be sure that the vehicle will not move when being cranked include the following:

- Many automobile manufacturers use an electric switch called a **neutral safety switch,** which opens the circuit between the ignition switch and the starter to prevent starter motor operation, unless the gear selector is in neutral or park. The safety switch can be attached either

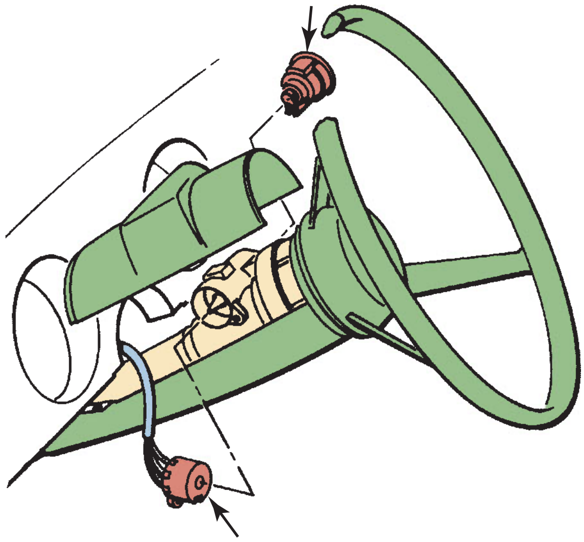


FIGURE 17–2 Some column-mounted ignition switches act directly on the electrical ignition switch itself, whereas others use a link from the lock cylinder to the ignition switch.

to the steering column inside the vehicle near the floor or on the side of the transmission.

- Many manufacturers use a mechanical blocking device in the steering column to prevent the driver from turning the key switch to the start position unless the gear selector is in neutral or park.
- Many manual transmission vehicles also use a safety switch to permit cranking only if the clutch is depressed. This switch is commonly called the *clutch safety switch.* ● **SEE FIGURE 17–3.**

COMPUTER-CONTROLLED STARTING

OPERATION Some key-operated ignition systems and most push-button-to-start systems use the computer to crank the engine. The ignition switch start position on the push-to-start button is used as an input signal to the powertrain control module (PCM). Before the PCM cranks the engine, the following conditions must be met.

- The brake pedal is depressed.
- The gear selector is in park or neutral.
- The correct key fob (code) is present in the vehicle.

A typical push-button start system includes the following sequence.

- The ignition key can be turned to the start position, released, and the PCM cranks the engine until it senses that the engine has started.

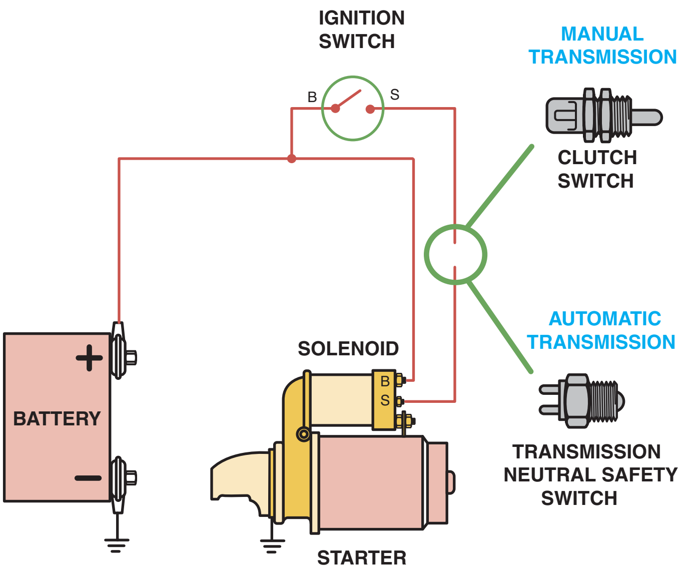


FIGURE 17–3 To prevent the engine from cranking, an electrical switch is usually installed to open the circuit between the ignition switch and the starter solenoid.

FIGURE 17–4 Instead of using an ignition key to start the engine, some vehicles are using a start button which is also used to stop the engine, as shown on this Jaguar.

- The PCM can detect that the engine has started by looking at the engine speed signal.
- Normal cranking speed can vary between 100 and 250 RPM. If the engine speed exceeds 400 RPM, the PCM determines that the engine started and opens the circuit to the "S" (start) terminal of the starter solenoid that stops the starter motor.

Computer-controlled starting is almost always part of the system if a push-button start is used. ● **SEE FIGURE 17–4.**

REMOTE STARTING Remote starting, sometimes called **remote vehicle start (RVS),** is a system that allows the driver to start the engine of the vehicle from inside the house or a building at a distance of about 200 ft (65 m). The doors remain locked

FIGURE 17–5 The top button on this key fob is the remote start button.

to reduce the possibility of theft. This feature allows the heating or air-conditioning system to start before the driver arrives. ● **SEE FIGURE 17–5.**

NOTE: Most remote start systems will turn off the engine after 10 minutes of run time unless reset by using the remote.

STARTER MOTOR OPERATION

PRINCIPLES A starter motor uses electromagnetic principles to convert electrical energy from the battery (up to 300 amperes) to mechanical power (up to 8 horsepower [6 kilowatts]) to crank the engine. Current for the starter motor or power circuit is controlled by a solenoid or relay, which is itself controlled by the driver-operated ignition switch.

The current travels through the brushes and into the armature windings, where other magnetic fields are created around each copper wire loop in the armature. The two strong magnetic fields created inside the starter housing create the force that rotates the armature.

Inside the starter housing is a strong magnetic field created by the field coil magnets. The armature, a conductor, is installed inside this strong magnetic field, with little clearance between the armature and the field coils.

The two magnetic fields act together, and their lines of force "bunch up" or are strong on one side of the armature loop wire and become weak on the other side of the conductor. This causes the conductor (armature) to move from the area of strong magnetic field strength toward the area of weak magnetic field strength. ● **SEE FIGURES 17–6 AND 17–7.**

The difference in magnetic field strength causes the armature to rotate. This rotation force (torque) is increased as the current flowing through the starter motor increases. The torque of a starter is determined by the strength of the magnetic fields inside the starter. Magnetic field strength is measured in ampere-turns. If the current or the number of turns of wire is increased, the magnetic field strength is increased.

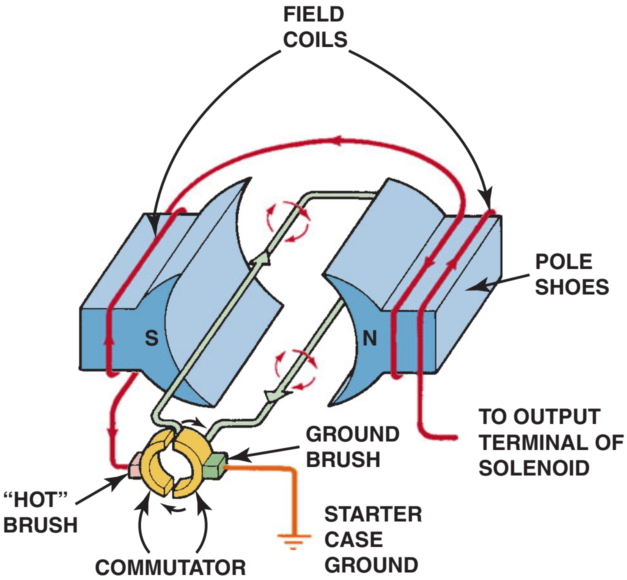


FIGURE 17–6 This series-wound electric motor shows the basic operation with only two brushes: one hot brush and one ground brush. The current flows through both field coils, then through the hot brush and the loop winding of the armature, before reaching ground through the ground brush.

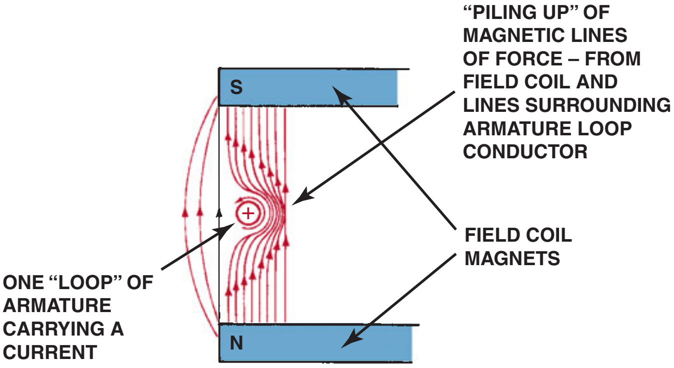


FIGURE 17–7 The interaction of the magnetic fields of the armature loops and field coils creates a stronger magnetic field on the right side of the conductor, causing the armature loop to move toward the left.

The magnetic field of the starter motor is provided by two or more pole shoes and field windings. The pole shoes are made of iron and are attached to the frame with large screws. ● **SEE FIGURE 17–8.**

● **FIGURE 17–9** shows the paths of magnetic flux lines within a four-pole motor.

The field windings are usually made of a heavy copper ribbon to increase their current-carrying capacity and electromagnetic field strength. ● **SEE FIGURE 17–10.**

Automotive starter motors usually have four pole shoes and two to four field windings to provide a strong magnetic field within the motor. Pole shoes that do not have field windings are magnetized by flux lines from the wound poles.

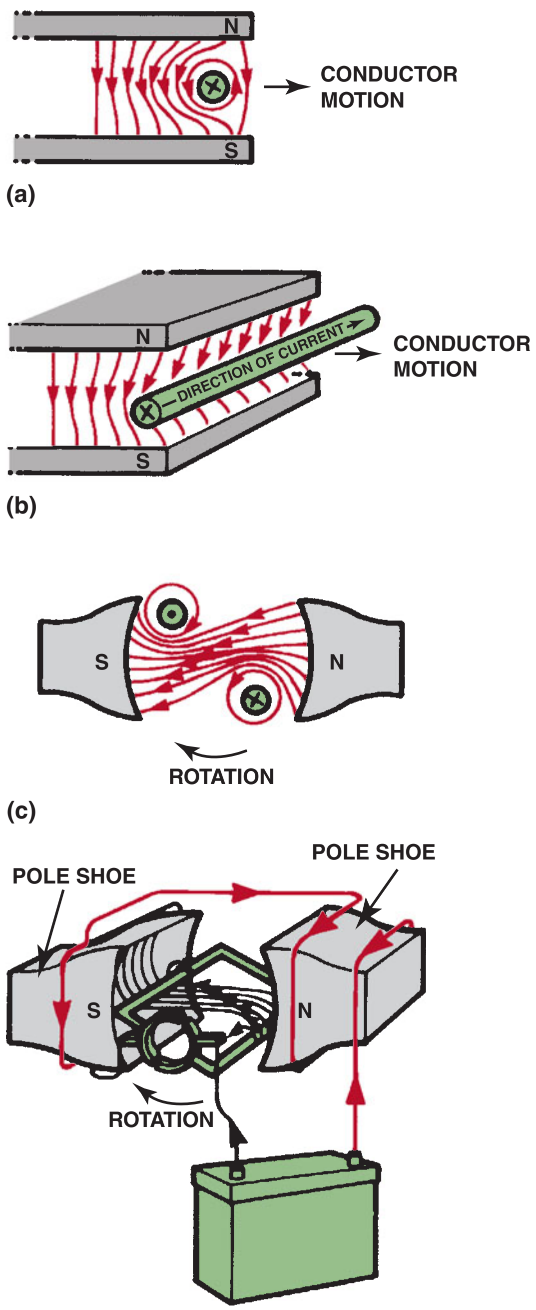


FIGURE 17–8 The armature loops rotate due to the difference in the strength of the magnetic field. The loops move from a strong magnetic field strength toward a weaker magnetic field strength.

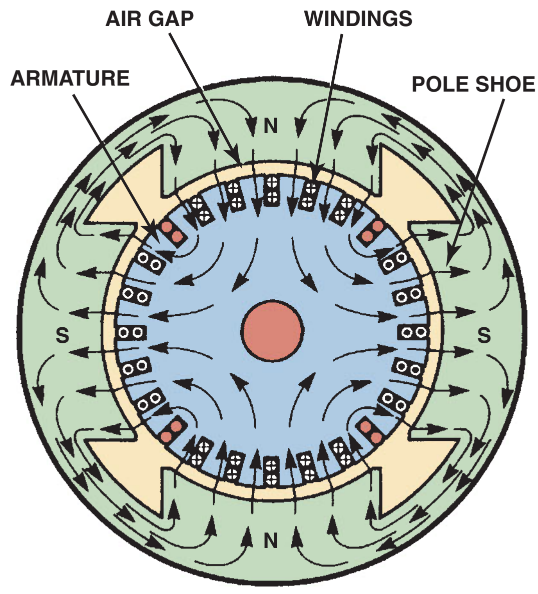


FIGURE 17–9 Magnetic lines of force in a four-pole motor.

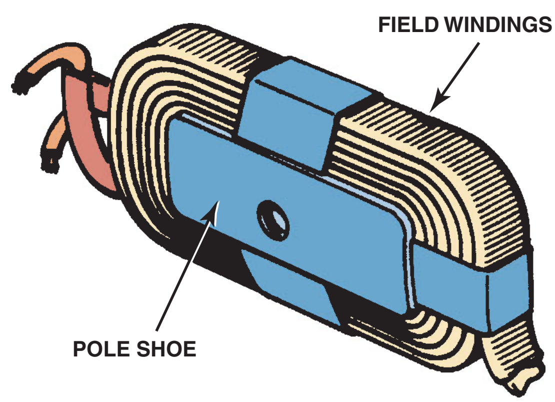


FIGURE 17–10 A pole shoe and field winding.

SERIES MOTORS A series motor develops its maximum torque at the initial start (0 RPM) and develops less torque as the speed increases.

- A series motor is commonly used for an automotive starter motor because of its high starting power characteristics.
- A series starter motor develops less torque at high RPM, because a current is produced in the starter itself that acts against the current from the battery. Because this current works against battery voltage, it is called **counterelectromotive force,** or **CEMF.** This CEMF is produced by electromagnetic induction in the armature conductors, which are cutting across the magnetic lines of force formed by the field coils. This induced voltage operates against the applied voltage supplied by the battery, which reduces the strength of the magnetic field in the starter.
- Because the power (torque) of the starter depends on the strength of the magnetic fields, the torque of the starter decreases as the starter speed increases. A series-wound starter also draws less current at higher speeds and will keep increasing in speed under light loads. This could lead to the destruction of the starter motor unless controlled or prevented. ● **SEE FIGURE 17–11.**

SHUNT MOTORS Shunt-type electric motors have the field coils in parallel (or shunt) across the armature.

A shunt-type motor has the following features.

- A shunt motor does not decrease in torque at higher motor RPM, because the CEMF produced in the armature does not decrease the field coil strength.

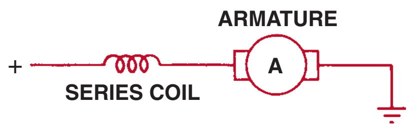


FIGURE 17–11 This wiring diagram illustrates the construction of a series-wound electric motor. Notice that all current flows through the field coils, then through the armature (in series) before reaching ground.

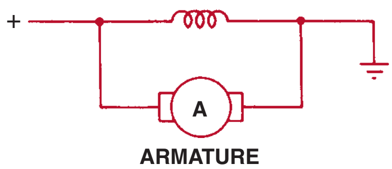


FIGURE 17–12 This wiring diagram illustrates the construction of a shunt-type electric motor, and shows the field coils in parallel (or shunt) across the armature.

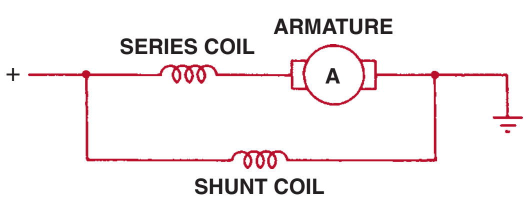


FIGURE 17–13 A compound motor is a combination of series and shunt types, using part of the field coils connected electrically in series with the armature and some in parallel (shunt).

- A shunt motor, however, does not produce as high a starting torque as that of a series-wound motor, and is not used for starters. Some small electric motors, such as used for windshield wiper motors, use a shunt motor but most use permanent magnets rather than electromagnets.
  ● **SEE FIGURE 17–12.**

PERMANENT MAGNET MOTORS A **permanent magnet (PM) starter** uses permanent magnets that maintain constant field strength, the same as a shunt-type motor, so they have similar operating characteristics. To compensate for the lack of torque, all PM starters use gear reduction to multiply starter motor torque. The permanent magnets used are an alloy of neodymium, iron, and boron, and are almost 10 times more powerful than previously used permanent magnets.

COMPOUND MOTORS A compound-wound, or compound, motor has the operating characteristics of a series motor *and* a shunt-type motor, because some of the field coils are connected to the armature in series and some (usually only one) are connected directly to the battery in parallel (shunt) with the armature.

Compound-wound starter motors are commonly used in Ford, Chrysler, and some GM starters. The shunt-wound field coil is called a shunt coil and is used to limit the maximum speed of the starter. Because the shunt coil is energized as soon as the battery current is sent to the starter, it is used to engage the starter drive on older Ford positive engagement–type starters. ● **SEE FIGURE 17–13.**

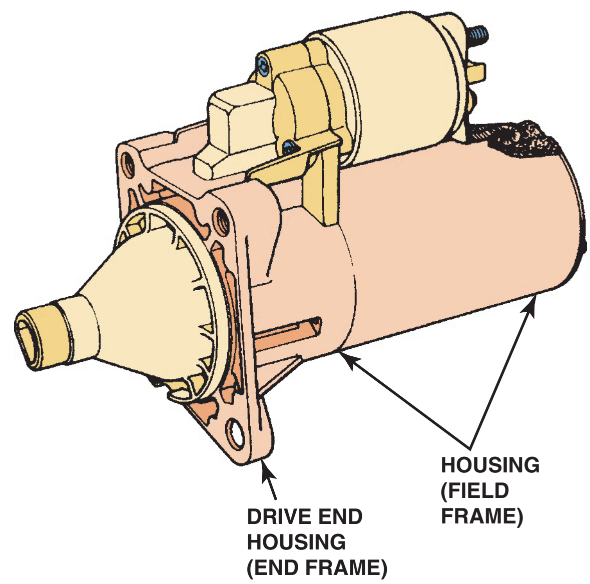


FIGURE 17–14 A typical starter motor showing the drive-end housing.

HOW THE STARTER MOTOR WORKS

PARTS INVOLVED A starter consists of the main structural support of a starter called the main **field housing,** one end of which is called a **commutator-end** (or **brush-end**) **housing** and the other end a **drive-end housing.** The drive-end housing contains the drive pinion gear, which meshes with the engine flywheel gear teeth to start the engine. The commutator-end plate supports the end containing the starter brushes. **Through bolts** hold the three components together. ● **SEE FIGURE 17–14.**

- **Field coils.** The steel housing of the starter motor contains permanent magnets or four electromagnets that are connected directly to the positive post of the battery to provide a strong magnetic field inside the starter. The four electromagnets use heavy copper or aluminum wire wrapped around a soft-iron core, which is contoured to fit against the rounded internal surface of the starter frame. The soft-iron cores are called **pole shoes.** Two of the four pole shoes are wrapped with copper wire in one direction to create a north pole magnet, and the other two pole shoes are wrapped in the opposite direction to create a south pole magnet. These magnets, when energized, create strong magnetic fields inside the starter housing and, therefore, are called **field coils.** The soft-iron cores (pole shoes) are often called **field poles.** ● **SEE FIGURE 17–15.**

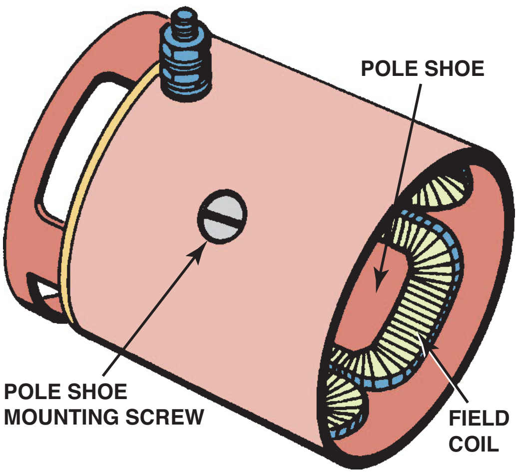


FIGURE 17–15 Pole shoes and field windings installed in the housing.

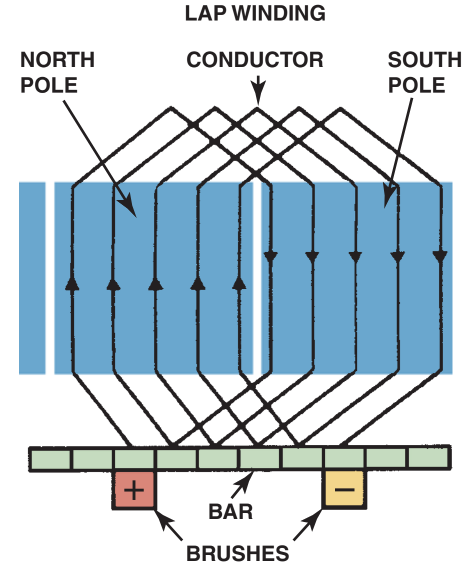


FIGURE 17–17 An armature showing how its copper wire loops are connected to the commutator.

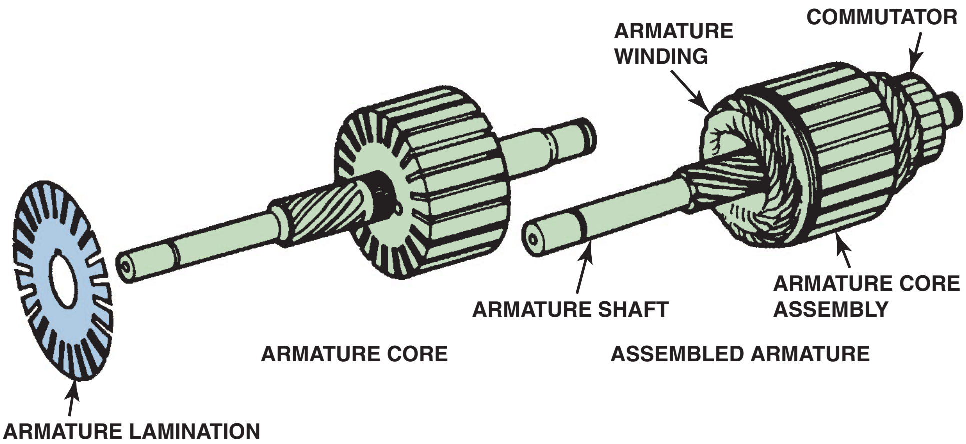


FIGURE 17–16 A typical starter motor armature. The armature core is made from thin sheet metal sections assembled on the armature shaft, which is used to increase the magnetic field strength.

- **Armature.** Inside the field coils is an **armature** that is supported with either bushings or ball bearings at both ends, which permit it to rotate. The armature is constructed of thin, circular disks of steel laminated together and wound lengthwise with heavy-gauge insulated copper wire. The laminated iron core supports the copper loops of wire and helps concentrate the magnetic field produced by the coils. ● **SEE FIGURE 17–16.**

Insulation between the laminations helps to increase the magnetic efficiency in the core. For reduced resistance, the armature conductors are made of a thick copper wire. The two ends of each conductor are attached to two adjacent commutator bars.

The commutator is made of copper bars insulated from each other by mica or some other insulating material. ● **SEE FIGURE 17–17.**

The armature core, windings, and commutator are assembled on a long armature shaft. This shaft also carries the pinion gear that meshes with the engine flywheel ring gear.

STARTER BRUSHES To supply the proper current to the armature, a four-pole motor must have four brushes riding on the commutator. Most automotive starters have two grounded and two insulated brushes, which are held against the commutator by spring force.

The ends of the copper armature windings are soldered to **commutator segments.** The electrical current that passes through the field coils is then connected to the commutator of the armature by brushes that can move over the segments of the rotating armature. These **brushes** are made of a combination of copper and carbon.

- The copper is a good conductor material.
- The carbon added to the starter brushes helps provide the graphite-type lubrication needed to reduce wear of the brushes and the commutator segments.

The starter uses four brushes—two brushes to transfer the current from the field coils to the armature, and two brushes to provide the ground return path for the current that flows through the armature.

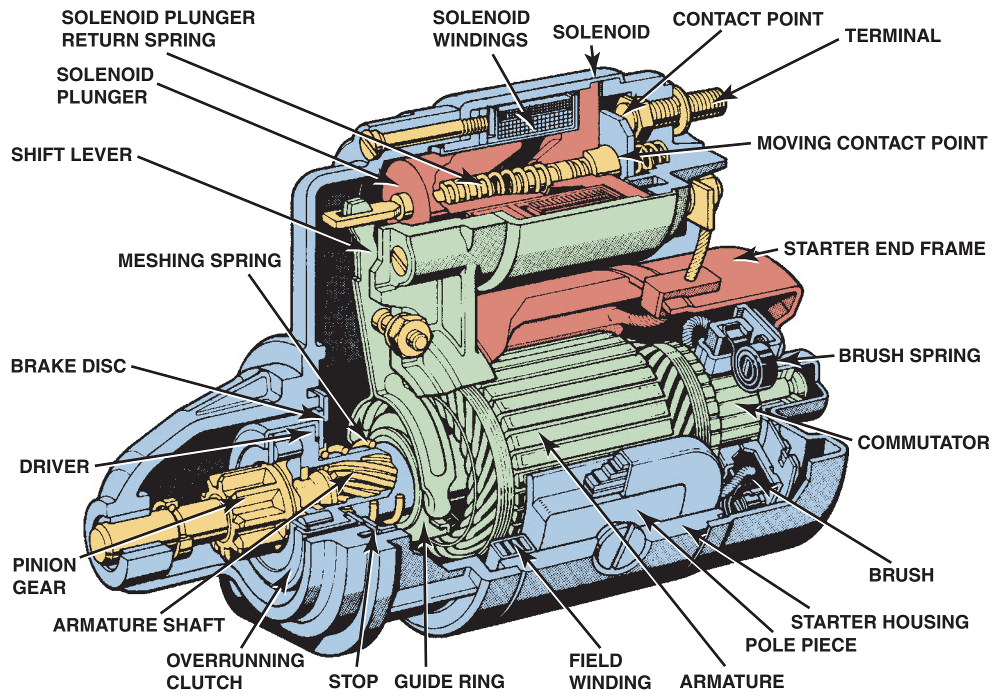


FIGURE 17–18 A cutaway of a typical starter motor showing the commutator, brushes, and brush spring.

The two sets of brushes include:

1. Two **insulated brushes,** which are in holders and are insulated from the housing.
2. Two **ground brushes,** which use bare, stranded copper wire connections to the brushes. The ground brush holders are not insulated and attach directly to the field housing or brush-end housing.

● **SEE FIGURE 17–18.**

PERMANENT MAGNET FIELDS Permanent magnets are used in place of the electromagnetic field coils and pole shoes in many starters today. This eliminates the motor field circuit, which in turn eliminates the potential for field coil faults and other electrical problems. The motor has only an armature circuit.

GEAR-REDUCTION STARTERS

PURPOSE AND FUNCTION Gear-reduction starters are used by many automotive manufacturers. The purpose of the gear reduction (typically 2:1 to 4:1) is to increase starter motor speed and provide the torque multiplication necessary to crank an engine.

As a series-wound motor increases in rotational speed, the starter produces less power, and less current is drawn from the battery because the armature generates greater CEMF as the starter speed increases. However, a starter motor's maximum torque occurs at 0 RPM and torque decreases with increasing RPM. A smaller starter using a gear-reduction design can produce the necessary cranking power with reduced starter amperage requirements. Lower current requirements mean that smaller battery cables can be used. Many permanent magnet starters use a planetary gear set (a type of gear reduction) to provide the necessary torque for starting. ● **SEE FIGURE 17–20.**

TECH TIP

Don't Hit That Starter!

In the past, it was common to see service technicians hitting a starter in their effort to diagnose a no-crank condition. Often the shock of the blow to the starter aligned or moved the brushes, armature, and bushings. Many times, the starter functioned after being hit, even if only for a short time.

However, most starters today use permanent magnet fields, and the magnets can be easily broken if hit. A magnet that is broken becomes two weaker magnets. Some early PM starters used magnets that were glued or bonded to the field housing. If struck with a heavy tool, the magnets could be broken with parts of the magnet falling onto the armature and into the bearing pockets, making the starter impossible to repair or rebuild. ● **SEE FIGURE 17–19.**

FIGURE 17–19 This starter permanent magnet field housing was ruined when someone used a hammer on the field housing in an attempt to "fix" a starter that would not work. A total replacement is the only solution in this case.

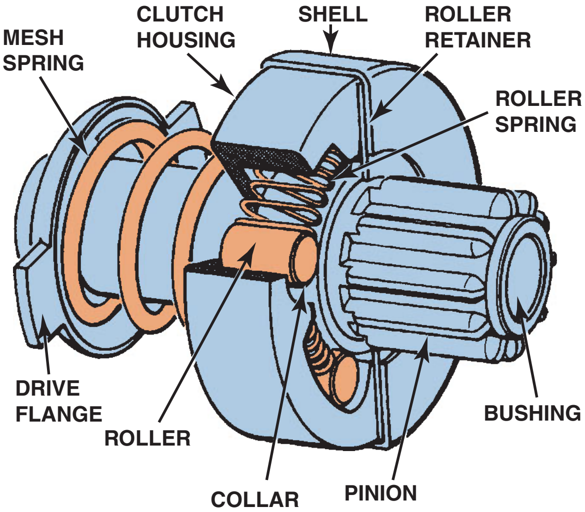


FIGURE 17–21 A cutaway of a typical starter drive showing all of the internal parts.

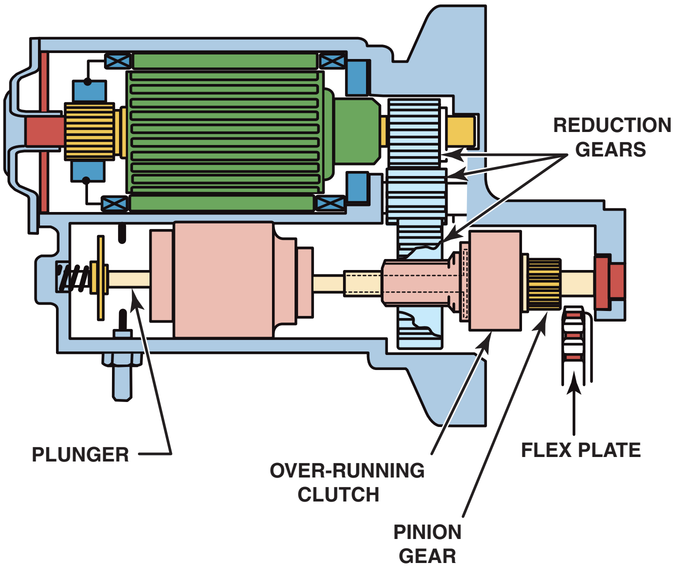


FIGURE 17–20 A typical gear-reduction starter.

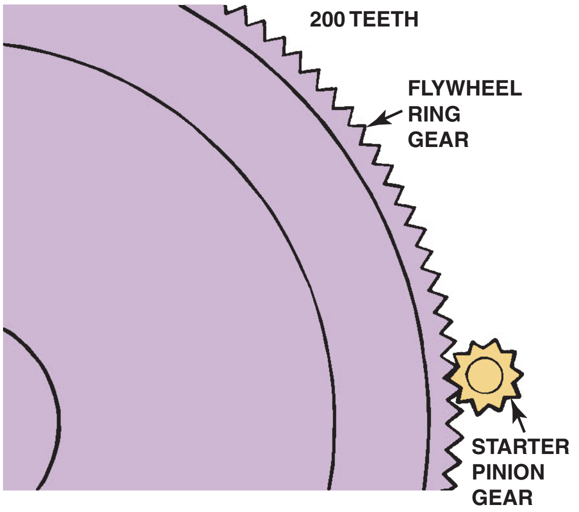


FIGURE 17–22 The ring gear to pinion gear ratio is usually 15:1 to 20:1.

STARTER DRIVES

PURPOSE AND FUNCTION A **starter drive** includes small pinion gears that mesh with and rotate the larger gear on the engine flywheel or flex plate for starting. The pinion gear must engage with the engine gear slightly *before* the starter motor rotates, to prevent serious damage to either the starter gear or the engine, but must be disengaged after the engine starts. The ends of the starter pinion gear are tapered to help the teeth mesh more easily without damaging the flywheel ring gear teeth. ● **SEE FIGURE 17–21.**

STARTER DRIVE GEAR RATIO The ratio of the number of teeth on the engine ring gear to the number on the starter pinion is between 15:1 and 20:1. A typical small starter pinion gear has 9 teeth that turn an engine ring gear with 166 teeth. This provides an 18:1 gear reduction; thus, the starter motor is rotating approximately 18 times faster than the engine. Normal cranking speed for the engine is 200 RPM (varies from 70 to 250 RPM). This means that the starter motor speed is 18 times faster, or 3600 starter RPM ($200 \times 18 = 3600$). If the engine starts and is accelerated to 2000 RPM (normal cold engine speed), the starter will be destroyed by the high speed (36,000 RPM) if the starter was not disengaged from the engine. ● **SEE FIGURE 17–22.**

STARTER DRIVE OPERATION All starter drive mechanisms use a type of one-way clutch that allows the starter to rotate the engine, but then turns freely if the engine speed is

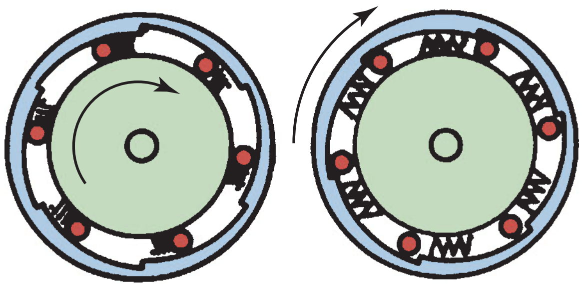


FIGURE 17–23 Operation of the overrunning clutch. (a) Starter motor is driving the starter pinion and cranking the engine. The rollers are wedged against spring force into their slots. (b) The engine has started and is rotating faster than the starter armature. Spring force pushes the rollers so they can rotate freely.

greater than the starter motor speed. This clutch, called an **overrunning clutch,** protects the starter motor from damage if the ignition switch is held in the start position after the engine starts. The overrunning clutch, which is built in as a part of the starter drive unit, uses steel balls or rollers installed in tapered notches. ● **SEE FIGURE 17–23.**

This taper forces the balls or rollers tightly into the notch, when rotating in the direction necessary to start the engine. When the engine rotates faster than the starter pinion, the balls or rollers are forced out of the narrow tapered notch, allowing the pinion gear to turn freely (overrun).

The spring between the drive tang or pulley and the overrunning clutch and pinion is called a **mesh spring.** It helps to cushion and control the engagement of the starter drive pinion with the engine flywheel gear. This spring is also called a **compression spring,** because the starter solenoid or starter yoke compresses the spring and the spring tension causes the starter pinion to engage the engine flywheel.

FAILURE MODE A starter drive is generally a dependable unit and does not require replacement unless defective or worn. The major wear occurs in the overrunning clutch section of the starter drive unit. The steel balls or rollers wear and often do not wedge tightly into the tapered notches as is necessary for engine cranking. A worn starter drive can cause the starter motor to operate and then stop cranking the engine and creating a "whining" noise. The whine indicates that the starter motor is operating and that the starter drive is not rotating the engine flywheel. The entire starter drive is replaced as a unit. The overrunning clutch section of the starter drive cannot be serviced or repaired separately because the drive is a sealed unit. Starter drives are most likely to fail intermittently at first and then more frequently, until replacement becomes necessary to start the engine. Intermittent starter drive failure (starter whine) is often most noticeable during cold weather.

? FREQUENTLY ASKED QUESTION

What Is a Bendix?

Older-model starters often used a Bendix drive mechanism, which used inertia to engage the starter pinion with the engine flywheel gear. Inertia is the tendency of a stationary object to remain stationary, because of its weight, unless forced to move. On these older-model starters, the small starter pinion gear was attached to a shaft with threads, and the weight of this gear caused it to be spun along the threaded shaft and mesh with the flywheel whenever the starter motor spun. If the engine speed was greater than the starter speed, the pinion gear was forced back along the threaded shaft and out of mesh with the flywheel gear. The Bendix drive mechanism has generally not been used since the early 1960s, but some technicians use this term when describing a starter drive.

POSITIVE ENGAGEMENT STARTERS

OPERATION Positive engagement starters (direct drive) were used on Ford engines from 1973 to 1990. These starters use the shunt coil winding and a movable pole shoe to engage the starter drive. The high starting current is controlled by an ignition switch–operated starter solenoid, usually mounted near the positive post of the battery. When this control circuit is closed, current flows through a hollow coil (called a drive coil) that attracts a movable pole shoe.

As soon as the starter drive has engaged the engine flywheel, a tang on the movable pole shoe "opens" a set of contact points. The contact points provide the ground return path for the drive coil operation. After these grounding contacts are opened, all of the starter current can flow through the remaining three field coils and through the brushes to the armature, causing the starter to operate.

The movable pole shoe is held down (which keeps the starter drive engaged) by a smaller coil on the inside of the main drive coil. This coil, called the *holding coil,* is strong enough to hold the starter drive engaged while permitting the flow of the maximum possible current to operate the starter. ● **SEE FIGURE 17–24.**

ADVANTAGES The movable metal pole shoe is attached to and engages the starter drive with a lever (called the plunger lever). As a result, this type of starter does not use a solenoid to engage the starter drive.

DISADVANTAGES If the grounding contact points are severely pitted, the starter may not operate the starter drive or the starter motor because of the resulting poor ground for the

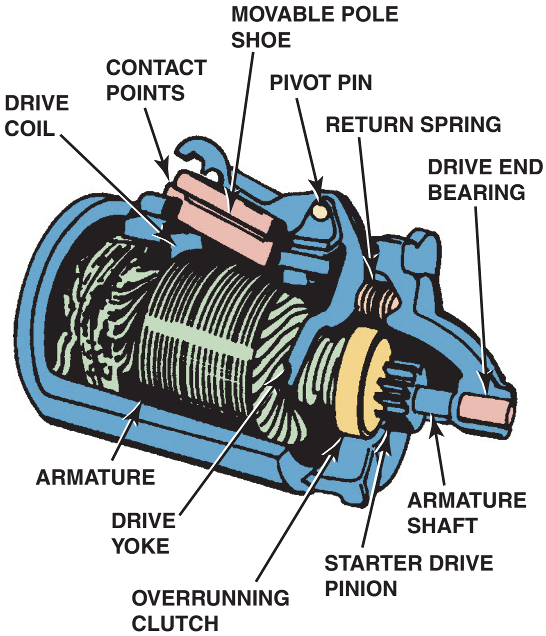


FIGURE 17–24 A Ford movable pole shoe starter.

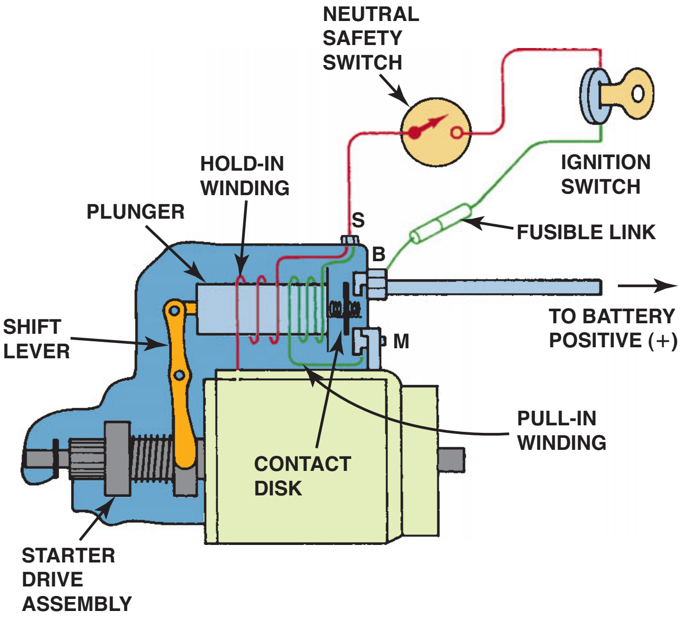


FIGURE 17–25 Wiring diagram of a typical starter solenoid. Notice that both the pull-in winding and the hold-in winding are energized when the ignition switch is first turned to the "start" position. As soon as the solenoid contact disk makes electrical contact with both the B and M terminals, the battery current is conducted to the starter motor and electrically neutralizes the pull-in winding.

drive coil. If the contact points are bent or damaged enough to prevent them from opening, the starter will "clunk" the starter drive into engagement but will not allow the starter motor to operate.

SOLENOID-OPERATED STARTERS

SOLENOID OPERATION A **starter solenoid** is an electromagnetic switch containing two separate, but connected, electromagnetic windings. This switch is used to engage the starter drive and control the current from the battery to the starter motor.

SOLENOID WINDINGS The two internal windings contain approximately the same number of turns but are made from different-gauge wire. Both windings together produce a strong magnetic field that pulls a metal plunger into the solenoid. The plunger is attached to the starter drive through a shift fork lever. When the ignition switch is turned to the start position, the motion of the plunger into the solenoid causes the starter drive to move into mesh with the flywheel ring gear.

1. The heavier-gauge winding (called the **pull-in winding**) is needed to draw the plunger into the solenoid and is grounded through the starter motor.
2. The lighter-gauge winding (called the **hold-in winding**), which is grounded through the starter frame, produces enough magnetic force to keep the plunger in position. The main purpose of using two separate windings is to permit as much current as possible to operate the starter and yet provide the strong magnetic field required to move the starter drive into engagement.

● **SEE FIGURE 17–25.**

OPERATION

1. The solenoid operates as soon as the ignition or computer-controlled relay energizes the "S" (start) terminals. At that instant, the plunger is drawn into the solenoid enough to engage the starter drive.
2. The plunger makes contact with a metal disk that connects the battery terminal post of the solenoid to the motor terminal. This permits full battery current to flow through the solenoid to operate the starter motor.
3. The contact disk also electrically disconnects the pull-in winding. The solenoid *has* to work to supply current to the starter. Therefore, if the starter motor operates at all, the solenoid is working, even though it may have high external resistance that could cause slow starter motor operation.

FREQUENTLY ASKED QUESTION

How Are Starters Made So Small?

Starters and most components in a vehicle are being made as small and as light in weight as possible to help increase vehicle performance and fuel economy. A starter can be constructed smaller due to the use of gear reduction and permanent magnets to achieve the same cranking torque as a straight drive starter, but using much smaller components. ● **SEE FIGURE 17–26** for an example of an automotive starter armature that is palm size.

FIGURE 17–26 A palm-size starter armature.

SUMMARY

1. All starter motors use the principle of magnetic interaction between the field coils attached to the housing and the magnetic field of the armature.
2. The control circuit includes the ignition switch, neutral safety (clutch) switch, and solenoid.
3. The power circuit includes the battery, battery cables, solenoid, and starter motor.
4. The parts of a typical starter include the main field housing, commutator-end (or brush-end) housing, drive-end housing, brushes, armature, and starter drive.

REVIEW QUESTIONS

1. What is the difference between the control circuit and the power (motor) circuit sections of a typical cranking circuit?
2. What are the parts of a typical starter?
3. Why does a gear-reduction unit reduce the amount of current required by the starter motor?
4. What are the symptoms of a defective starter drive?

CHAPTER QUIZ

1. Starter motors operate on the principle that ________.
   - **a.** The field coils rotate in the opposite direction from the armature
   - **b.** Opposite magnetic poles repel
   - **c.** Like magnetic poles repel
   - **d.** The armature rotates from a strong magnetic field toward a weaker magnetic field
2. Series-wound electric motors ________.
   - **a.** Produce electrical power
   - **b.** Produce maximum power at 0 RPM
   - **c.** Produce maximum power at high RPM
   - **d.** Use a shunt coil
3. Technician A says that a defective solenoid can cause a starter whine. Technician B says that a defective starter drive can cause a starter whining noise. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. The neutral safety switch is located ________.
   - **a.** Between the starter solenoid and the starter motor
   - **b.** Inside the ignition switch itself
   - **c.** Between the ignition switch and the starter solenoid
   - **d.** In the battery cable between the battery and the starter solenoid

5. The brushes are used to transfer electrical power between ________.
   a. Field coils and the armature
   b. The commutator segments
   c. The solenoid and the field coils
   d. The armature and the solenoid
6. The faster a starter motor rotates, ________.
   a. The more current it draws from the battery
   b. The less CEMF is generated
   c. The less current it draws from the battery
   d. The greater the amount of torque produced
7. Normal cranking speed of the engine is about ________.
   a. 2000 RPM
   b. 1500 RPM
   c. 1000 RPM
   d. 200 RPM
8. A starter motor rotates about ________ times faster than the engine.
   a. 18
   b. 10
   c. 5
   d. 2
9. Permanent magnets are commonly used for what part of the starter?
   a. Armature
   b. Solenoid
   c. Field coils
   d. Commutator
10. What unit contains a hold-in winding and a pull-in winding?
   a. Field coil
   b. Starter solenoid
   c. Armature
   d. Ignition switch

chapter 18

CRANKING SYSTEM DIAGNOSIS AND SERVICE

OBJECTIVES: After studying Chapter 18, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "C" (Starting System Diagnosis and Repair). • Explain how to disassemble and reassemble a starter motor and solenoid. • Discuss how to perform a voltage drop test on the cranking circuit. • Describe how to perform cranking system repair procedures. • Describe testing and repair procedures of the cranking circuit and components.

KEY TERMS: Bench testing 234 • Growler 232 • Shims 234 • Voltage drop 229

STARTING SYSTEM TROUBLESHOOTING PROCEDURE

OVERVIEW The proper operation of the starting system depends on a good battery, good cables and connections, and a good starter motor. Because a starting problem can be caused by a defective component anywhere in the starting circuit, it is important to check for the proper operation of each part of the circuit to diagnose and repair the problem quickly.

STEPS INVOLVED Following are the steps involved in the diagnosis of a fault in the cranking circuit.

STEP 1 **Verify the customer concern.** Sometimes the customer is not aware of how the cranking system is supposed to work, especially if it is computer controlled.

STEP 2 **Visually inspect the battery and battery connections.** The starter is the highest amperage draw device used in a vehicle and any faults, such as corrosion on battery terminals, can cause cranking system problems.

STEP 3 **Test battery condition.** Perform a battery load or conductance test on the battery to be sure that the battery is capable of supplying the necessary current for the starter.

STEP 4 **Check the control circuit.** An open or high resistance anywhere in the control circuit can cause the starter motor to not engage. Items to check include:

- "S" terminal of the starter solenoid
- Neutral safety or clutch switch
- Starter enable relay (if equipped)
- Antitheft system fault (If the engine does not crank or start and the theft indicator light is on or flashing,

> **TECH TIP**
>
> **Voltage Drop Is Resistance**
>
> Many technicians have asked, "Why measure voltage drop when the resistance can be easily measured using an ohmmeter?" Think of a battery cable with all the strands of the cable broken, except for one strand. If an ohmmeter were used to measure the resistance of the cable, the reading would be very low, probably less than 1 ohm. However, the cable is not capable of conducting the amount of current necessary to crank the engine. In less severe cases, several strands can be broken, thereby affecting the operation of the starter motor. Although the resistance of the battery cable will not indicate an increase, the restriction to current flow will cause heat and a drop of voltage available at the starter. Because resistance is not effective until current flows, measuring the voltage drop (differences in voltage between two points) is the most accurate method of determining the true resistance in a circuit.
>
> How much is too much? According to Bosch Corporation, all electrical circuits should have a maximum of 3% loss of the circuit voltage to resistance. Therefore, in a 12 volt circuit, the maximum loss of voltage in cables and connections should be 0.36 volt ($12 \times 0.03 = 0.36$ volt). The remaining 97% of the circuit voltage (11.64 volts) is available to operate the electrical device (load). Just remember:
>
> - Low-voltage drop = Low resistance
> - High-voltage drop = High resistance

there is likely a fault in the theft deterrent system. Check service information for the exact procedures to follow before attempting to service the cranking circuit. ● **SEE FIGURE 18–1.**)

STEP 5 **Check voltage drop of the starter circuit.** Any high resistance in either the power side or ground side of the starter circuit will cause the starter to rotate slowly or not at all.

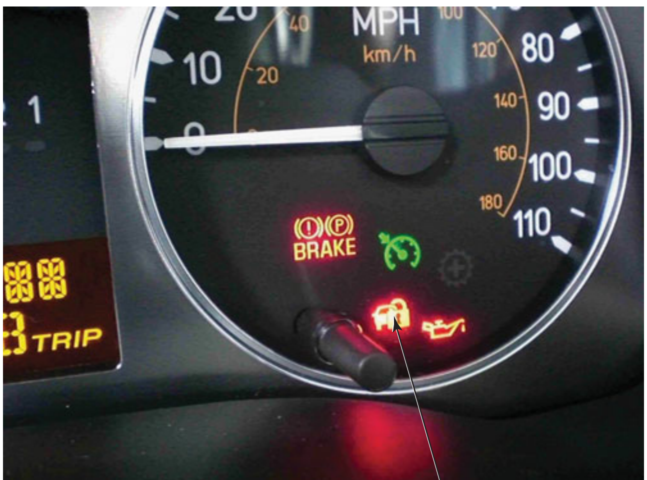


FIGURE 18–1 A theft deterrent indicator lamp of the dash. A flashing lamp usually indicates a fault in the system, and the engine may not start.

VOLTAGE DROP TESTING

PURPOSE **Voltage drop** is the drop in voltage that occurs when current is flowing through a resistance. For example, a voltage drop is the difference between voltage at the source and voltage at the electrical device to which it is flowing. The higher the voltage drop is, the greater the resistance in the circuit. Even though voltage drop testing can be performed on any electrical circuit, the most common areas of testing include the cranking circuit and the charging circuit wiring and connections. Voltage drop testing should be performed on both the power side and ground side of the circuit.

A high voltage drop (high resistance) in the cranking circuit wiring can cause slow engine cranking with less than normal starter amperage drain as a result of the excessive circuit resistance. If the voltage drop is high enough, such as that caused by dirty battery terminals, the starter may not operate. A typical symptom of high resistance in the cranking circuit is a "clicking" of the starter solenoid.

TEST PROCEDURE Voltage drop testing of the wire involves connecting a voltmeter set to read DC volts to the suspected high-resistance cable ends and cranking the engine. ● **SEE FIGURES 18–2 THROUGH 18–4.**

NOTE: Before a difference in voltage (voltage drop) can be measured between the ends of a battery cable, current must be flowing through the cable. Resistance is not effective unless current is flowing. If the engine is not being cranked, current is not flowing through the battery cables and the voltage drop cannot be measured.

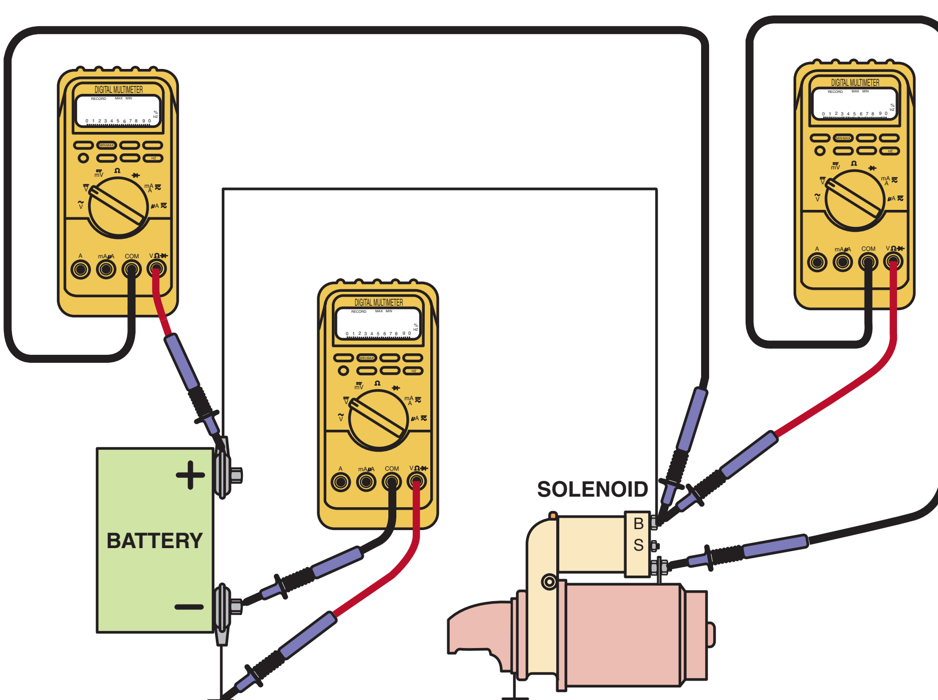


FIGURE 18–2 Voltmeter hookups for voltage drop testing of a solenoid-type cranking circuit.

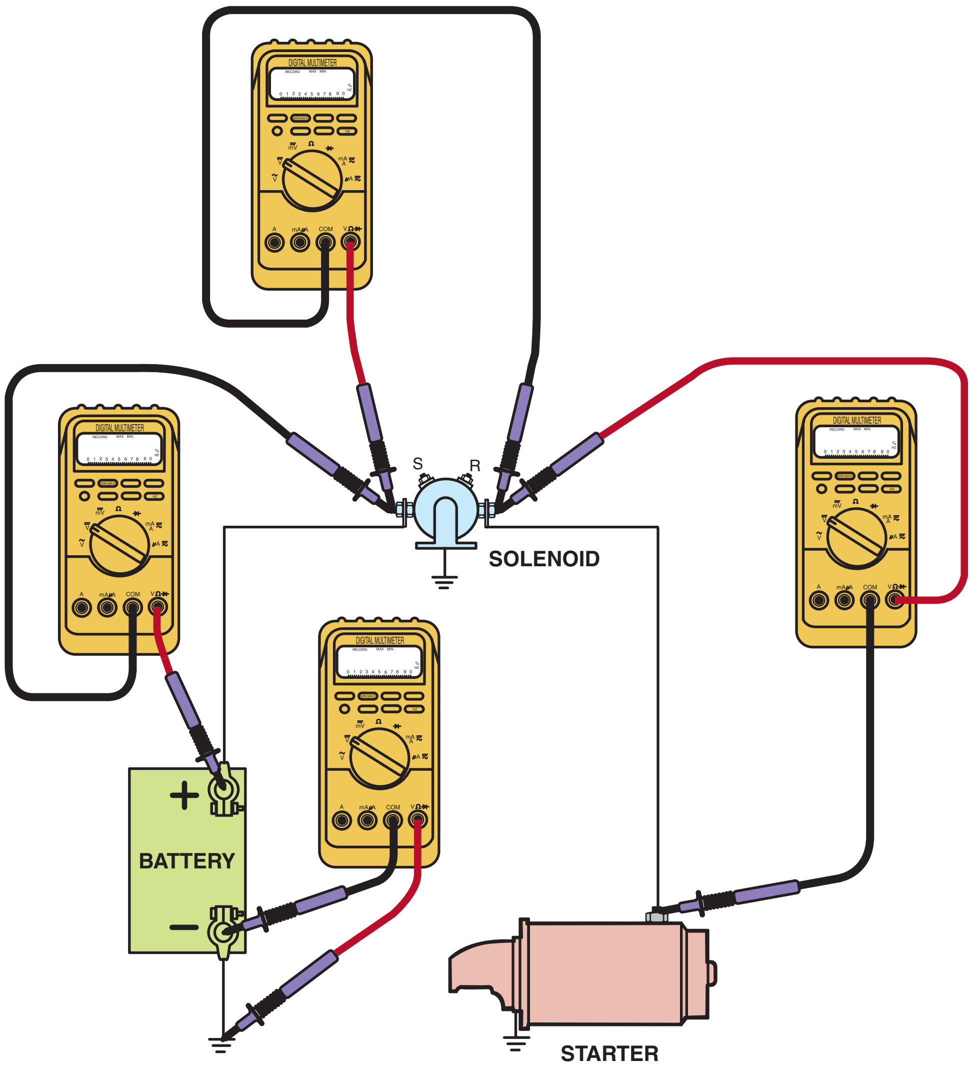


FIGURE 18–3 Voltmeter hookups for voltage drop testing of a Ford cranking circuit.

FIGURE 18–4 To test the voltage drop of the battery cable connection, place one voltmeter lead on the battery terminal and the other voltmeter lead on the cable end and crank the engine. The voltmeter will read the difference in voltage between the two leads, which should not exceed 0.20 volt (200 mV).

TECH TIP

A Warm Cable Equals High Resistance

If a cable or connection is warm to the touch, there is electrical resistance in the cable or connection. The resistance changes electrical energy into heat energy. Therefore, if a voltmeter is not available, touch the battery cables and connections while cranking the engine. If any cable or connection is hot to the touch, it should be cleaned or replaced.

STEP 1 Disable the ignition or fuel injection as follows:

- Disconnect the primary (low-voltage) electrical connection(s) from the ignition module or ignition coils.
- Remove the fuel-injection fuse or relay, or the electrical connection leading to all of the fuel injectors.

CAUTION: Never disconnect the high-voltage ignition wires unless they are connected to ground. The high voltage that could occur when cranking can cause the ignition coil to fail (arc internally).

STEP 2 Connect one lead of the voltmeter to the starter motor battery terminal and the other end to the positive battery terminal.

STEP 3 Crank the engine and observe the reading while cranking. (Disregard the first higher reading.) The reading should be less than 0.20 volt (200 mV).

STEP 4 If accessible, test the voltage drop across the "B" and "M" terminals of the starter solenoid with the engine cranking. The voltage drop should be less than 0.20 volt (200 mV).

STEP 5 Repeat the voltage drop on the ground side of the cranking circuit by connecting one voltmeter lead to the negative battery terminal and the other at the starter housing. Crank the engine and observe the voltmeter display. The voltage drop should be less than 0.2 volt (200 mV).

CONTROL CIRCUIT TESTING

PARTS INVOLVED The control circuit for the starting circuit includes the battery, ignition switch, neutral or clutch safety switch, theft deterrent system, and starter solenoid. When the ignition switch is rotated to the start position, current flows through the ignition switch and neutral safety switch to activate the solenoid. High current then flows directly from the battery through the solenoid and to the starter motor. Therefore, an open or break anywhere in the control circuit will prevent the operation of the starter motor.

If a starter is inoperative, first check for voltage at the "S" (start) terminal of the starter solenoid. Check for faults with the following:

- Neutral safety or clutch switch
- Blown crank fuse
- Open at the ignition switch in the crank position

Some models with antitheft controls use a relay to open this control circuit to prevent starter operation.

STARTER AMPERAGE TEST

REASON FOR A STARTER AMPERAGE TEST A starter should be tested to see if the reason for slow or no cranking is due to a fault with the starter motor or another problem. A voltage drop test is used to find out if the battery cables and connections are okay. A starter amperage draw test determines if the starter motor is the cause of a no or slow cranking concern.

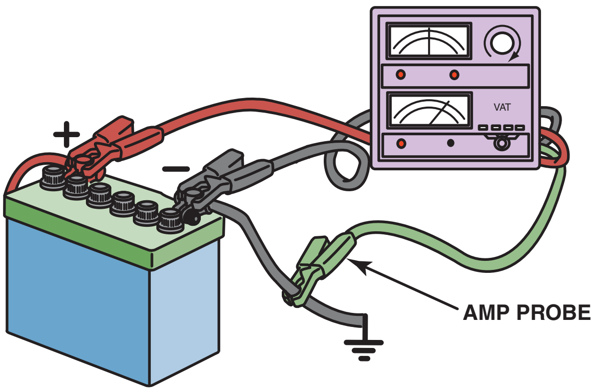


FIGURE 18–5 A starter amperage tester uses an amp probe around the positive or negative battery cables.

TEST PREPARATION Before performing a starter amperage test, be certain that the battery is sufficiently charged (75% or more) and capable of supplying adequate starting current. Connect a starter amperage tester following the tester's instructions. ● **SEE FIGURE 18–5.**

A starter amperage test should be performed when the starter fails to operate normally (is slow in cranking) or as part of a routine electrical system inspection.

SPECIFICATIONS Some service manuals specify normal starter amperage for starter motors being tested on the vehicle; however, most service manuals only give the specifications for bench testing a starter without a load applied. These specifications are helpful in making certain that a repaired starter meets exact specifications, but they do not apply to starter testing on the vehicle. If exact specifications are not available, the following can be used as general *maximum* amperage draw specifications for testing a starter on the vehicle.

- **4-cylinder engines** = 150 to 185 amperes (normally less than 100 A) at room temperature
- **6-cylinder engines** = 160 to 200 amperes (normally less than 125 A) at room temperature
- **8-cylinder engines** = 185 to 250 amperes (normally less than 150 A) at room temperature

Excessive current draw may indicate one or more of the following:

1. Binding of starter armature as a result of worn bushings
2. Oil too thick (viscosity too high) for weather conditions
3. Shorted or grounded starter windings or cables
4. Tight or seized engine
5. Shorted starter motor (usually caused by fault with the field coils or armature)
   - High mechanical resistance = High starter amperage draw
   - High electrical resistance = Low starter amperage draw

TECH TIP

Watch the Dome Light

When diagnosing any starter-related problem, open the door of the vehicle and observe the brightness of the dome or interior light(s).

The brightness of any electrical lamp is proportional to the voltage of the battery.

Normal operation of the starter results in a slight dimming of the dome light.

If the light remains bright, the problem is usually an open in the control circuit.

If the light goes out or almost goes out, there could be a problem with the following:

- A shorted or grounded armature of field coils inside the starter
- Loose or corroded battery connections or cables
- Weak or discharged battery

Lower amperage draw and slow or no cranking may indicate one or more of the following:

- Dirty or corroded battery connections
- High internal resistance in the battery cable(s)
- High internal starter motor resistance
- Poor ground connection between the starter motor and the engine block

STARTER REMOVAL

PROCEDURE After testing has confirmed that a starter motor may need to be replaced, most vehicle manufacturers recommend the following general steps and procedures.

STEP 1 Disconnect the negative battery cable.

STEP 2 Hoist the vehicle safely.

NOTE: This step may not be necessary. Check service information for the specified procedure for the vehicle being serviced. Some starters are located under the intake manifold. SEE FIGURE 18–6.

STEP 3 Remove the starter retaining bolts and lower the starter to gain access to the wire(s) connection(s) on the starter.

STEP 4 Disconnect and label the wire(s) from the starter and remove the starter.

STEP 5 Inspect the flywheel (flexplate) for ring gear damage. Also check that the mounting holes are clean and the mounting flange is clean and smooth. Service as needed.

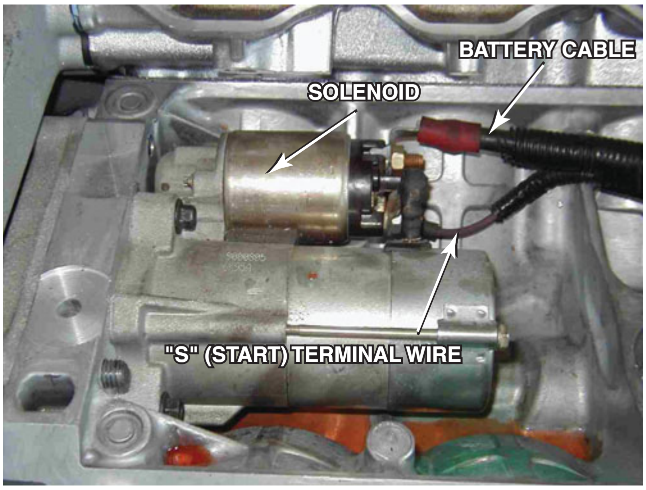


FIGURE 18–6 The starter is located under the intake manifold on this Cadillac Northstar engine.

STARTER MOTOR SERVICE

PURPOSE Most starter motors are replaced as an assembly or not easily disassembled or serviced. However, some starters, especially on classic muscle or collector vehicles, can be serviced.

DISASSEMBLY PROCEDURE Disassembly of a starter motor usually includes the following steps.

STEP 1 Remove the starter solenoid assembly.

STEP 2 Mark the location of the through bolts on the field housing to help align them during reassembly.

STEP 3 Remove the drive-end housing and then the armature assembly.

SEE FIGURE 18–7.

INSPECTION AND TESTING The various parts should be inspected and tested to see if the components can be used to restore the starter to serviceable condition.

- **Solenoid.** Check the resistance of the solenoid winding. The solenoid can be tested using an ohmmeter to check for the proper resistance in the hold-in and pull-in windings. **SEE FIGURE 18–8.**

Most technicians replace the solenoid whenever the starter is replaced and is usually included with a replacement starter.

- **Starter armature.** After the starter drive has been removed from the armature, it can be checked for runout using a dial indicator and V-blocks, as shown in **FIGURE 18–9.**
- **Growler.** Because the loops of copper wire are interconnected in the armature of a starter, an armature can be accurately tested only by use of a **growler.** A growler is a 110 volt AC test unit that generates an alternating (60 hertz) magnetic field around an armature. A starter armature is placed into the V-shaped top portion of a

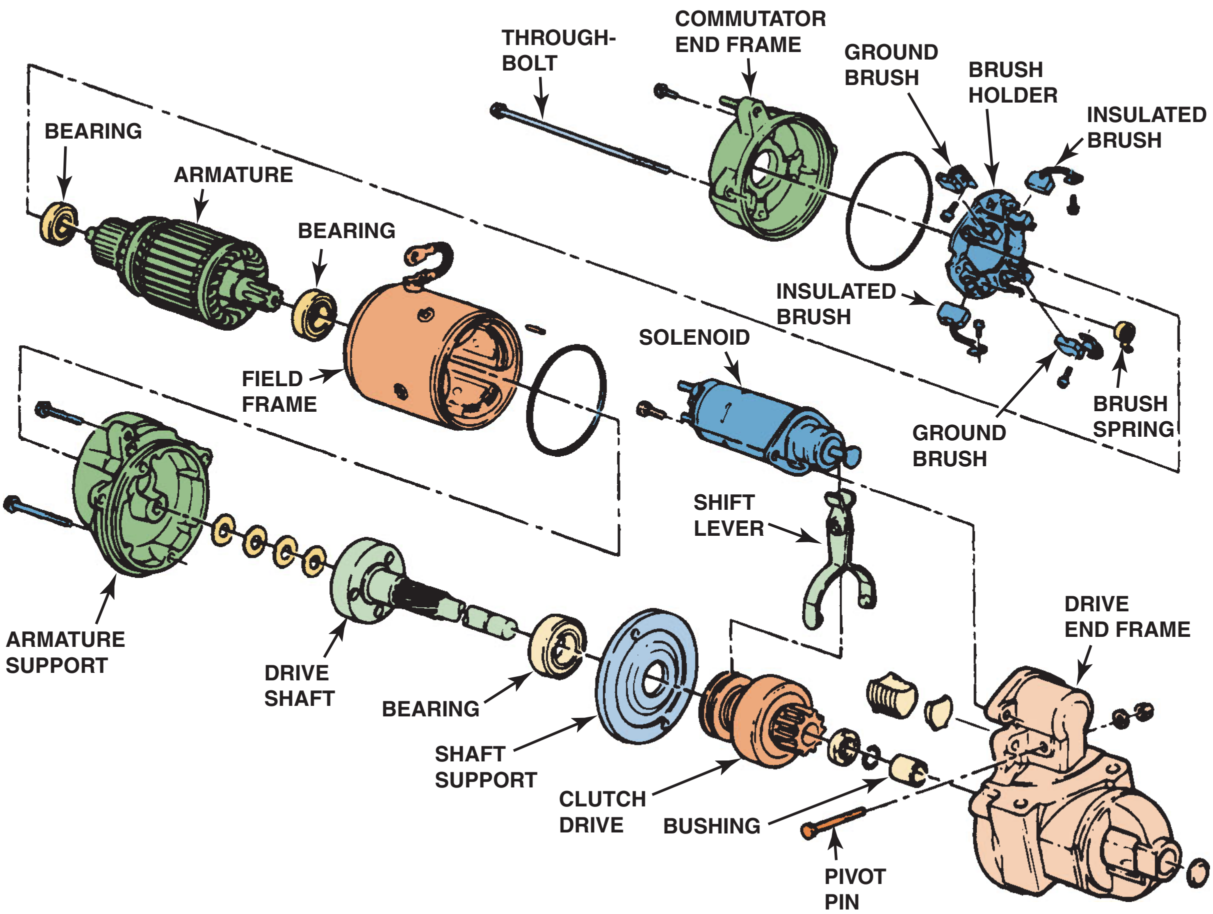


FIGURE 18–7 An exploded view of a typical solenoid-operated starter.

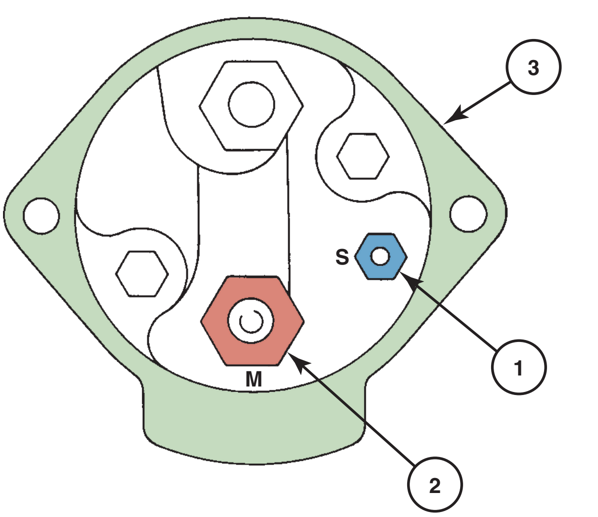


FIGURE 18–8 GM solenoid ohmmeter check. The reading between 1 and 3 (S terminal and ground) should be 0.4 to 0.6 ohm (hold-in winding). The reading between 1 and 2 (S terminal and M terminal) should be 0.2 to 0.4 ohm (pull-in winding).

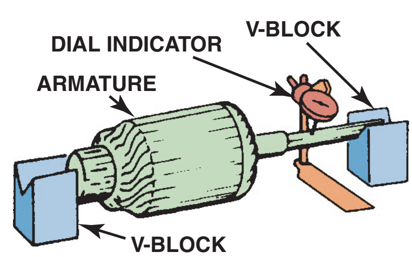


FIGURE 18–9 Measuring an armature shaft for runout using a dial indicator and V-blocks.

laminated soft-iron core surrounded by a coil of copper wire. Plug the growler into a 110 volt outlet and and then follow the instructions for testing the armature.

- **Starter motor field coils.** With the armature removed from the starter motor, the field coils should be tested for opens and grounds using a powered test light or an ohmmeter. To test for a grounded field coil, touch one lead of the tester to a field brush (insulated or hot) and the other end to the starter field housing. The ohmmeter should indicate infinity (no continuity), and the test light should *not* light. If there is continuity, replace the field coil housing assembly. The ground brushes should show continuity to the starter housing.

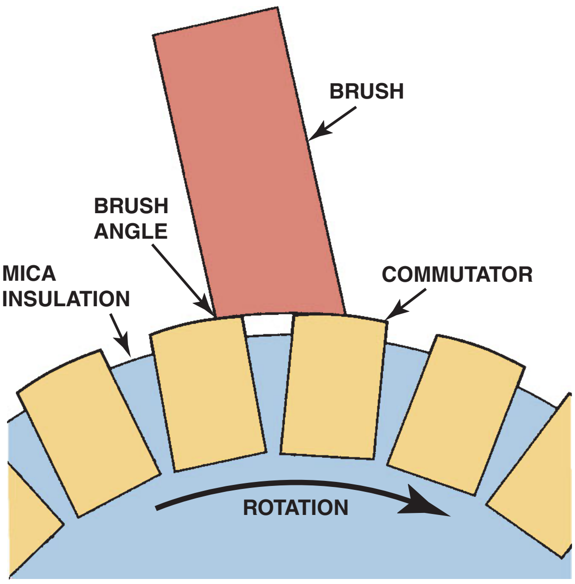


FIGURE 18–10 Replacement starter brushes should be installed so the beveled edge matches the rotation of the commutator.

NOTE: Many starters use removable field coils. These coils must be rewound using the proper equipment and insulating materials. Usually, the cost involved in replacing defective field coils exceeds the cost of a replacement starter.

- **Starter brush inspection.** Starter brushes should be replaced if the brush length is less than half of its original length (less than 0.5 in. [13 mm]). On some models of starter motors, the field brushes are serviced with the field coil assembly and the ground brushes with the brush holder. Many starters use brushes that are held in with screws and are easily replaced, whereas other starters may require soldering to remove and replace the brushes. **SEE FIGURE 18–10.**

BENCH TESTING

Every starter should be tested before installation in a vehicle. **Bench testing** is the usual method and involves clamping the starter in a vise to prevent rotation during operation and connecting heavy-gauge jumper wires (minimum 4 gauge) to both a battery known to be good and the starter. The starter motor should rotate as fast as specifications indicate and not draw more than the free-spinning amperage permitted. A typical amperage specification for a starter being tested on a bench (not installed in a vehicle) usually ranges from 60 to 100 amperes.

STARTER INSTALLATION

After verifying that the starter assembly is functioning correctly, verify that the negative battery cable has been disconnected. Then safely hoist the vehicle, if necessary. Following are the usual steps to install a starter. Be sure to check service information for the exact procedures to follow for the vehicle being serviced.

STEP 1 Check service information for the exact wiring connections to the starter and/or solenoid.

STEP 2 Verify that all electrical connections on the starter motor and/or solenoid are correct for the vehicle and that they are in good condition.

NOTE: Be sure that the locking nuts for the studs are tight. Often, the retaining nut that holds the wire to the stud will be properly tightened, but if the stud itself is loose, cranking problems can occur.

STEP 3 Attach the power and control wires.

STEP 4 Install the starter, and torque all the fasteners to factory specifications and tighten evenly.

STEP 5 Perform a starter amperage draw test and check for proper engine cranking.

CAUTION: Be sure to install all factory heat shields to help ensure problem starter operation under all weather and driving conditions.

STARTER DRIVE-TO-FLYWHEEL CLEARANCE

NEED FOR SHIMS For the proper operation of the starter and absence of abnormal starter noise, there must be a slight clearance between the starter pinion and the engine flywheel ring gear. Many starters use **shims,** which are thin metal strips between the flywheel and the engine block mounting pad to provide the proper clearance. **SEE FIGURE 18–11.**

Some manufacturers use shims under the starter drive-end housings during production. Other manufacturers *grind* the mounting pads at the factory for proper starter pinion gear clearance. If a GM starter is replaced, the starter pinion should be checked and corrected as necessary to prevent starter damage and excessive noise.

SYMPTOMS OF CLEARANCE PROBLEMS

- If the clearance is too great, the starter will produce a high-pitched whine *during* cranking.
- If the clearance is too small, the starter may bind, crank slowly, or produce a high-pitched whine *after* the engine starts, just as the ignition key is released.

PROCEDURE FOR PROPER CLEARANCE To be sure that the starter is shimmed correctly, use the following procedure.

STEP 1 Place the starter in position and finger-tighten the mounting bolts.

STEP 2 Use a 1/8 in. diameter drill bit (or gauge tool) and insert between the armature shaft and a tooth of the engine flywheel.

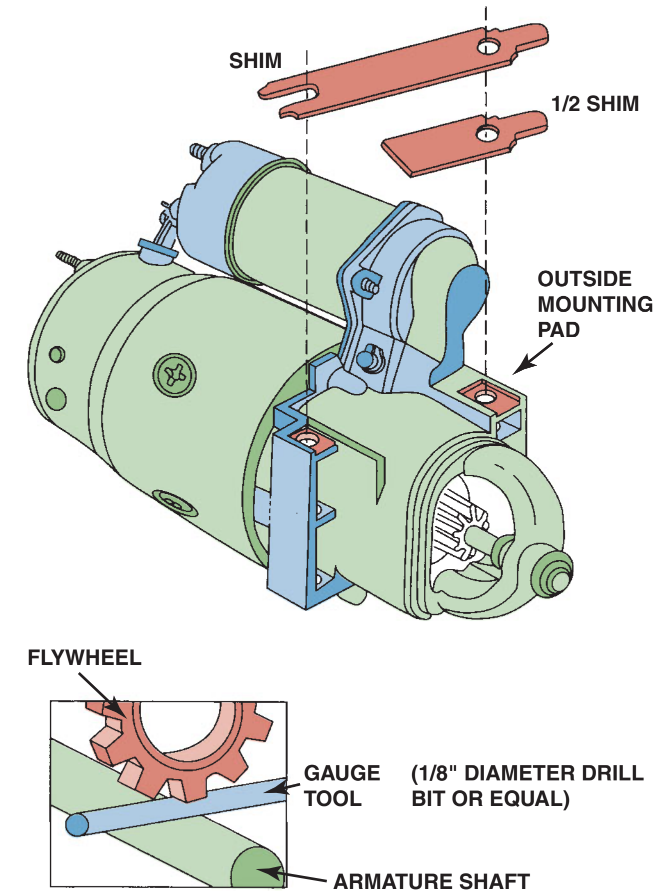


FIGURE 18–11 A shim (or half shim) may be needed to provide the proper clearance between the flywheel teeth of the engine and the pinion teeth of the starter.

TECH TIP

Reuse Drive-End Housing to Be Sure

Most GM starter motors use a pad mount and attach to the engine with bolts through the drive-end (nose) housing. Many times when a starter is replaced on a GM vehicle, the starter makes noise because of improper starter pinion-to-engine flywheel ring gear clearance. Instead of spending a lot of time shimming the new starter, simply remove the drive-end housing from the original starter and install it on the replacement starter. Service the bushing in the drive-end housing if needed. Because the original starter did not produce excessive gear engagement noise, the replacement starter will also be okay. Reuse any shims that were used with the original starter. This is preferable to removing and reinstalling the replacement starter several times until the proper clearance is determined.

STEP 3 If the gauge tool cannot be inserted, use a full-length shim across both mounting holes to move the starter away from the flywheel.

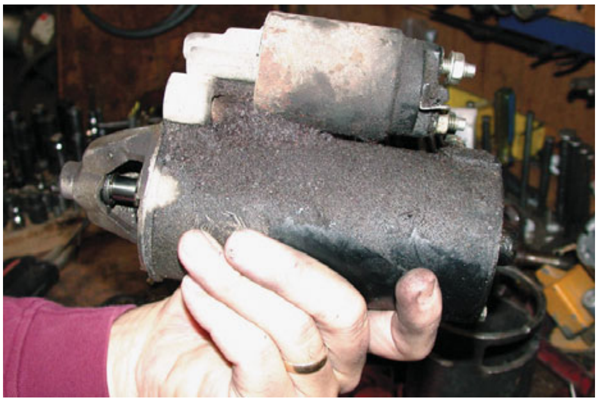
STEP 4 Remove a shim (or shims) if the gauge tool is loose between the shaft and the tooth of the engine flywheel.

STEP 5 If no shims have been used and the fit of the gauge tool is too loose, add a half shim to the outside pad only. This moves the starter closer to the teeth of the engine flywheel.

STARTING SYSTEM SYMPTOM GUIDE

The following list will assist technicians in troubleshooting starting systems.

Problem	Possible Causes
1. Starter motor whines	1. Possible defective starter drive; worn starter drive engagement yoke; defective flywheel; improper starter drive to flywheel clearance
2. Starter rotates slowly	2. Possible high resistance in the battery cables or connections; possible defective or discharged battery; possible worn starter bushings, causing the starter armature to drag on the field coils; possible worn starter brushes or weak brush springs; possible defective (open or shorted) field coil
3. Starter fails to rotate	3. Possible defective ignition switch or neutral safety switch, or open in the starter motor control circuit; theft deterrent system fault; possible defective starter solenoid
4. Starter produces grinding noise	4. Possible defective starter drive unit; possible defective flywheel; possible incorrect distance between the starter pinion and the flywheel; possible cracked or broken starter drive-end housing; worn or damaged flywheel or ring gear teeth
5. Starter clicks when engaged	5. Low battery voltage; loose or corroded battery connections



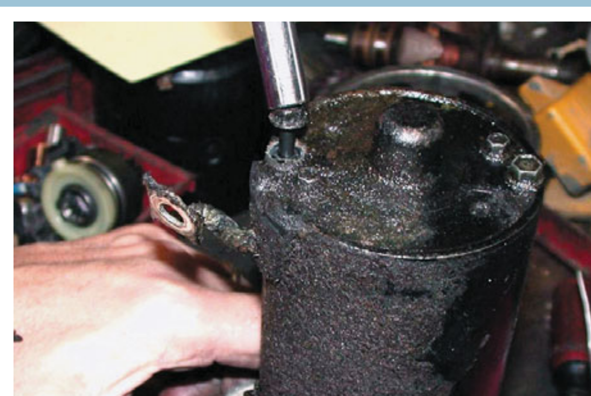
1 This dirty and greasy starter can be restored to useful service.

2 The connecting wire between the solenoid and the starter is removed.

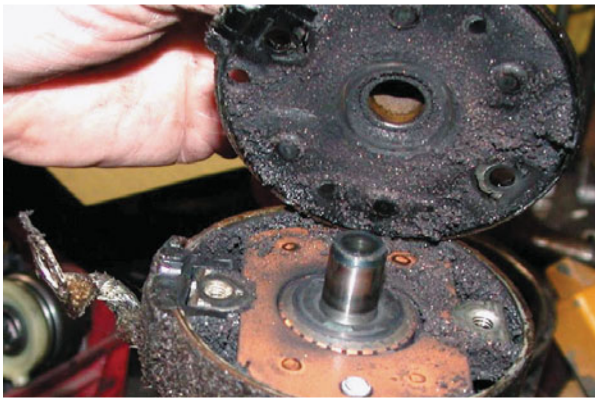
3 An old starter field housing is being used to support the drive-end housing of the starter as it is being disassembled. This rebuilder is using an electric impact wrench to remove the solenoid fasteners.

4 A Torx driver is used to remove the solenoid attaching screws.

5 After the retaining screws have been removed, the solenoid can be separated from the starter motor. This rebuilder always replaces the solenoid.



6 The through-bolts are being removed.

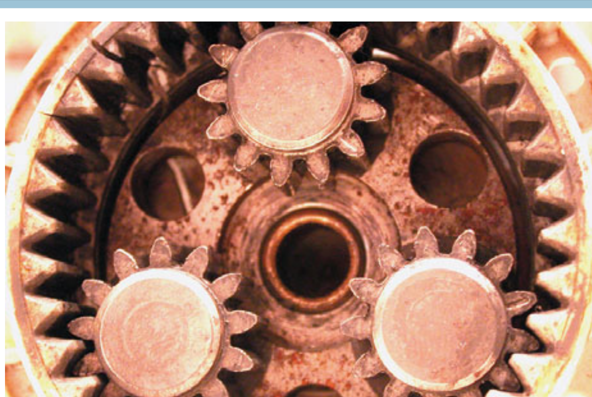


7 The brush end plate is removed.

8 The armature assembly is removed from the field frame.

9 Notice that the length of a direct-drive starter armature (top) is the same length as the overall length of a gear-reduction armature except smaller in diameter.

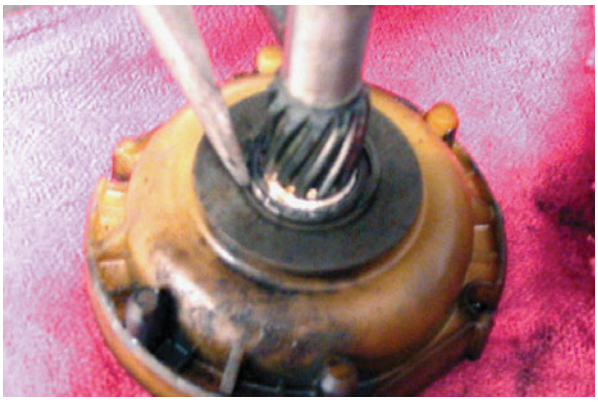
10 A light tap with a hammer dislodges the armature thrust ball (in the palm of the hand) from the center of the gear reduction assembly.



11 This figure shows the planetary ring gear and pinion gears.

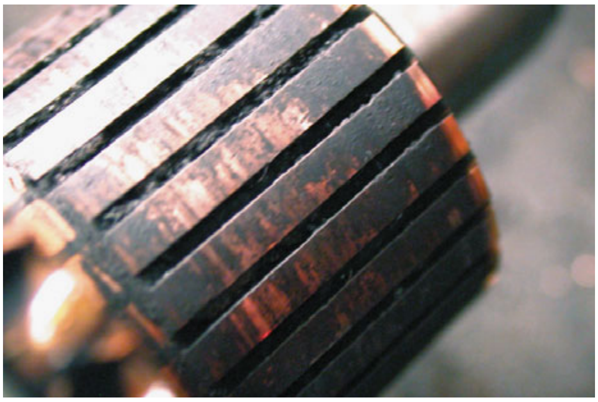
12 A close-up of one of the planetary gears, which shows the small needle bearings on the inside.

CONTINUED ▶



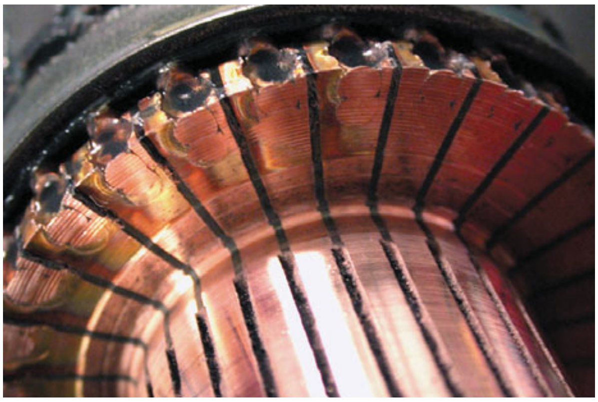
13 The clip is removed from the shaft so the planetary gear assembly can be separated and inspected.

14 The shaft assembly is being separated from the stationary gear assembly.



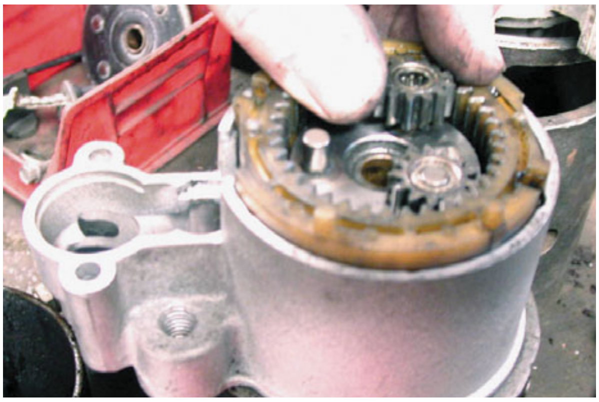
15 The commutator on the armature is discolored and the brushes may not have been making good contact with the segments.

16 All of the starter components are placed in a tumbler with water-based cleaner. The armature is installed in a lathe and the commutator is resurfaced using emery cloth.

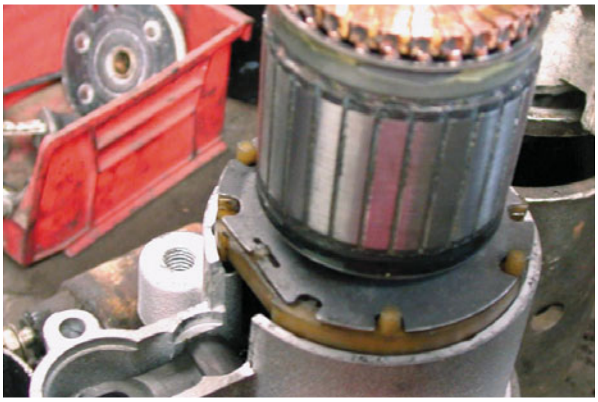


17 The finished commutator looks like new.

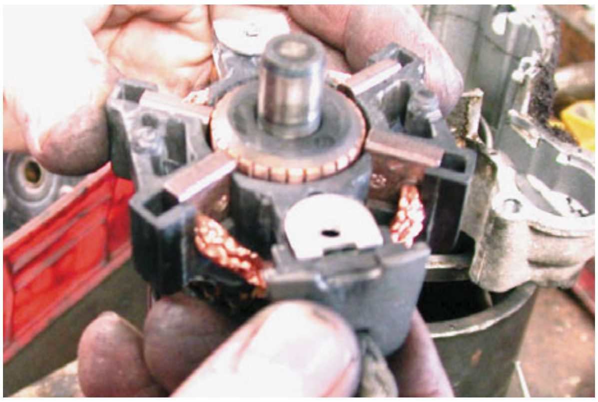
18 Starter reassembly begins by installing a new starter drive on the shaft assembly. The stop ring and stop ring retainer are then installed.



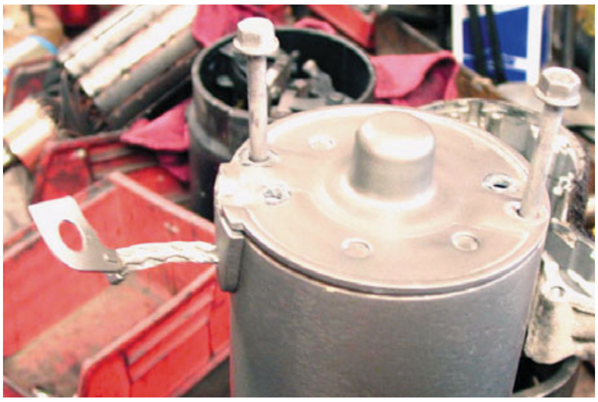
19 The gear-reduction assembly is positioned along with the shift fork (drive lever) into the cleaned drive-end housing.



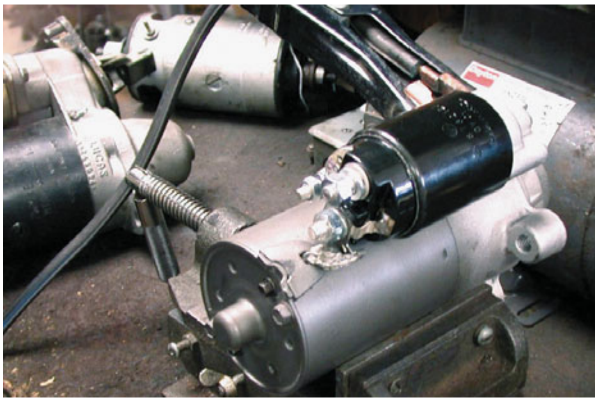
20 After gear retainer has been installed over the gear reduction assembly, the armature is installed.



21 New brushes are being installed into the brush holder assembly.



22 The brush end plate and the through-bolts are installed, being sure that the ground connection for the brushes is clean and tight.



23 This starter was restored to useful service by replacing the solenoid, the brushes, and the starter drive assembly plus a thorough cleaning and attention to detail in the reassembly.

SUMMARY

1. Proper operation and testing of the starter motor depends on the battery being at least 75% charged and the battery cables being of the correct size (gauge) and having no more than a 0.2 volt drop.
2. Voltage drop testing includes cranking the engine, measuring the drop in voltage from the battery to the starter, and measuring the drop in voltage from the negative terminal of the battery to the engine block.
3. The cranking circuit should be tested for proper amperage draw.
4. An open in the control circuit can prevent starter motor operation.

REVIEW QUESTIONS

1. What are the parts of the cranking circuit?
2. What are the steps taken to perform a voltage drop test of the cranking circuit?
3. What are the steps necessary to replace a starter?

CHAPTER QUIZ

1. A growler is used to test what starter component?
   - **a.** Field coils
   - **b.** Armatures
   - **c.** Commutator
   - **d.** Solenoid
2. Two technicians are discussing what could be the cause of slow cranking and excessive current draw. Technician A says that an engine mechanical fault could be the cause. Technician B says that the starter motor could be binding or defective. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. A V-6 is being checked for starter amperage draw. The initial surge current was about 210 amperes and about 160 amperes during cranking. Technician A says the starter is defective and should be replaced because the current flow exceeds 200 amperes. Technician B says this is normal current draw for a starter motor on a V-6 engine. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. What component or circuit can keep the engine from cranking?
   - **a.** Antitheft
   - **b.** Solenoid
   - **c.** Ignition switch
   - **d.** All of the above
5. Technician A says that a discharged battery (lower than normal battery voltage) can cause solenoid clicking. Technician B says that a discharged battery or dirty (corroded) battery cables can cause solenoid clicking. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Slow cranking by the starter can be caused by all *except* ________.
   - **a.** A low or discharged battery
   - **b.** Corroded or dirty battery cables
   - **c.** Engine mechanical problems
   - **d.** An open neutral safety switch
7. Bench testing of a starter should be done ________.
   - **a.** After reassembling an old starter
   - **b.** Before installing a new starter
   - **c.** After removing the old starter
   - **d.** Both a and b

8. If the clearance between the starter pinion and the engine flywheel is too great, ________.
   a. The starter will produce a high-pitched whine during cranking
   b. The starter will produce a high-pitched whine after the engine starts
   c. The starter drive will not rotate at all
   d. The solenoid will not engage the starter drive unit
9. A technician connects one lead of a digital voltmeter to the positive (+) terminal of the battery and the other meter lead to the battery terminal (B) of the starter solenoid and then cranks the engine. During cranking, the voltmeter displays a reading of 878 mV. Technician A says that this reading indicates that the positive battery cable has too high resistance. Technician B says that this reading indicates that the starter is defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A vehicle equipped with a V-8 engine does not crank fast enough to start. Technician A says the battery could be discharged or defective. Technician B says that the negative cable could be loose at the battery. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

chapter 19

CHARGING SYSTEM

OBJECTIVES: After studying Chapter 19, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "D" (Charging System Diagnosis and Repair). • List the parts of a typical alternator. • Describe how an alternator works. • Explain how the powertrain control module (PCM) controls the charging circuit.

KEY TERMS: Alternator 242 • Claw poles 244 • Delta winding 248 • Diodes 245 • Drive-end (DE) housing 242 • Duty cycle 251 • EPM 251 • IDP 243 • OAD 243 • OAP 242 • Rectifier 245 • Rotor 244 • Slip-ring-end (SRE) housing 242 • Stator 245 • Thermistor 250

PRINCIPLES OF ALTERNATOR OPERATION

TERMINOLOGY It is the purpose and function of the charging system to keep the battery fully charged. The Society of Automotive Engineers (SAE) term for the unit that generates electricity is *generator.* The term **alternator** is most commonly used in the trade and will be used in this title.

PRINCIPLES All electrical alternators use the principle of electromagnetic induction to generate electrical power from mechanical power. Electromagnetic induction involves the generation of an electrical current in a conductor when the conductor is moved through a magnetic field. The amount of current generated can be increased by the following factors.

1. Increasing the *speed* of the conductors through the magnetic field
2. Increasing the *number* of conductors passing through the magnetic field
3. Increasing the *strength* of the magnetic field

CHANGING AC TO DC An alternator generates an alternating current (AC) because the current changes polarity during the alternator's rotation. However, a battery cannot "store" alternating current; therefore, this alternating current is changed to direct current (DC) by diodes inside the alternator. Diodes are one-way electrical check valves that permit current to flow in only one direction.

ALTERNATOR CONSTRUCTION

HOUSING An alternator is constructed using a two-piece cast aluminum housing. Aluminum is used because of its lightweight, nonmagnetic properties and heat transfer properties needed to help keep the alternator cool. A front ball bearing is pressed into the front housing, called the **drive-end (DE) housing,** to provide the support and friction reduction necessary for the belt-driven rotor assembly. The rear housing, or the **slip-ring-end (SRE) housing,** usually contains either a roller bearing or ball bearing support for the rotor and mounting for the brushes, diodes, and internal voltage regulator (if so equipped). ● **SEE FIGURES 19–1 AND 19–2.**

ALTERNATOR OVERRUNNING PULLEYS

PURPOSE AND FUNCTION Many alternators are equipped with an **overrunning alternator pulley (OAP),** also called an *overrunning clutch pulley* or an *alternator clutch pulley*. The purpose of this pulley is to help eliminate noise and vibration in the accessory drive belt system, especially when the engine is at idle speed. At idle, engine impulses are transmitted to the alternator through the accessory drive belt. The mass of the rotor of the alternator tends to want to keep spinning, but the engine crankshaft speeds up and slows down slightly due to the power impulses. Using a one-way clutch in the alternator pulley allows the belt to apply power to the alternator in only

FIGURE 19–1 A typical alternator on a Chevrolet V-8 engine.

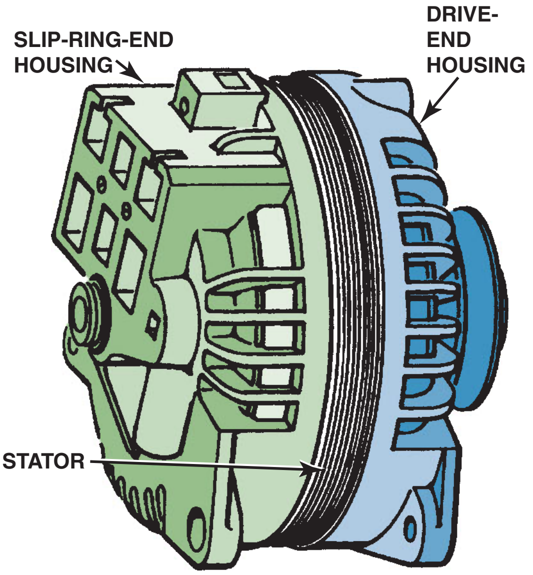


FIGURE 19–2 The end frame toward the drive belt is called the drive-end housing and the rear section is called the slip-ring-end housing.

TECH TIP

Alternator Horsepower and Engine Operation

Many technicians are asked how much power certain accessories require. A 100 ampere alternator requires about 2 horsepower from the engine. One horsepower is equal to 746 watts. Watts are calculated by multiplying amperes times volts.

Power in watts = 100 A × 14.5 V = 1,450 W
1 hp = 746 W

Therefore, 1,450 watts is about 2 horsepower.

Allowing about 20% for mechanical and electrical losses adds another 0.4 horsepower. Therefore, when someone asks how much power it takes to produce 100 amperes from an alternator, the answer is 2.4 horsepower.

Many alternators delay the electrical load to prevent the engine from stumbling when a heavy electrical load is applied. The voltage regulator or vehicle computer is capable of gradually increasing the output of the alternator over a period of several minutes. Even though 2 horsepower does not sound like much, a sudden demand for 2 horsepower from an idling engine can cause the engine to run rough or stall. The difference in part numbers of various alternators is often an indication of the time interval over which the load is applied. Therefore, using the wrong replacement alternator could cause the engine to stall!

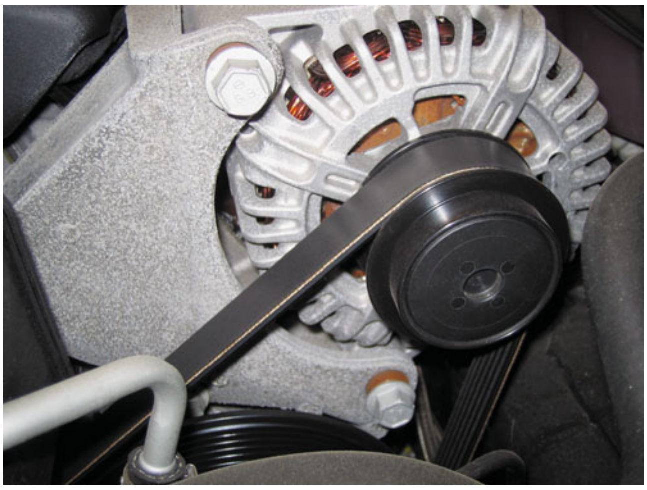


FIGURE 19–3 An OAP on a Chevrolet Corvette alternator.

one direction, thereby reducing fluctuations in the belt. ● **SEE FIGURES 19–3 AND 19-4.**

A conventional drive pulley attaches to the alternator (rotor) shaft with a nut and lock washer. In the overrunning clutch pulley, the inner race of the clutch acts as the nut as it screws on to the shaft. Special tools are required to remove and install this type of pulley.

Another type of alternator pulley uses a dampener spring inside, plus a one-way clutch. These units have the following names.

- **Isolating Decoupler Pulley (IDP)**
- **Active Alternator Pulley (AAP)**
- **Alternator Decoupler Pulley (ADP)**
- **Alternator Overrunning Decoupler Pulley**
- **Overrunning Alternator Dampener (OAD)** (most common term)

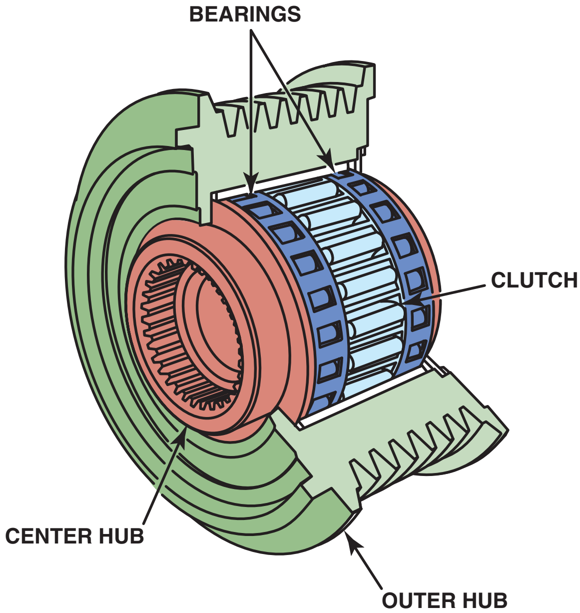


FIGURE 19–4 An exploded view of an overrunning alternator pulley showing all of the internal parts.

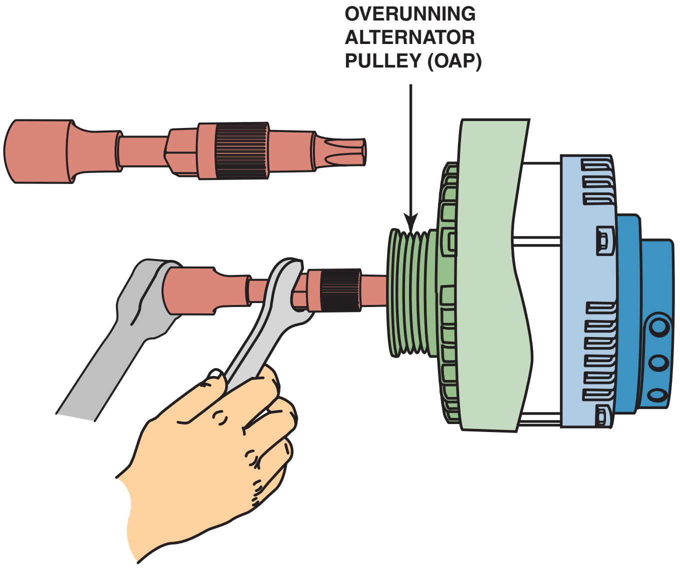


FIGURE 19–5 A special tool is needed to remove and install overrunning alternator pulleys or dampeners.

? FREQUENTLY ASKED QUESTION

Can I Install an OAP or an OAD to My Alternator?

Usually, no. An alternator needs to be equipped with the proper shaft to allow the installation of an OAP or OAD. This also means that a conventional pulley often cannot be used to replace a defective overrunning alternator pulley or dampener with a conventional pulley. Check service information for the exact procedure to follow.

TECH TIP

Always Check the OAP or OAD First

Overrunning alternator pulleys and overrunning alternator dampeners can fail. The most common factor is the one-way clutch. If it fails, it can freewheel and not power the alternator or it can lock up and not provide the dampening as designed. If the charging system is not working, the OAP or OAD could be the cause, rather than a fault in the alternator itself.

In most cases, the entire alternator assembly will be replaced because each OAP or OAD is unique for each application and both require special tools to remove and replace.

● **SEE FIGURE 19–5.**

OAP or OAD pulleys are primarily used on vehicles equipped with diesel engines or on luxury vehicles where noise and vibration need to be kept at a minimum. Both are designed to:

- Reduce accessory drive belt noise
- Improve the life of the accessory drive belt
- Improve fuel economy by allowing the engine to be operated at a low idle speed

ALTERNATOR COMPONENTS AND OPERATION

ROTOR CONSTRUCTION The **rotor** is the rotating part of the alternator and is driven by the accessory drive belt. The rotor creates the magnetic field of the alternator and produces a current by electromagnetic induction in the stationary stator windings. The rotor is constructed of many turns of copper wire coated with a varnish insulation wound over an iron core. The iron core is attached to the rotor shaft.

At both ends of the rotor windings are heavy-gauge metal plates bent over the windings with triangular fingers called **claw poles.** These pole fingers do not touch, but alternate or interlace, as shown in ● **FIGURE 19–6.**

HOW ROTORS CREATE MAGNETIC FIELDS The two ends of the rotor winding are connected to the rotor's slip rings. Current for the rotor flows from the battery into one brush that rides on one of the slip rings, then flows through the rotor winding, then exits the rotor through the other slip ring and brush. One alternator brush is considered to be the "positive" brush and one is considered to be the "negative" or "ground" brush. The voltage regulator is connected to either the positive or the negative brush

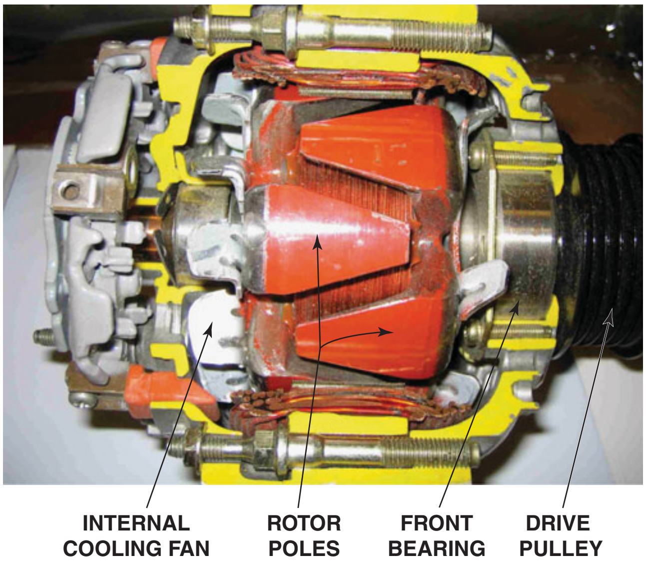


FIGURE 19–6 A cutaway of an alternator, showing the rotor and cooling fan that is used to force air through the unit to remove the heat created when it is charging the battery and supplying electrical power for the vehicle.

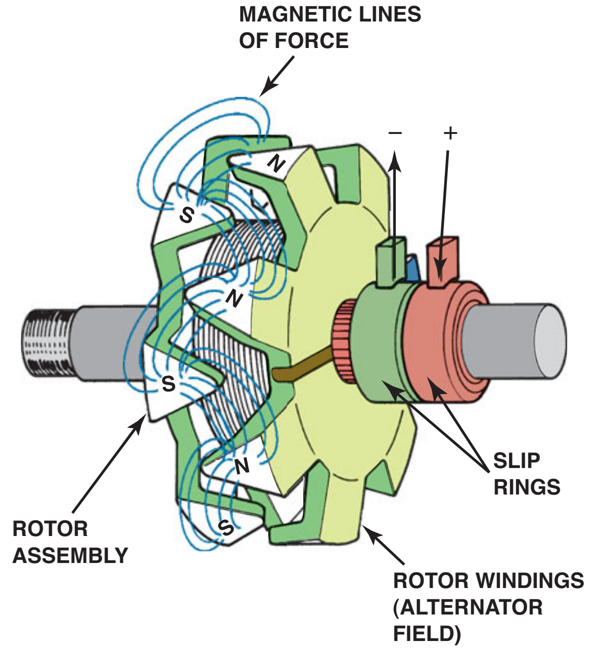


FIGURE 19–7 Rotor assembly of a typical alternator. Current through the slip rings causes the "fingers" of the rotor to become alternating north and south magnetic poles. As the rotor revolves, these magnetic lines of force induce a current in the stator windings.

and controls the field current through the rotor that controls the output of the alternator.

If current flows through the rotor windings, the metal pole pieces at each end of the rotor become electromagnets. Whether a north or a south pole magnet is created depends on the *direction* in which the wire coil is wound. Because the pole pieces are attached to each end of the rotor, one pole piece will be a north pole magnet. The other pole piece is on the opposite end of the rotor and therefore is viewed as being wound in the opposite direction, creating a south pole. Therefore, the rotor fingers are alternating north and south magnetic poles. The magnetic fields are created between the alternating pole piece fingers. These individual magnetic fields produce a current by electromagnetic induction in the stationary stator windings. ● **SEE FIGURE 19–7.**

ROTOR CURRENT The current necessary for the field (rotor) windings is conducted through slip rings with carbon brushes. The maximum rated alternator output in amperes depends on the number and gauge of the rotor windings. Substituting rotors from one alternator to another can greatly affect maximum output. Many commercially rebuilt alternators are tested and then display a sticker to indicate their tested output. The original rating stamped on the housing is then ground off.

The current for the field is controlled by the voltage regulator and is conducted to the slip rings through carbon brushes. The brushes conduct only the field current which is usually between 2 and 5 amperes.

STATOR CONSTRUCTION The **stator** consists of the stationary coil windings inside the alternator. The stator is supported between the two halves of the alternator housing, with three copper wire windings that are wound on a laminated metal core.

As the rotor revolves, its moving magnetic field induces a current in the stator windings. ● **SEE FIGURE 19–8.**

DIODES **Diodes** are constructed of a semiconductor material (usually silicon) and operate as a one-way electrical check valve that permits the current to flow in only one direction. Alternators often use six diodes (one positive and one negative set for each of the three stator windings) to convert alternating current to direct current.

Diodes used in alternators are included in a single part called a **rectifier,** or *rectifier bridge*. A rectifier not only includes the diodes (usually six), but also the cooling fins and connections for the stator windings and the voltage regulator. ● **SEE FIGURE 19–9.**

DIODE TRIO Some alternators are equipped with a diode trio that supplies current to the brushes from the stator windings. A diode trio uses three diodes, in one housing, with one diode for each of the three stator windings and then one output terminal.

HOW AN ALTERNATOR WORKS

FIELD CURRENT IS PRODUCED A rotor inside an alternator is turned by a belt and drive pulley which are turned by the engine. The magnetic field of the rotor generates a current in the stator windings by electromagnetic induction. ● **SEE FIGURE 19–10.**

Field current flowing through the slip rings to the rotor creates an alternating north and south pole on the rotor, with a magnetic field between each finger of the rotor.

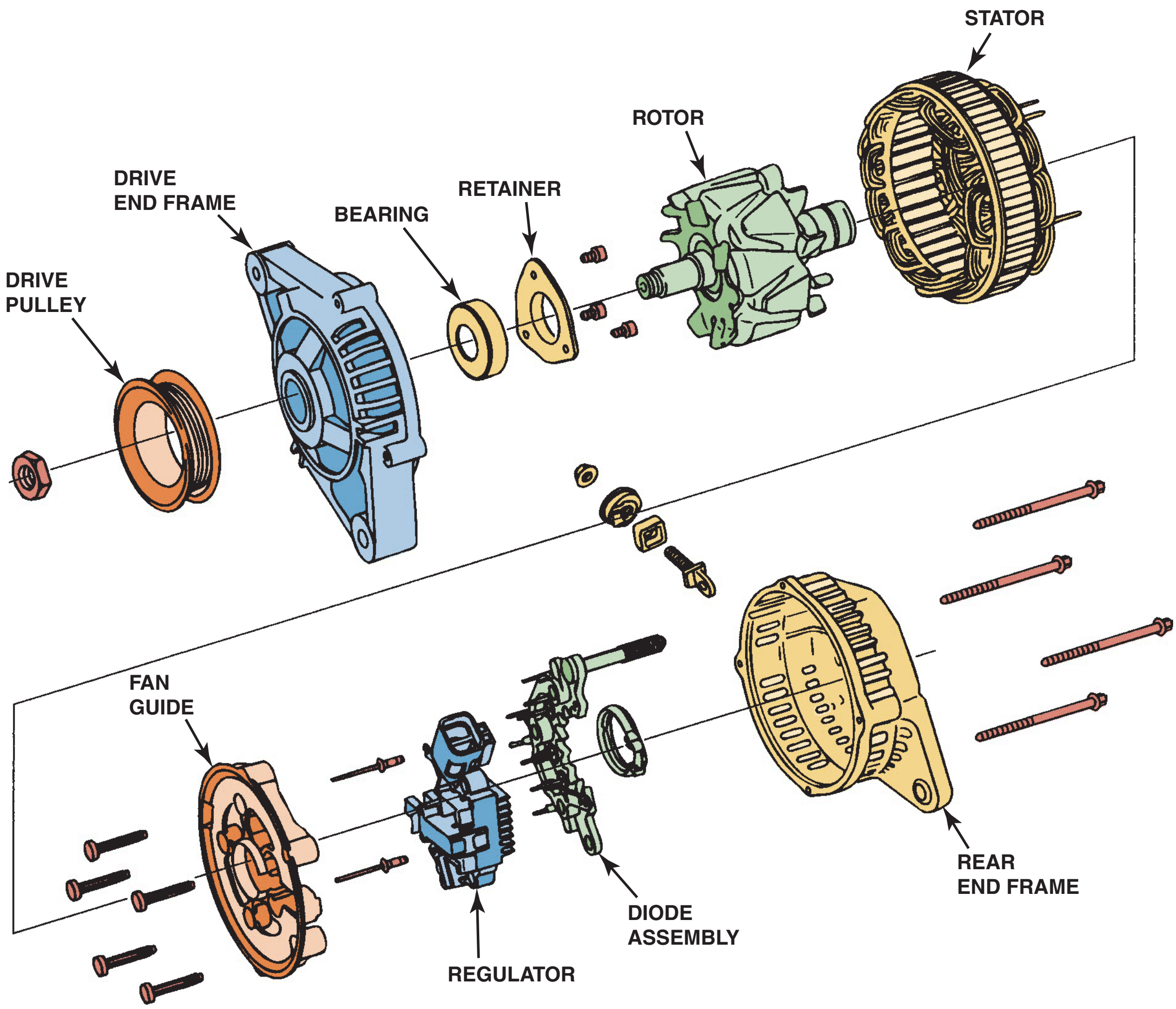


FIGURE 19–8 An exploded view of a typical alternator showing all of its internal parts including the stator windings.

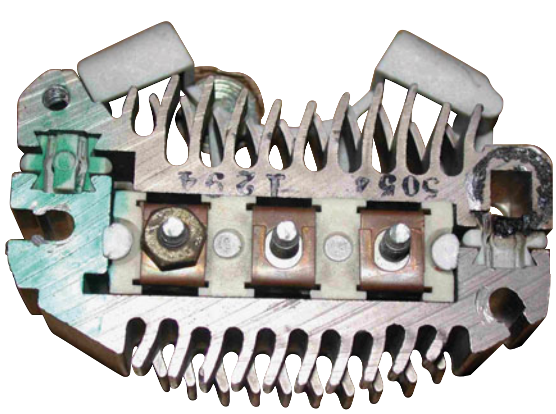


FIGURE 19–9 A rectifier usually includes six diodes in one assembly and is used to rectify AC voltage from the stator windings into DC voltage suitable for use by the battery and electrical devices in the vehicle.

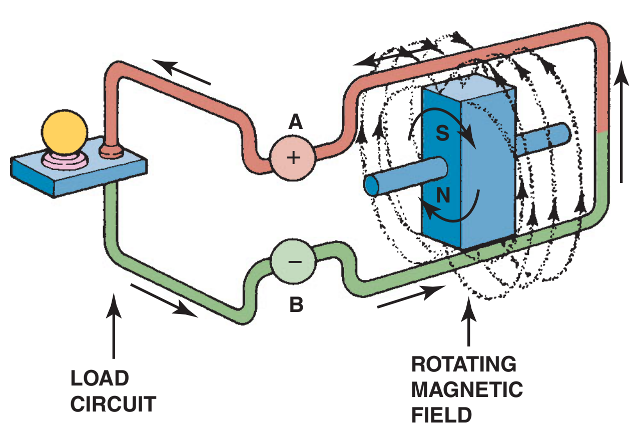


FIGURE 19–10 Magnetic lines of force cutting across a conductor induce a voltage and current in the conductor.

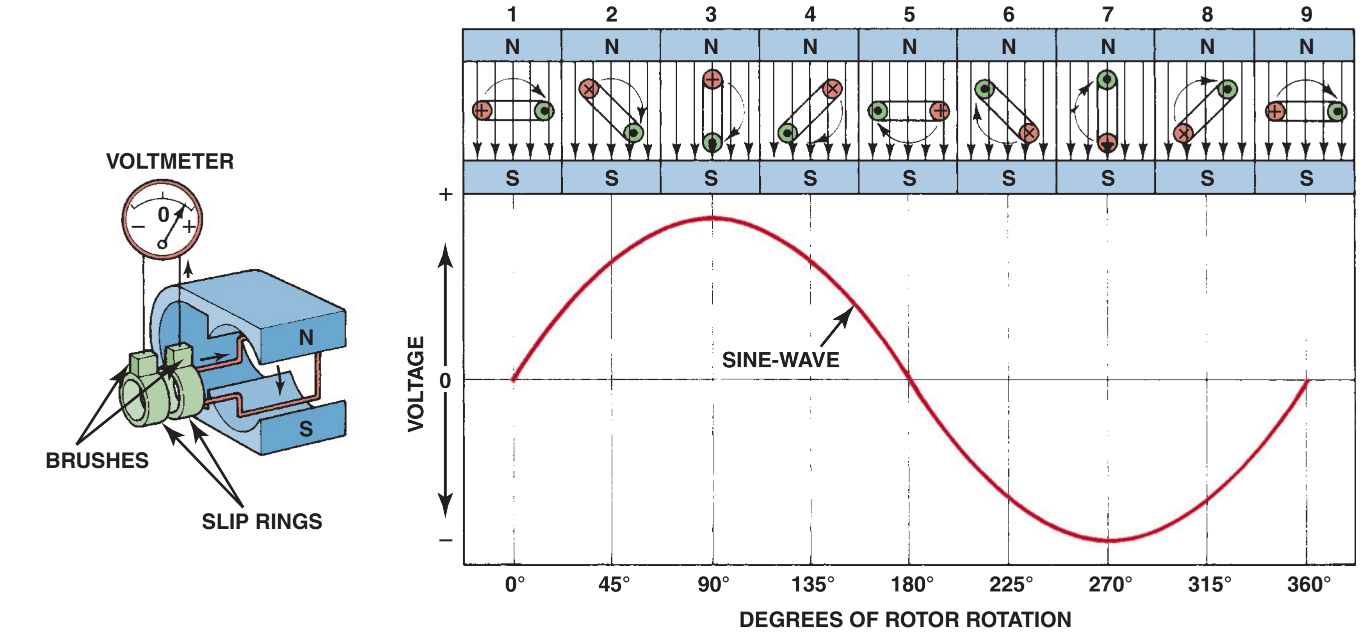


FIGURE 19–11 A sine wave (shaped like the letter *S* on its side) voltage curve is created by one revolution of a winding as it rotates in a magnetic field.

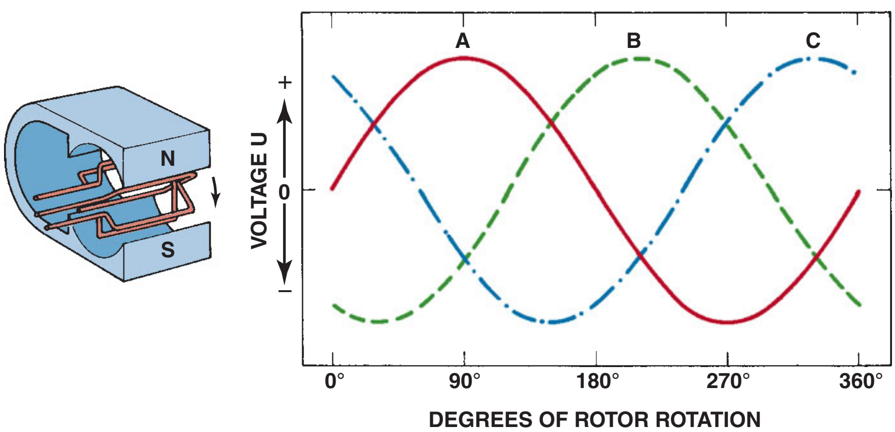


FIGURE 19–12 When three windings (A, B, and C) are present in a stator, the resulting current generation is represented by the three sine waves. The voltages are 120 degrees out of phase. The connection of the individual phases produces a three-phase alternating voltage.

CURRENT IS INDUCED IN THE STATOR The induced current in the stator windings is an alternating current because of the alternating magnetic field of the rotor. The induced current starts to increase as the magnetic field starts to induce current in each winding of the stator. The current then peaks when the magnetic field is the strongest and starts to decrease as the magnetic field moves away from the stator winding. Therefore, the current generated is described as being of a sine wave or alternating current pattern. ● **SEE FIGURE 19–11.**

As the rotor continues to rotate, this sine wave current is induced in each of the three windings of the stator.

Because each of the three windings generates a sine wave current, as shown in ● **FIGURE 19–12,** the resulting currents combine to form a three-phase voltage output.

The current induced in the stator windings connects to diodes (one-way electrical check valves) that permit the alternator output current to flow in only one direction. All alternators contain six diodes, one pair (a positive and a negative diode) for each of the three stator windings. Some alternators contain eight diodes with another pair connected to the center connection of a wye-type stator.

WYE-CONNECTED STATORS The Y (pronounced "wye" and generally so written) type or star pattern is the most commonly used alternator stator winding connection. ● **SEE FIGURE 19–13.**

The output current with a wye-type stator connection is constant over a broad alternator speed range.

Current is induced in each winding by electromagnetic induction from the rotating magnetic fields of the rotor. In a wye-type stator connection, the currents must combine because two windings are always connected in series. ● **SEE FIGURE 19–14.**

The current produced in each winding is added to the other windings' current and then flows through the diodes to the alternator output terminal. One-half of the current produced is available at the neutral junction (usually labeled "STA" for

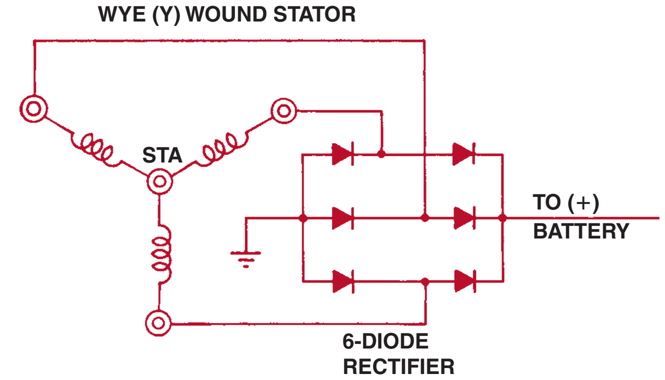


FIGURE 19–13 Wye-connected stator winding.

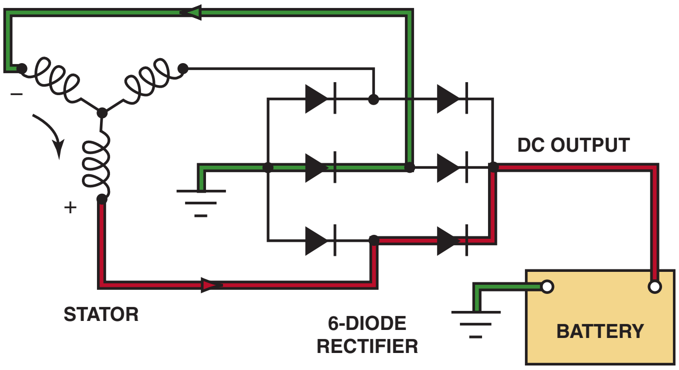


FIGURE 19–14 As the magnetic field, created in the rotor, cuts across the windings of the stator, a current is induced. Notice that the current path includes passing through one positive (+) diode on the way to the battery and one negative (−) diode as a complete circuit is completed through the rectifier and stator.

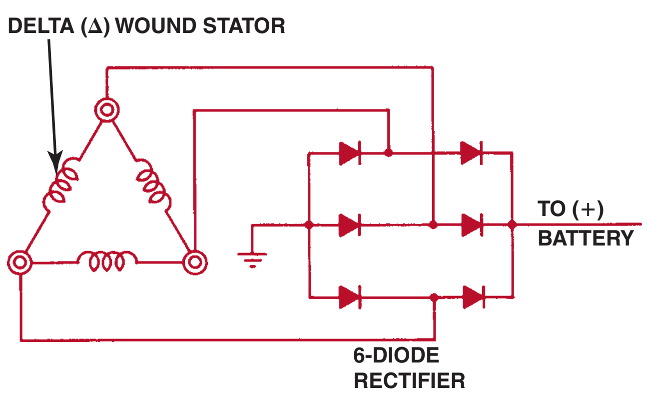


FIGURE 19–15 Delta-connected stator winding.

stator). The voltage at this center point is used by some alternator manufacturers (especially Ford) to control the charge indicator light or is used by the voltage regulator to control the rotor field current.

DELTA-CONNECTED STATORS The **delta winding** is connected in a triangular shape. Delta is a Greek letter shaped like a triangle. ● **SEE FIGURE 19–15.**

FIGURE 19–16 A stator assembly with six, rather than the normal three, windings.

Current induced in each winding flows to the diodes in a parallel circuit. More current can flow through two parallel circuits than can flow through a series circuit (as in a wye-type stator connection).

Delta-connected stators are used on alternators where high output at high-alternator RPM is required. The delta-connected alternator can produce 73% more current than the same alternator with wye-type stator connections. For example, if an alternator with a wye-connected stator can produce 55 A, the *same* alternator with delta-connected stator windings can produce 73% more current, or 95 A (55 × 1.73 = 95). The delta-connected alternator, however, produces lower current at low speed and must be operated at high speed to produce its maximum output.

ALTERNATOR OUTPUT FACTORS

The output voltage and current of an alternator depend on the following factors.

1. **Speed of rotation.** Alternator output is increased with alternator rotational speed up to the alternator's maximum possible ampere output. Alternators normally rotate at a speed two to three times faster than engine speed, depending on the relative pulley sizes used for the belt drive. For example, if an engine is operating at 5000 RPM, the alternator will be rotating at about 15,000 RPM.
2. **Number of conductors.** A high-output alternator contains more turns of wire in the stator windings. Stator winding connections (whether wye or delta) also affect the maximum alternator output. ● **SEE FIGURE 19–16** for an example of a stator that has six rather than three windings, which greatly increases the amperage output of the alternator.
3. **Strength of the magnetic field.** If the magnetic field is strong, a high output is possible because the current generated by electromagnetic induction is dependent on the number of magnetic lines of force that are cut.

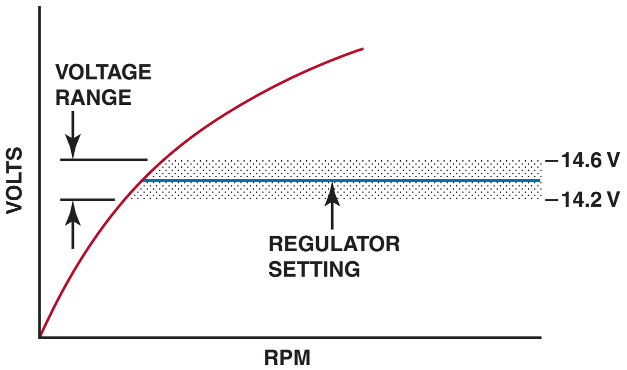


FIGURE 19–17 Typical voltage regulator range.

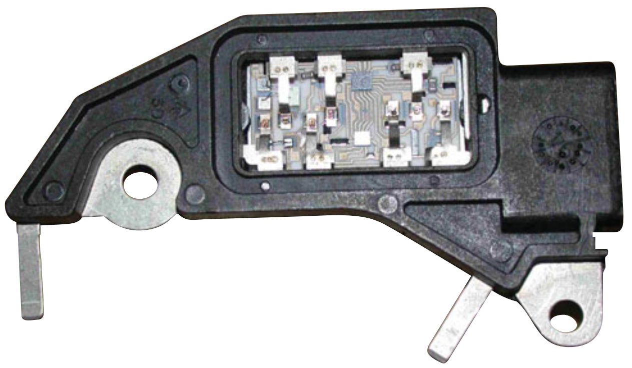


FIGURE 19–18 A typical electronic voltage regulator with the cover removed showing the circuits inside.

a. The strength of the magnetic field can be increased by increasing the number of turns of conductor wire wound on the rotor. A higher output alternator rotor has more turns of wire than an alternator rotor with a low rated output.

b. The strength of the magnetic field also depends on the current through the field coil (rotor). Because magnetic field strength is measured in ampere-turns, the greater the amperage or the number of turns, or both, the greater the alternator output.

ALTERNATOR VOLTAGE REGULATION

PRINCIPLES An automotive alternator must be able to produce electrical pressure (voltage) higher than battery voltage to charge the battery. Excessively high voltage can damage the battery, electrical components, and the lights of a vehicle. Basic principles include the following:

- If no (zero) amperes of current existed throughout the field coil of the alternator (rotor), alternator output would be zero because without field current a magnetic field does not exist.
- The field current required by most automotive alternators is less than 3 amperes. It is the *control* of the *field* current that controls the output of the alternator.
- Current for the rotor flows from the battery positive post, through the rotor positive brush, into the rotor field winding, and exits the rotor winding through the rotor ground brush. Most voltage regulators control field current by controlling the amount of field current through the ground brush.
- The voltage regulator simply opens the field circuit if the voltage reaches a predetermined level, then closes the field circuit again as necessary to maintain the correct charging voltage. ● **SEE FIGURE 19–17.**
- The electronic circuit of the voltage regulator cycles between 10 and 7,000 times per *second* as needed to accurately control the field current through the rotor, and therefore control the alternator output.

REGULATOR OPERATION

- The control of the field current is accomplished by opening and closing the *ground* side of the field circuit through the rotor on most alternators.
- The zener diode is a major electronic component that makes voltage regulation possible. A zener diode blocks current flow until a specific voltage is reached, then it permits current to flow. Alternator voltage from the stator and diodes is first sent through a thermistor, which changes resistance with temperature, and then to a zener diode. When the upper-limit voltage is reached, the zener diode conducts current to a transistor, which then opens the field (rotor) circuit. The electronics are usually housed in a separate part inside the alternator. ● **SEE FIGURES 19–18 AND 19–19.**

BATTERY CONDITION AND CHARGING VOLTAGE If the automotive battery is discharged, its voltage will be lower than the voltage of a fully charged battery. The alternator will supply charging current, but it may not reach the maximum charging voltage. For example, if a vehicle is jump started and run at a fast idle (2,000 RPM), the charging voltage may be only 12 volts. In this case, the following may occur.

- As the battery becomes charged and the battery voltage increases, the charging voltage will also increase, until the voltage regulator limit is reached.
- Then the voltage regulator will start to control the charging voltage. A good, but discharged, battery should be able to convert into chemical energy all the current the alternator can produce. As long as alternator voltage is higher than battery voltage, current will flow from the alternator (high voltage) to the battery (lower voltage).
- Therefore, if a voltmeter is connected to a discharged battery with the engine running, it may indicate charging voltage that is lower than normally acceptable.

In other words, the condition and voltage of the battery *do* determine the charging rate of the alternator. It is often stated

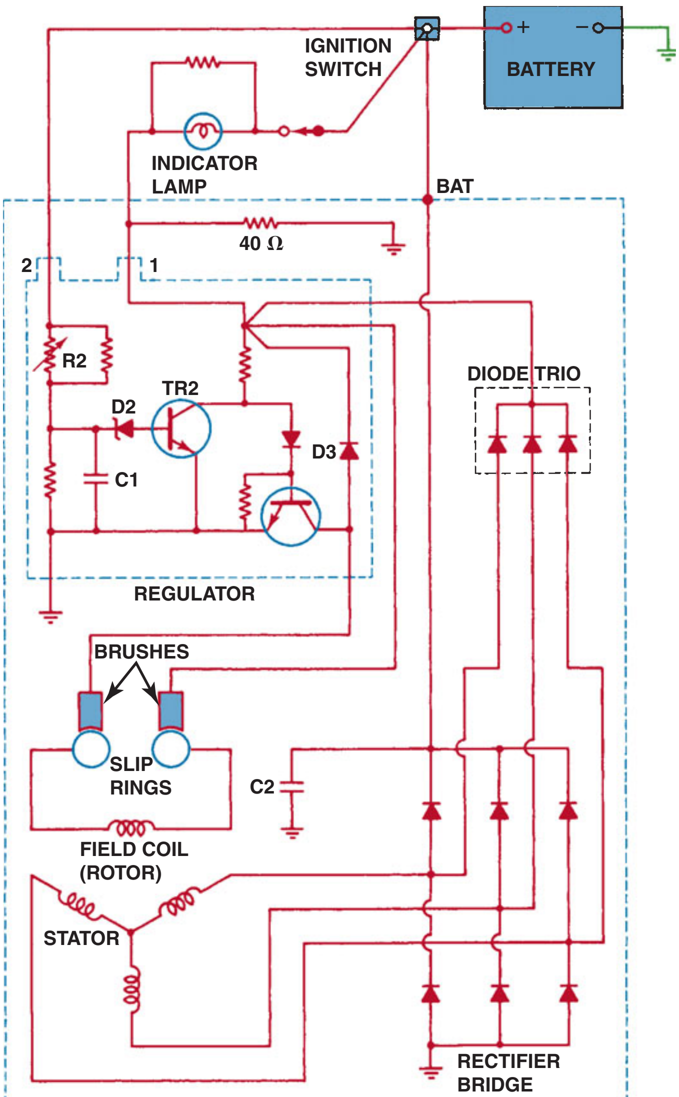


FIGURE 19–19 Typical General Motors SI-style alternator with an integral voltage regulator. Voltage present at terminal 2 is used to reverse bias the zener diode (D2) that controls TR2. The positive brush is fed by the ignition current (terminal I) plus current from the diode trio.

FIGURE 19–20 A coolant-cooled alternator showing the hose connections where coolant from the engine flows through the rear frame of the alternator.

that the battery is the true "voltage regulator" and that the voltage regulator simply acts as the upper-limit voltage control. This is the reason why all charging system testing *must* be performed with a reliable and known to be good battery, at least 75% charged, to be assured of accurate test results. If a discharged battery is used during charging system testing, tests could mistakenly indicate a defective alternator and/or voltage regulator and could cause the stator windings to overheat.

TEMPERATURE COMPENSATION All voltage regulators (mechanical or electronic) provide a method for increasing the charging voltage slightly at low temperatures and for lowering the charging voltage at high temperatures. A battery requires a higher charging voltage at low temperatures because of the resistance to chemical reaction changes. However, the battery would be overcharged if the charging voltage were not reduced during warm weather. Electronic voltage regulators use a temperature-sensitive resistor in the regulator circuit. This resistor, called a **thermistor,** provides lower resistance as the temperature increases. A thermistor is used in the electronic circuits of the voltage regulator to control charging voltage over a wide range of underhood temperatures.

NOTE: Voltmeter test results may vary according to temperature. Charging voltage tested at 32°F (0°C) will be higher than for the same vehicle tested at 80°F (27°C) because of the temperature-compensation factors built into voltage regulators.

ALTERNATOR COOLING

Alternators create heat during normal operation and this heat must be removed to protect the components inside, especially the diodes and voltage regulator. The types of cooling include:

- External fan
- Internal fan(s)
- Both an external fan and an internal fan
- Coolant cooled (**SEE FIGURE 19–20.**)

FIGURE 19–21 A Hall-effect current sensor attached to the positive battery cable is used as part of the EPM system.

COMMAND DUTY CYCLE	ALTERNATOR OUTPUT VOLTAGE
10%	11.0 V
20%	11.6 V
30%	12.1 V
40%	12.7 V
50%	13.3 V
60%	13.8 V
70%	14.4 V
80%	14.9 V
90%	15.5 V

CHART 19–1

The output voltage is controlled by varying the duty cycle as controlled by the PCM.

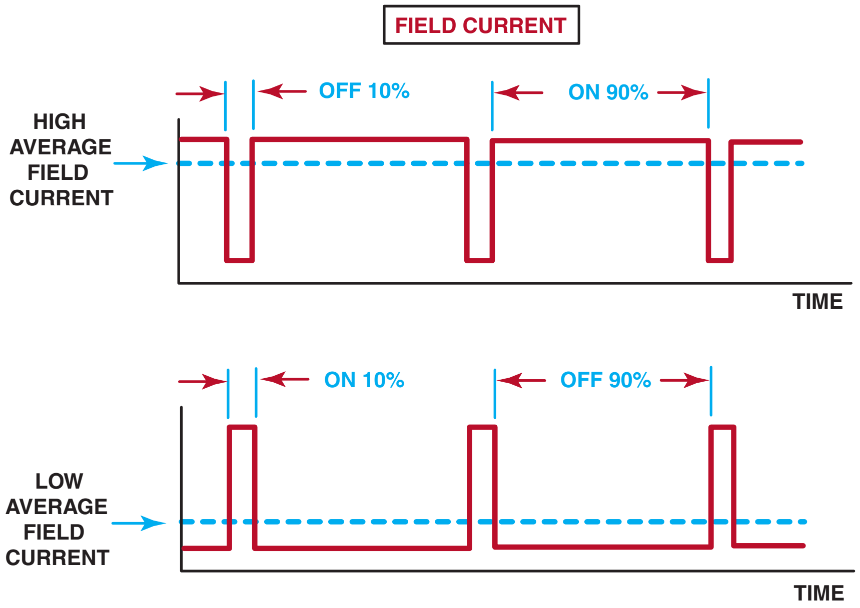


FIGURE 19–22 The amount of time current is flowing through the field (rotor) determines the alternator output.

COMPUTER-CONTROLLED ALTERNATORS

TYPES OF SYSTEMS Computers can interface with the charging system in three ways.

1. The computer can *activate* the charging system by turning on and off the field current to the rotor. In other words, the computer, usually the powertrain control module (PCM), controls the field current to the rotor.
2. The computer can *monitor* the operation of the alternator and increase engine speed if needed during conditions when a heavy load is demanded by the alternator.
3. The computer can *control* the alternator by controlling alternator output to match the needs of the electrical system. This system detects the electrical needs of the vehicle and commands the alternator to charge only when needed to improve fuel economy.

GM ELECTRICAL POWER MANAGEMENT SYSTEM A typical system used on some General Motors vehicles is called **electrical power management (EPM)**. It uses a Hall-effect sensor attached to the negative or positive battery cable to measure the current leaving and entering the battery. ● **SEE FIGURE 19–21.**

The engine control module (ECM) controls the alternator by changing the on-time of the current through the rotor. ● **SEE FIGURE 19–22.**

The on-time, called **duty cycle,** varies from 5% to 95%. ● **SEE CHART 19–1.**

This system has six modes of operation.

1. **Charge mode.** The charge mode is activated when any of the following occurs.
   - Electric cooling fans are on high speed.
   - Rear window defogger is on.
   - Battery state of charge (SOC) is less than 80%.
   - Outside (ambient) temperature is less than 32°F (0°C).
2. **Fuel economy mode.** This mode reduces the load on the engine from the alternator for maximum fuel economy. This mode is activated when the following conditions are met.
   - Ambient temperature is above 32°F (0°C).
   - The state of charge of the battery is 80% or higher.
   - The cooling fans and rear defogger are off.

   The target voltage is 13 volts and will return to the charge mode, if needed.
3. **Voltage reduction mode.** This mode is commanded to reduce the stress on the battery during low-load conditions. This mode is activated when the following conditions are met.
   - Ambient temperature is above 32°F (0°C).
   - Battery discharge rate is less than 7 amperes.
   - Rear defogger is off.
   - Cooling fans are on low or off.
   - Target voltage is limited to 12.7 volts.
4. **Start-up mode.** This mode is selected after engine start and commands a charging voltage of 14.5 volts for 30 seconds. After 30 seconds, the mode is changed depending on conditions.
5. **Battery sulfation mode.** This mode is commanded if the output voltage is less than 13.2 volts for 45 minutes, which can indicate that sulfated plates could be the cause. The target voltage is 13.9 to 15.5 volts for three minutes. After three minutes, the system returns to another mode based on conditions.
6. **Headlight mode.** This mode is selected when the headlights are on and the target voltage is 14.5 volts.

COMPUTER-CONTROLLED CHARGING SYSTEMS

Computer control of the charging system has the following advantages.

1. The computer controls the field of the alternator, which can pulse it on or off as needed for maximum efficiency, thereby saving fuel.

NOTE: Some vehicle manufacturers, such as Honda/Acura, use an *electronic load control (ELC)*, which turns on the alternator when decelerating, where the additional load on the engine is simply used to help slow the vehicle. This allows the battery to be charged without placing a load on the engine, helping to increase fuel economy.

2. Engine idle can also be improved by turning on the alternator slowly, rather than all at once, if an electrical load is switched on, such as the air-conditioning system.
3. Most computers can also reduce the load on the electrical system if the demand exceeds the capacity of the charging system by reducing fan speed, shutting off rear window defoggers, or increasing engine speed to cause the alternator to increase the amperage output.

NOTE: A commanded higher-than-normal idle speed may be the result of the computer compensating for an abnormal electrical load. This higher idle speed could indicate a defective battery or other electrical system faults.

4. The computer can monitor the charging system and set diagnostic trouble codes (DTCs) if a fault is detected. Many systems allow the service technician to control the charging of the alternator using a scan tool.
5. Because the charging system is computer controlled, it can be checked using a scan tool. Some vehicle systems allow the scan tool to activate the alternator field and then monitor the output to help detect fault locations. Always follow the vehicle manufacturer's diagnostic procedure.

TECH TIP

The Voltage Display Can Be a Customer Concern

A customer may complain that the voltmeter reading on the dash fluctuates up and down. This may be normal as the computer-controlled charging system commands various modes of operation based on the operating conditions. Follow the vehicle manufacturer's recommended procedures to verify proper operation.

SUMMARY

1. Alternator output is increased if the speed of the alternator is increased.
2. The parts of a typical alternator include the drive-end (DE) housing, slip-ring-end (SRE) housing, rotor assembly, stator, rectifier bridge, brushes, and voltage regulator.
3. The magnetic field is created in the rotor.
4. The alternator output current is created in the stator windings.
5. The voltage regulator controls the current flow through the rotor winding.

REVIEW QUESTIONS

1. How can a small electronic voltage regulator control the output of a typical 100 ampere alternator?
2. What are the component parts of a typical alternator?
3. How is the computer used to control an alternator?
4. Why do voltage regulators include temperature compensation?
5. How is AC voltage inside the alternator changed to DC voltage at the output terminal?
6. What is the purpose of an OAP or OAD?

CHAPTER QUIZ

1. Technician A says that the diodes regulate the alternator output voltage. Technician B says that the field current can be computer controlled. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A magnetic field is created in the ________ in an alternator (AC alternator).
   - **a.** Stator
   - **b.** Diodes
   - **c.** Rotor
   - **d.** Drive-end frame
3. The voltage regulator controls current through the ________.
   - **a.** Alternator brushes
   - **b.** Rotor
   - **c.** Alternator field
   - **d.** All of the above
4. Technician A says that two diodes are required for each stator winding lead. Technician B says that diodes change alternating current into direct current. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. The alternator output current is produced in the ________.
   - **a.** Stator
   - **b.** Rotor
   - **c.** Brushes
   - **d.** Diodes (rectifier bridge)
6. Alternator brushes are constructed from ________.
   - **a.** Copper
   - **b.** Aluminum
   - **c.** Carbon
   - **d.** Silver-copper alloy
7. How much current flows through the alternator brushes?
   - **a.** All of the alternator output flows through the brushes
   - **b.** 25 to 35 A, depending on the vehicle
   - **c.** 10 to 15 A
   - **d.** 2 to 5 A
8. Technician A says that an alternator overrunning pulley is used to reduce vibration and noise. Technician B says that an overrunning alternator pulley or dampener uses a one-way clutch. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Operating an alternator in a vehicle with a defective battery can harm the ________.
   - **a.** Diodes (rectifier bridge)
   - **b.** Stator
   - **c.** Voltage regulator
   - **d.** Brushes
10. Technician A says that a wye-wound stator produces more maximum output than the same alternator equipped with a delta-wound stator. Technician B says that an alternator equipped with a delta-wound stator produces more maximum output than a wye-wound stator. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

chapter 20 CHARGING SYSTEM DIAGNOSIS AND SERVICE

OBJECTIVES: After studying Chapter 20, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "D" (Charging System Diagnosis and Repair). • Describe how to perform a charging voltage test. • Discuss how to perform an AC ripple voltage test. • Explain how to perform an alternator output test. • Explain how to disassemble an alternator and test its component parts. • Discuss how to check the wiring from the alternator to the battery. • Describe how to test the operation of a computer-controlled charging system.

KEY TERMS: AC ripple voltage 257 • Alternator output test 259 • Charging voltage test 254 • Cores 265

CHARGING SYSTEM TESTING AND SERVICE

BATTERY STATE OF CHARGE The charging system can be tested as part of a routine vehicle inspection or to determine the reason for a no-charge or reduced charging circuit performance. The battery *must* be at least 75% charged before testing the alternator and the charging system. A weak or defective battery will cause inaccurate test results. If in doubt, replace the battery with a known good shop battery for testing.

CHARGING VOLTAGE TEST The **charging voltage test** is the easiest way to check the charging system voltage at the battery. Use a digital multimeter to check the voltage, as follows:

STEP 1 Select DC volts.

STEP 2 Connect the red meter lead to the positive (+) terminal of the battery and the black meter lead to the negative (−) terminal of the battery.

NOTE: The polarity of the meter leads is not too important when using a digital multimeter. If the meter leads are connected backward on the battery, the resulting readout will simply have a negative (−) sign in front of the voltage reading.

STEP 3 Start the engine and increase the engine speed to about 2000 RPM (fast idle) and record the charging voltage. ● **SEE FIGURE 20–1.**

Specifications for charging voltage = 13.5 to 15 V

- If the voltage is too high, check that the alternator is properly grounded.

FIGURE 20–1 The digital multimeter should be set to read DC volts, with the red lead connected to the positive (+) battery terminal and the black meter lead connected to the negative (−) battery terminal.

- If the voltage is lower than specifications, then there is a fault with the wiring or the alternator.
- If the wiring and the connections are okay, then additional testing is required to help pinpoint the root cause. Replacement of the alternator and/or battery is often required if the charging voltage is not within factory specifications.

SCAN TESTING THE CHARGING CIRCUIT Most vehicles that use a computer-controlled charging system can be diagnosed using a scan tool. Not only can the charging voltage be monitored, but also in many vehicles, the field circuit can be controlled and the output voltage monitored to check that the system is operating correctly. ● **SEE FIGURE 20–2.**

FIGURE 20–2 A scan tool can be used to diagnose charging system problems.

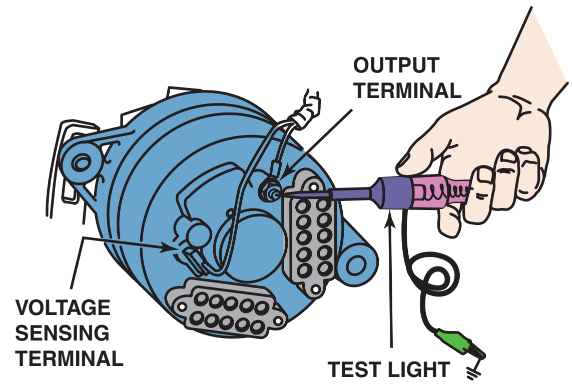


FIGURE 20–3 Before replacing an alternator, the wise technician checks that battery voltage is present at the output and battery voltage sense terminals. If not, then there is a fault in the wiring.

FREQUENTLY ASKED QUESTION

What Is a Full-Fielding Test?

Full fielding is a procedure used on older noncomputerized vehicles for bypassing the voltage regulator that could be used to determine if the alternator is capable of producing its designed output. This test is no longer performed for the following reasons.

- The voltage regulator is built into the alternator, therefore requiring that the entire assembly be replaced even if just the regulator is defective.
- When the regulator is bypassed, the alternator can produce a high voltage (over 100 volts in some cases) which could damage all of the electronic circuits in the vehicle.

Always follow the vehicle manufacturer's recommended testing procedures.

NOTE: Some charging systems, such as those on many Honda/Acura vehicles, use an electronic load detection circuit that energizes the field circuit only when an electrical load is detected. For example, if the engine is running and there are no accessories on, the voltage read at the battery may be 12.6 V, which could indicate that the charging system is not operating. In this situation, turning on the headlights or an accessory should cause the computer to activate the field circuit, and the alternator should produce normal charging voltage.

TECH TIP

Use a Test Light to Check for a Defective Fusible Link

Most alternators use a fusible link or mega fuse between the output terminal and the positive (+) terminal of the battery. If this fusible link or fuse is defective (blown), then the charging system will not operate at all. Many alternators have been replaced repeatedly because of a blown fusible link that was not discovered until later. A quick and easy test to check if the fusible link is okay is to touch a test light to the output terminal. With the other end of the test light attached to a good ground, the fusible link or mega fuse is okay if the light lights. This test confirms that the circuit between the alternator and the battery has continuity. ● **SEE FIGURE 20–3.**

DRIVE BELT INSPECTION AND ADJUSTMENT

BELT VISUAL INSPECTION It is generally recommended that all belts be inspected regularly and replaced as needed. Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3 in. span. Check service information for the specified procedure and recommended replacement interval. ● **SEE FIGURE 20–4.**

BELT TENSION MEASUREMENT If the vehicle does not use a belt tensioner, then a belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory

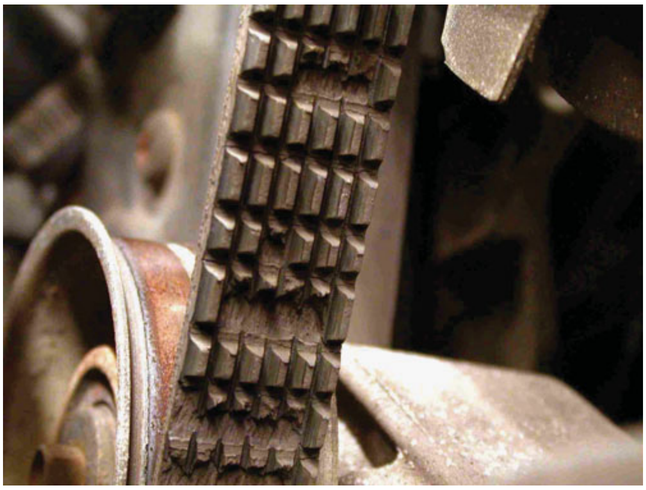


FIGURE 20–4 This accessory drive belt is worn and requires replacement. Newer belts are made from ethylene propylene diene monomer (EPDM). This rubber does not crack like older belts and may not show wear even though the ribs do wear and can cause slippage.

FIGURE 20–5 Check service information for the exact marks where the tensioner should be located for proper belt tension.

TECH TIP

The Hand Cleaner Trick

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the Vs of the belt and the angle of the Vs on the pulley. As the belt wears, the interference angles are worn off of both edges of the belt. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A common trick used to determine if the noise is belt related is to use grit-type hand cleaner or scouring powder. With the engine off, sprinkle some powder onto the pulley side of the belt. Start the engine. The excess powder will fly into the air, so get away from under the hood when the engine starts. If the belts are now quieter, you know that it was the glazed belt that made the noise.

The noise can sound exactly like a noisy bearing. Therefore, before you start removing and replacing parts, try the hand cleaner trick.

Often, the grit from the hand cleaner will remove the glaze from the belt and the noise will not return. However, if the belt is worn or loose, the noise will return and the belt should be replaced. A fast, alternative method to see if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates and, therefore, unlike the gritty hand cleaner, water simply finds the problem—it does not provide a short-term fix.

SERPENTINE BELTS	
NUMBER OF RIBS USED	TENSION RANGE (LB)
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145
V-BELTS	
V-BELT TOP WIDTH (IN.)	TENSION RANGE (LB)
1/4	45–65
5/16	60–85
25/64	85–115
31/64	105–145

CHART 20–1

Typical belt tension for various widths of belts. Tension is the force needed to depress the belt as displayed on a belt tension gauge.

drive belt to factory specifications or use the following table for an example of the proper tension based on the size of the belt.

There are four ways that vehicle manufacturers specify that the belt tension is within factory specifications.

1. **Belt tension gauge.** A belt tension gauge is needed to determine if it is at the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications, or see ● **CHART 20–1** for an example of the proper tension based on the size of the belt.
2. **Marks on a tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the preferred location of the tensioner mark. ● **SEE FIGURE 20–5.**

TECH TIP

Check the Overrunning Clutch

If low or no alternator output is found, remove the alternator drive belt and check the overrunning alternator pulley (OAP) or overrunning alternator dampener (OAD) for proper operation. Both types of overrunning clutches use a one-way clutch. Therefore, the pulley should freewheel in one direction and rotate the alternator rotor when rotated in the opposite direction. ● **SEE FIGURE 20–6.**

FIGURE 20–6 This overrunning alternator dampener (OAD) is longer than an overrunning alternator pulley (OAP) because it contains a dampener spring as well as a one way clutch. Be sure to check that it locks in one direction.

3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart; the flex or deflection should be 1/2 in. (13 mm).

AC RIPPLE VOLTAGE CHECK

PRINCIPLES A good alternator should produce very little AC voltage or current output. It is the purpose of the diodes in the alternator to rectify or convert most AC voltage into DC voltage. While it is normal to measure some AC voltage from an alternator, excessive AC voltage, called AC ripple, is undesirable and indicates a fault with the rectifier diodes or stator windings inside the alternator.

TESTING AC RIPPLE VOLTAGE The procedure to check for **AC ripple voltage** includes the following steps.

STEP 1 Set the digital meter to read AC volts.

STEP 2 Start the engine and operate it at 2000 RPM (fast idle).

STEP 3 Connect the voltmeter leads to the positive and negative battery terminals.

STEP 4 Turn on the headlights to provide an electrical load on the alternator.

NOTE: A more accurate reading can be obtained by touching the meter lead to the output or "battery" terminal of the alternator. ● **SEE FIGURE 20–7.**

The results should be interpreted as follows: If the rectifier diodes are good, the voltmeter should read *less* than 400 mV (0.4 volt) AC. If the reading is over 500 mV (0.5 volt) AC, the rectifier diodes are defective.

NOTE: Many conductance testers, such as Midtronic and Snap-On, automatically test for AC ripple.

MEASURING THE AC RIPPLE FROM THE ALTERNATOR TELLS A LOT ABOUT ITS CONDITION. IF THE AC RIPPLE IS ABOVE 500 MILLIVOLTS, OR .5 VOLTS, LOOK FOR A PROBLEM IN THE DIODES OR STATOR. IF THE RIPPLE IS BELOW 500 MILLIVOLTS, CHECK THE ALTERNATOR OUTPUT TO DETERMINE ITS CONDITION.

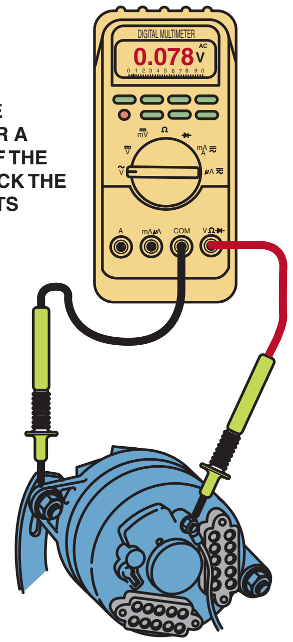


FIGURE 20–7 Testing AC ripple at the output terminal of the alternator is more accurate than testing at the battery due to the resistance of the wiring between the alternator and the battery. The reading shown on the meter, set to AC volts, is only 78 mV (0.078 V), far below what the reading would be if a diode were defective.

TESTING AC RIPPLE CURRENT

All alternators should create direct current (DC) if the diodes and stator windings are functioning correctly. A mini clamp-on meter capable of measuring AC amperes can be used to check the alternator. A good alternator should produce less than 10% of its rated amperage output in AC ripple amperes. For example, an alternator rated at 100 amperes should not produce more than 10 amperes AC ripple ($100 \times 10\% = 10$). It is normal for a good alternator to produce 3 or 4 A of AC ripple current to the battery. Only if the AC ripple current exceeds 10% of the rating of the alternator should the alternator be repaired or replaced.

FIGURE 20–8 Charging system voltage can be easily checked at the lighter plug by connecting a lighter plug to the voltmeter through a double banana plug.

FIGURE 20–9 A mini clamp-on meter can be used to measure alternator output as shown here (105.2 Amp.). Then the meter can be used to check AC current ripple by selecting AC Amps on the rotary dial. AC ripple current should be less than 10% of the DC current output.

TECH TIP

The Lighter Plug Trick

Battery voltage measurements can be read through the lighter socket. Simply construct a test tool using a lighter plug at one end of a length of two-conductor wire and the other end connected to a double banana plug. The double banana plug will fit most meters in the common (COM) terminal and the volt terminal of the meter. This is handy to use while road testing the vehicle under real-life conditions. Both DC voltage and AC ripple voltage can be measured. ● **SEE FIGURE 20–8.**

TEST PROCEDURE To measure the AC current to the battery, perform the following steps.

STEP 1 Start the engine and turn on the lights to create an electrical load on the alternator.

STEP 2 Using a mini clamp-on digital multimeter, place the clamp around either all of the positive (+) battery cables or all of the negative (−) battery cables.

An AC/DC current clamp adapter can also be used with a conventional digital multimeter set on the DC millivolts scale.

STEP 3 To check for AC current ripple, switch the meter to read AC amperes and record the reading. Read the meter display.

STEP 4 The results should be within 10% of the specified alternator rating. A reading of greater than 10 amperes AC indicates defective alternator diodes. ● **SEE FIGURE 20–9.**

CHARGING SYSTEM VOLTAGE DROP TESTING

ALTERNATOR WIRING For the proper operation of any charging system, there must be good electrical connections between the battery positive terminal and the alternator output terminal. The alternator must also be properly grounded to the engine block.

Many manufacturers of vehicles run the lead from the output terminal of the alternator to other connectors or junction blocks that are electrically connected to the positive terminal of the battery. If there is high resistance (a high voltage drop) in these connections or in the wiring itself, the battery will not be properly charged.

VOLTAGE DROP TEST PROCEDURE When there is a suspected charging system problem (with or without a charge indicator light on), simply follow these steps to measure the voltage drop of the insulated (power-side) charging circuit.

STEP 1 Start the engine and run it at a fast idle (about 2000 engine RPM).

STEP 2 Turn on the headlights to ensure an electrical load on the charging system.

STEP 3 Using any voltmeter set to read DC volts, connect the positive test lead (red) to the output terminal of the alternator. Attach the negative test lead (black) to the positive post of the battery.

The results should be interpreted as follows:

1. If there is less than a 0.4 volt (400 mV) reading, then all wiring and connections are satisfactory.
2. If the voltmeter reads higher than 0.4 volt, there is excessive resistance (voltage drop) between the alternator output terminal and the positive terminal of the battery.

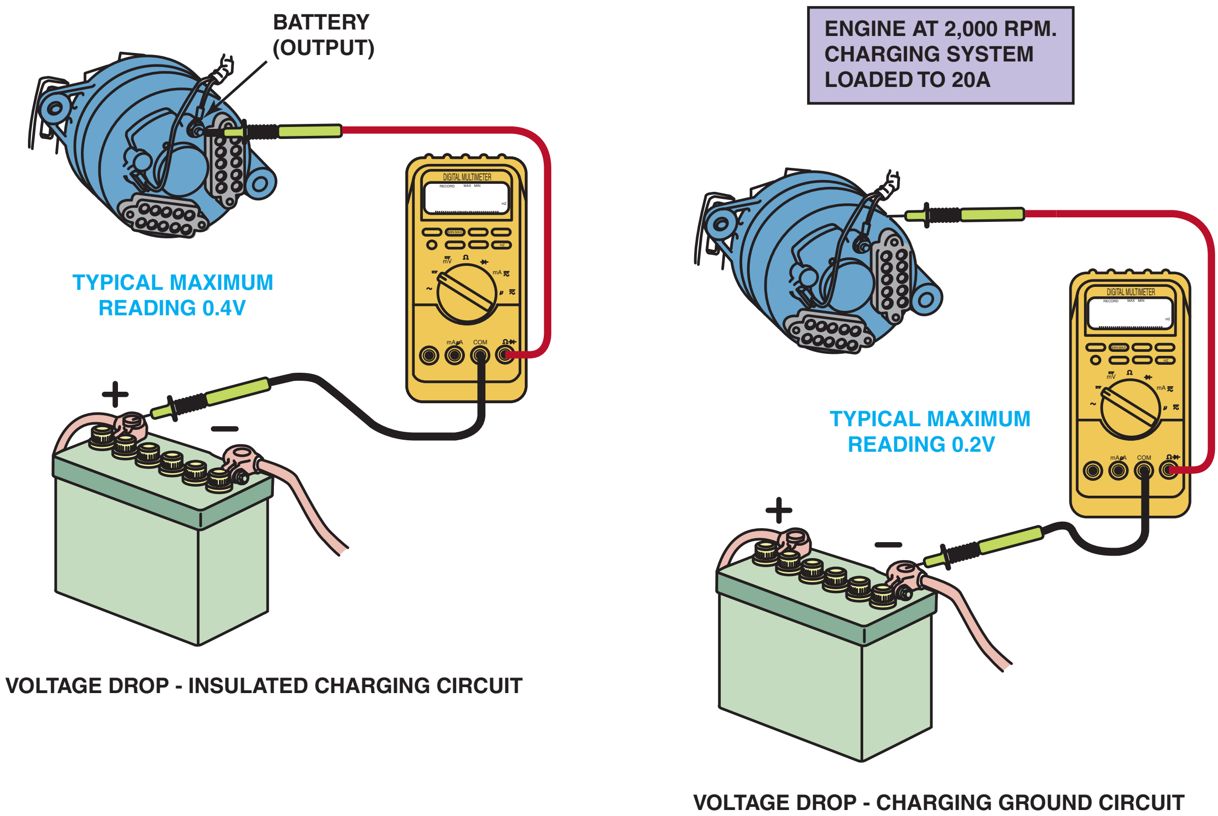


FIGURE 20–10 Voltmeter hookup to test the voltage drop of the charging circuit.

3. If the voltmeter reads battery voltage (or close to battery voltage), there is an open circuit between the battery and the alternator output terminal.

To determine whether the alternator is correctly grounded, maintain the engine speed at 2000 RPM with the headlights on. Connect the positive voltmeter lead to the case of the alternator and the negative voltmeter lead to the negative terminal of the battery. The voltmeter should read less than 0.2 volt (200 mV) if the alternator is properly grounded. If the reading is over 0.2 volt, connect one end of an auxiliary ground wire to the case of the alternator and the other end to a good engine ground. ● **SEE FIGURE 20–10.**

ALTERNATOR OUTPUT TEST

PRELIMINARY CHECKS An **alternator output test** measures the current (amperes) of the alternator. A charging circuit may be able to produce correct charging circuit voltage, but not be able to produce adequate amperage output. If in doubt about charging system output, first check the condition of the alternator drive belt. With the engine off, attempt to rotate the fan of the alternator by hand. Replace or tighten the drive belt if the alternator fan can be rotated this way.

TECH TIP

Use a Fused Jumper Wire as a Diagnostic Tool

When diagnosing an alternator charging problem, try using a fused jumper wire to connect the positive and negative terminals of the alternator directly to the positive and negative terminals of the battery. If a definite improvement is noticed, the problem is in the wiring of the vehicle. High resistance, due to corroded connections or loose grounds, can cause low alternator output, repeated regulator failures, slow cranking, and discharged batteries. A voltage drop test of the charging system can also be used to locate excessive resistance (high voltage drop) in the charging circuit, but using a fused jumper wire is often faster and easier.

CARBON PILE TEST PROCEDURE A carbon pile tester uses plates of carbon to create an electrical load. A carbon pile test is used to load test a battery and/or an alternator. ● **SEE FIGURE 20–11.**

The testing procedure for alternator output is as follows:

STEP 1 Connect the starting and charging test leads according to the manufacturer's instructions, which usually

FIGURE 20–11 A typical tester used to test batteries as well as the cranking and charging system. Always follow the operating instructions.

include installing the amp clamp around the output wire near the alternator.

STEP 2 Turn off all electrical accessories to be sure that the tester is measuring the true output of the alternator.

STEP 3 Start the engine and operate it at 2000 RPM (fast idle). Turn the load increase control slowly to obtain the highest reading on the ammeter scale. Do not allow the voltage to drop below 12.6 volts. Note the ampere reading.

STEP 4 Add 5 to 7 amperes to the reading because this amount of current is used by the ignition system to operate the engine.

STEP 5 Compare the output reading to factory specifications. The rated output may be stamped on the alternator or can be found in service information.

CAUTION: *NEVER* disconnect a battery cable with the engine running. All vehicle manufacturers warn not to do this, because this was an old test, before alternators, to see if a generator could supply current to operate the ignition system without a battery. When a battery cable is removed, the alternator (or PCM) will lose the battery voltage sense signal. Without a battery voltage sense circuit, the alternator will do one of two things, depending on the make and model of vehicle.

- **The alternator output can exceed 100 volts. This high voltage may not only damage the alternator but also electrical components in the vehicle, including the PCM and all electronic devices.**
- **The alternator stops charging as a fail safe measure to protect the alternator and all of the electronics in the vehicle from being damaged due to excessively high voltage.**

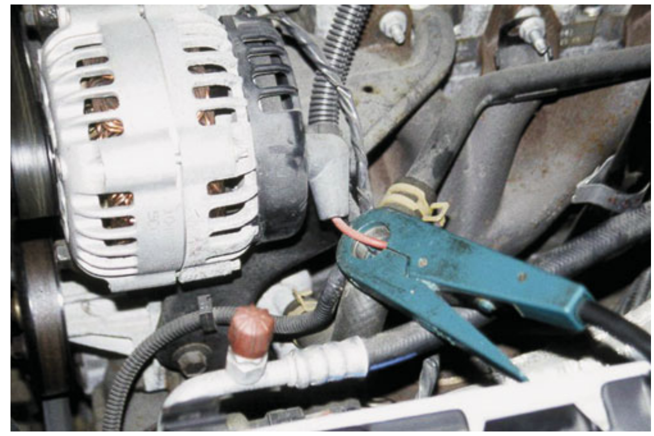


FIGURE 20–12 The best place to install a charging system tester amp probe is around the alternator output terminal wire, as shown.

MINIMUM REQUIRED ALTERNATOR OUTPUT

PURPOSE All charging systems must be able to supply the electrical demands of the electrical system. If lights and accessories are used constantly and the alternator cannot supply the necessary ampere output, the battery will be drained. To determine the minimum electrical load requirements, connect an inductive ammeter probe around either battery cable or the alternator output cable. ● **SEE FIGURE 20–12.**

NOTE: If using an inductive pickup ammeter, be certain that the pickup is over all the wires leaving the battery terminal.

Failure to include the small body ground wire from the negative battery terminal to the body or the small positive wire (if testing from the positive side) will *greatly decrease* the current flow readings.

PROCEDURE After connecting an ammeter correctly in the battery circuit, continue as follows:

1. Start the engine and operate to about 2000 RPM (fast idle).
2. Turn the heat selector to air conditioning (if the vehicle is so equipped).
3. Turn the blower motor to high speed.
4. Turn the headlights on bright.
5. Turn on the rear defogger.
6. Turn on the windshield wipers.
7. Turn on any other accessories that may be used continuously (do not operate the horn, power door locks, or other units that are not used for more than a few seconds).
8. Observe the ammeter. The current indicated is the electrical load that the alternator is able to exceed to keep the battery fully charged.

FIGURE 20–13 Replacing an alternator is not always as easy as it is from a Buick with a 3800 V-6, where the alternator is easy to access. Many alternators are difficult to access, and require the removal of other components.

TECH TIP

Bigger Is Not Always Better

Many technicians are asked to install a higher output alternator to allow the use of emergency equipment or other high-amperage equipment such as a high-wattage sound system.

Although many higher output units can be physically installed, it is important not to forget to upgrade the wiring and the fusible link(s) in the alternator circuit. Failure to upgrade the wiring could lead to overheating. The usual failure locations are at junctions or electrical connectors.

TEST RESULTS The minimum acceptable alternator output is 5 amperes greater than the accessory load. A negative (discharge) reading indicates that the alternator is not capable of supplying the current (amperes) that may be needed.

ALTERNATOR REMOVAL

After diagnosis of the charging system has determined that there is a fault with the alternator, it must be removed safely from the vehicle. Always check service information for the exact procedure to follow on the vehicle being serviced. A typical removal procedure includes the following steps.

STEP 1 Before disconnecting the negative battery cable, use a test light or a voltmeter and check for battery voltage at the output terminal of the alternator. A complete circuit must exist between the alternator and the battery. If there is no voltage at the alternator output terminal, check for a blown fusible link or other electrical circuit fault.

STEP 2 Disconnect the negative (−) terminal from the battery. (Use a memory saver to maintain radio, memory seats, and other functions.)

STEP 3 Remove the accessory drive belt that drives the alternator.

STEP 4 Remove electrical wiring, fasteners, spacers, and brackets, as necessary, and remove the alternator from the vehicle. ● **SEE FIGURE 20–13**.

TECH TIP

The Sniff Test

When checking for the root cause of an alternator failure, one test that a technician could do is to sniff (smell) the alternator. If the alternator smells like a dead rat (rancid smell), the stator windings have been overheated by trying to charge a discharged or defective battery. If the battery voltage is continuously low, the voltage regulator will continue supplying full-field current to the alternator. The voltage regulator is designed to cycle on and off to maintain a narrow charging system voltage range.

If the battery voltage is continually below the cutoff point of the voltage regulator, the alternator is continually producing current in the stator windings. This constant charging can often overheat the stator and burn the insulating varnish covering the stator windings. If the alternator fails the sniff test, the technician should replace the stator and other alternator components that are found to be defective and replace or recharge and test the battery.

ALTERNATOR DISASSEMBLY

DISASSEMBLY PROCEDURE

STEP 1 Mark the case with a scratch or with chalk to ensure proper reassembly of the alternator case. ● **SEE FIGURE 20–14.**

STEP 2 After the through bolts have been removed, carefully separate the two halves. The stator windings must stay with the rear case. When this happens, the brushes and springs will fall out.

STEP 3 Remove the rectifier assembly and voltage regulator.

ROTOR TESTING The slip rings on the rotor should be smooth and round (within 0.002 in. of being perfectly round).

- If grooved, the slip rings can be machined to provide a suitable surface for the brushes. Do not machine beyond the minimum slip-ring dimension as specified by the manufacturer.

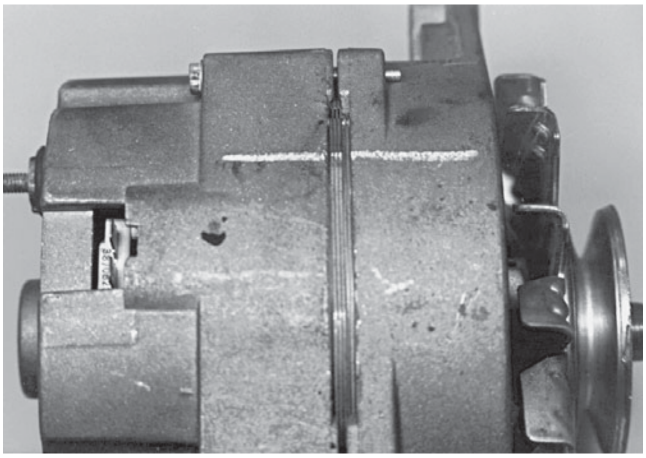


FIGURE 20–14 Always mark the case of the alternator before disassembly to be assured of correct reassembly.

FREQUENTLY ASKED QUESTION

What Is a "Clock Position"?

Most alternators of a particular manufacturer can be used on a variety of vehicles, which may require wiring connections placed in various locations. For example, a Chevrolet and a Buick alternator may be identical except for the position of the rear section containing the electrical connections. The four through bolts that hold the two halves together are equally spaced; therefore, the rear alternator housing *can* be installed in any one of four positions to match the wiring needs of various models. Always check the clock position of the original and be sure that it matches the replacement unit. ● **SEE FIGURE 20–15.**

- If the slip rings are discolored or dirty, they can be cleaned with 400-grit or fine emery (polishing) cloth. The rotor must be turned while being cleaned to prevent flat spots on the slip rings.
- Measure the resistance between the slip rings using an ohmmeter. Typical resistance values and results include the following:

1. The resistance measured between either slip ring and the steel rotor shaft should be infinity (OL). If there is continuity, then the rotor is shorted to ground.
2. Rotor resistance range is normally between 2.4 and 6 ohms.
3. If the resistance is below specification, the rotor is shorted.
4. If the resistance is above specification, the rotor connections are corroded or open.

If the rotor is found to be bad, it must be replaced or repaired at a specialized shop. ● **SEE FIGURE 20–16.**

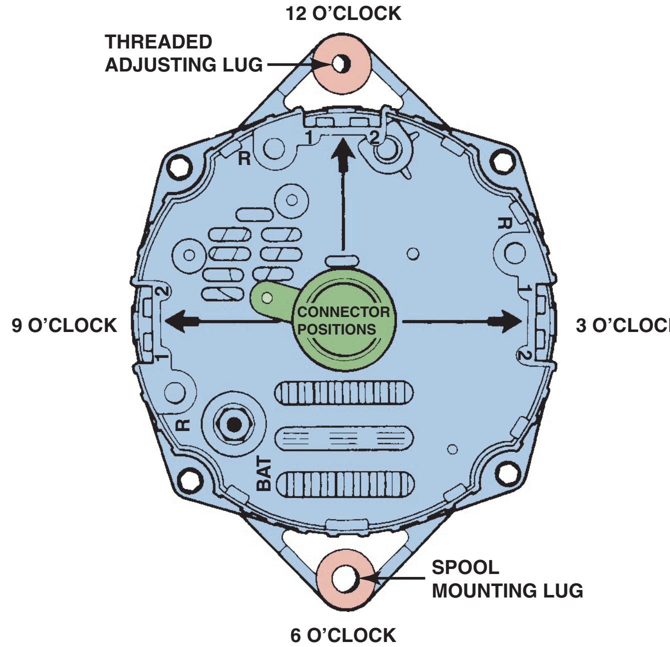


FIGURE 20–15 Explanation of clock positions. Because the four through bolts are equally spaced, it is possible for an alternator to be installed in one of four different clock positions. The connector position is determined by viewing the alternator from the diode end with the threaded adjusting lug in the up or 12 o'clock position. Select the 3 o'clock, 6 o'clock, 9 o'clock, or 12 o'clock position to match the unit being replaced.

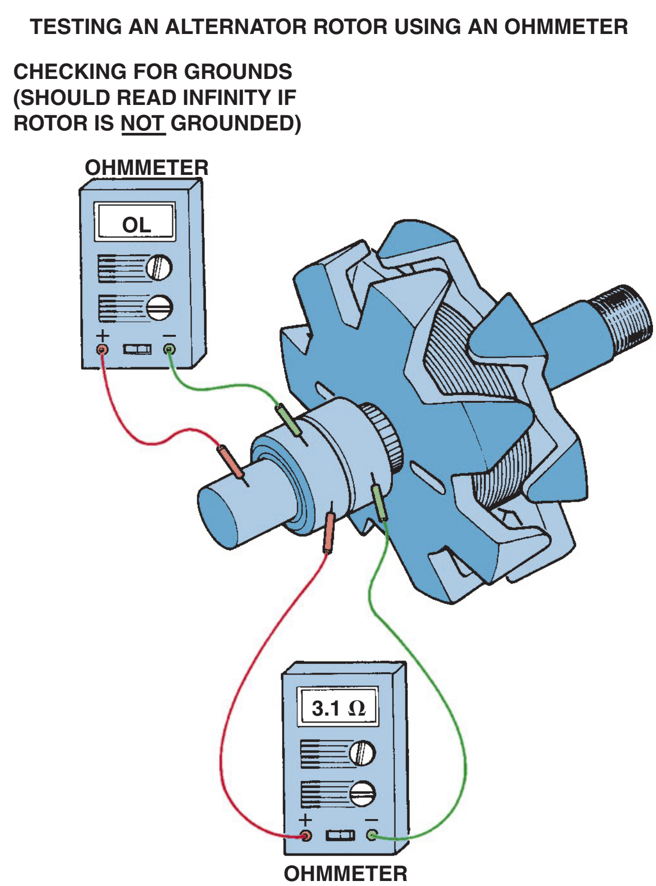


FIGURE 20–16 Testing an alternator rotor using an ohmmeter.

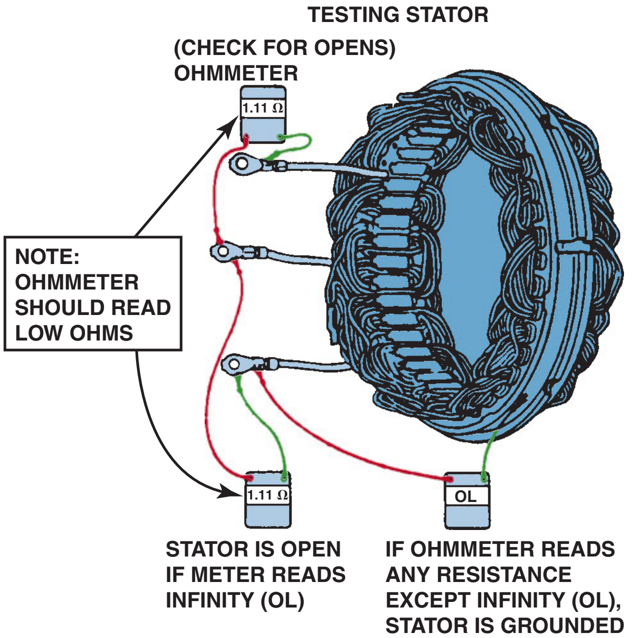


FIGURE 20–17 If the ohmmeter reads infinity between any two of the three stator windings, the stator is open and, therefore, defective. The ohmmeter should read infinity between any stator lead and the steel laminations. If the reading is less than infinity, the stator is grounded. Stator windings cannot be tested if shorted because the normal resistance is very low.

NOTE: The cost of a replacement rotor may exceed the cost of an entire rebuilt alternator. Be certain, however, that the rebuilt alternator is rated at the same output as the original or higher.

STATOR TESTING The stator must be disconnected from the diodes (rectifiers) before testing. Because all three windings of the stator are electrically connected (either wye or delta), an ohmmeter can be used to check a stator.

- There should be low resistance at all three stator leads (continuity).
- There should *not* be continuity (in other words, there should be a meter reading of infinity ohms) when the stator is tested between any stator lead and the metal stator core.
- If there is continuity, the stator is shorted-to-ground and must be repaired or replaced. ● **SEE FIGURE 20–17.**

NOTE: Because the resistance is very low for a normal stator, it is generally *not* possible to test for a *shorted* (copper-to-copper) stator. A shorted stator will, however, greatly reduce alternator output. An ohmmeter cannot detect an open stator if the stator is delta wound. The ohmmeter will still indicate low resistance because all three windings are electrically connected.

TESTING THE DIODE TRIO Many alternators are equipped with a diode trio. A diode is an electrical one-way check valve that permits current to flow in only one direction. Because *trio* means "three," a diode trio is three diodes connected together. ● **SEE FIGURE 20–18.**

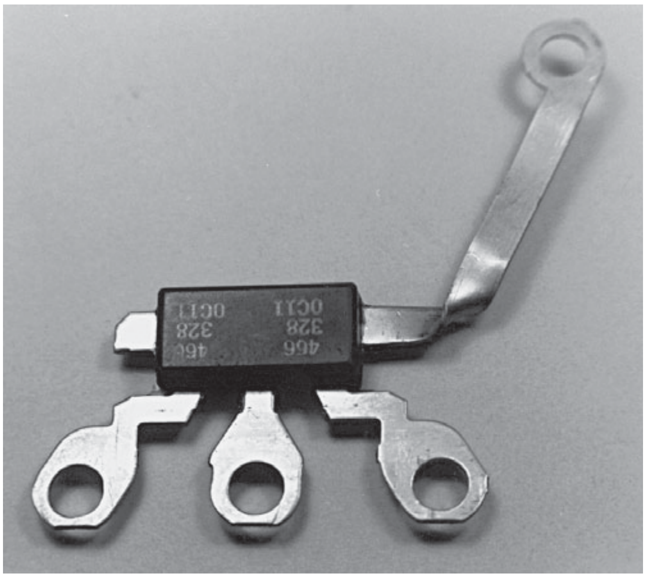


FIGURE 20–18 Typical diode trio. If one leg of a diode trio is open, the alternator may produce close to normal output, but the charge indicator light on the dash will be on dimly.

The diode trio is connected to all three stator windings. The current generated in the stator flows through the diode trio to the internal voltage regulator. The diode trio is designed to supply current for the field (rotor) and turns off the charge indicator light when the alternator voltage equals or exceeds the battery voltage. If one of the three diodes in the diode trio is defective (usually open), the alternator may produce close-to-normal output; however, the charge indicator light will be on dimly.

A diode trio should be tested with a digital multimeter. The meter should be set to the diode-check position. The multimeter should indicate 0.5 to 0.7 V (500 to 700 mV) one way and OL (overlimit) after reversing the test leads and touching all three connectors of the diode trio.

TESTING THE RECTIFIER

TERMINOLOGY The rectifier assembly usually is equipped with six diodes including three positive diodes and three negative diodes (one positive and one negative for each winding of the stator).

METER SETUP The rectifier(s) (diodes) should be tested using a multimeter that is set to "diode check" position on the digital multimeter (DMM).

Because a diode (rectifier) should allow current to flow in only one direction, each diode should be tested to determine if the diode allows current flow in one direction and blocks current flow in the opposite direction. To test some alternator diodes, it may be necessary to unsolder the stator connections. ● **SEE FIGURE 20–19.**

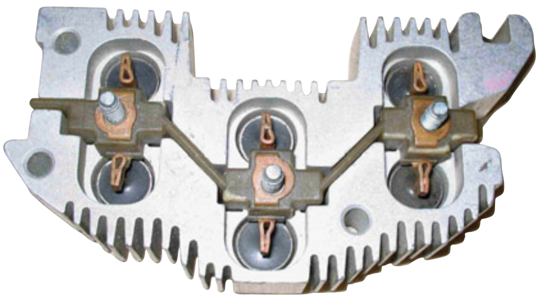


FIGURE 20–19 A typical rectifier bridge that contains all six diodes in one replaceable assembly.

Accurate testing is not possible unless the diodes are separated electrically from other alternator components.

TESTING PROCEDURE Connect the leads to the leads of the diode (pigtail and housing of the rectifier bridge). Read the meter. Reverse the test leads. A good diode should have high resistance (OL) one way (reverse bias) and low voltage drop of 0.5 to 0.7 V (500 to 700 mV) the other way (forward bias).

RESULTS Open or shorted diodes must be replaced. Most alternators group or combine all positive and all negative diodes in the one replaceable rectifier component.

REASSEMBLING THE ALTERNATOR

BRUSH HOLDER REPLACEMENT Alternator carbon brushes often last for many years and require no scheduled maintenance. The life of the alternator brushes is extended because they conduct only the field (rotor) current, which is normally only 2 to 5 amperes. The alternator brushes should be inspected when the alternator is disassembled and should be replaced when worn to less than 1/2 in. long. Brushes are commonly purchased assembled together in a brush holder. After the brushes are installed (usually retained by two or three screws) and the rotor is installed in the alternator housing, a brush retainer pin can be pulled out through an access hole in the rear of the alternator, allowing the brushes to be pressed against the slip rings by the brush springs. ● **SEE FIGURE 20–20.**

BEARING SERVICE AND REPLACEMENT The bearings of an alternator must be able to support the rotor and reduce friction. An alternator must be able to rotate at up to 15,000 RPM and withstand the forces created by the drive belt. The front bearing is usually a ball bearing type and the rear can be either a smaller roller or ball bearing.

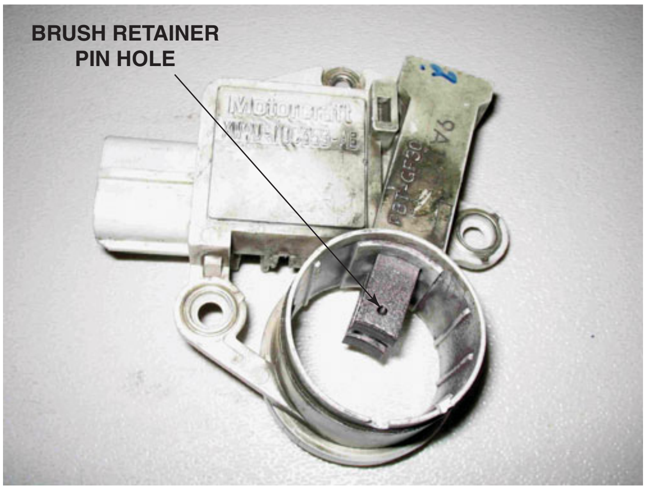


FIGURE 20–20 A brush holder assembly with new brushes installed. The holes in the brushes are used to hold the brushes up in the holder when it is installed in the alternator. After the rotor has been installed, the retaining pin is removed which allows the brushes to contact the slip rings of the rotor.

The old or defective bearing can sometimes be pushed out of the front housing and the replacement pushed in by applying pressure with a socket or pipe against the outer edge of the bearing (outer race). Replacement bearings are usually prelubricated and seated. Many alternator front bearings must be removed from the rotor using a special puller.

ALTERNATOR ASSEMBLY After testing or servicing, the alternator rectifier(s), regulator, stator, and brush holder must be reassembled using the following steps.

STEP 1 If the brushes are internally mounted, insert a wire through the holes in the brush holder to hold the brushes against the springs.

STEP 2 Install the rotor and front-end frame in proper alignment with the mark made on the outside of the alternator housing. Install the through bolts. Before removing the wire pin holding the brushes, spin the alternator pulley. If the alternator is noisy or not rotating freely, the alternator can easily be disassembled again to check for the cause. After making certain the alternator is free to rotate, remove the brush holder pin and spin the alternator again by hand. The noise level may be slightly higher with the brushes released onto the slip rings.

STEP 3 Alternators should be tested on a bench tester, if available, before they are reinstalled on a vehicle. When installing the alternator on the vehicle, be certain that all mounting bolts and nuts are tight. The battery terminal should be covered with a plastic or rubber protective cap to help prevent accidental shorting to ground, which could seriously damage the alternator.

REMANUFACTURED ALTERNATORS

Remanufactured or rebuilt alternators are totally disassembled and rebuilt. Even though there are many smaller rebuilders who may not replace all worn parts, the major national remanufacturers *totally* remanufacture the alternator. Old alternators (called **cores**) are totally disassembled and cleaned. Both bearings are replaced and all components are tested. Rotors are rewound to original specifications if required. The rotor windings are not counted but are rewound on the rotor "spool," using the correct-gauge copper wire, to the *weight* specified by the original manufacturer. New slip rings are replaced as required, soldered to the rotor spool windings, and machined. The rotors are also balanced and measured to ensure that the outside diameter of the rotor meets specifications. An undersized rotor will produce less alternator output because the field must be close to the stator windings for maximum output. Bridge rectifiers are replaced, if required. Every alternator is then assembled and tested for proper output, boxed, and shipped to a warehouse. Individual parts stores (called jobbers) purchase parts from various regional or local warehouses.

> **REAL WORLD FIX**
>
> **The Two-Minute Alternator Repair**
>
> A Chevrolet pickup truck was brought to a shop for routine service. The customer stated that the battery required a jump start after a weekend of sitting. The technician tested the battery and charging system voltage using a small handheld digital multimeter. The battery voltage was 12.4 volts (about 75% charged), but the charging voltage was also 12.4 volts at 2000 RPM. Because normal charging voltage should be 13.5 to 15 volts, it was obvious that the charging system was not operating correctly.
>
> The technician checked the dash and found that the "charge" light was *not* on. Before removing the alternator for service, the technician checked the wiring connection on the alternator. When the connector was removed, it was discovered to be rusty. After the contacts were cleaned, the charging system was restored to normal operation. The technician had learned that the simple things should always be checked first before tearing into a big (or expensive) repair.

ALTERNATOR INSTALLATION

Before installing a replacement alternator, check service information for the exact procedure to follow for the vehicle being serviced. A typical installation procedure includes the following steps.

STEP 1 Verify that the replacement alternator is the correct unit for the vehicle.

STEP 2 Install the alternator wiring on the alternator and install the alternator.

STEP 3 Check the condition of the drive belt and replace, if necessary. Install the drive belt over the drive pulley.

STEP 4 Properly tension the drive belt.

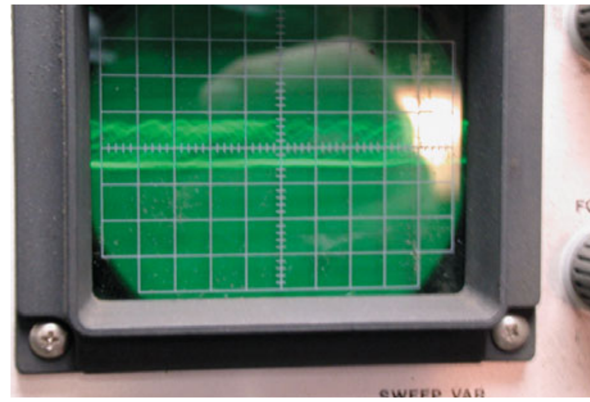
STEP 5 Tighten all fasteners to factory specifications.

STEP 6 Double-check that all fasteners are correctly tightened and remove all tools from the engine compartment area.

STEP 7 Reconnect the negative battery cable.

STEP 8 Start the engine and verify proper charging circuit operation.

1 Before the alternator is disassembled, it is spin tested and connected to a scope to check for possible defective components.



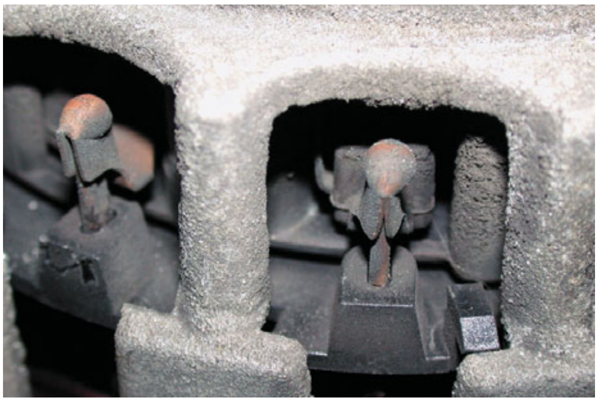
2 The scope pattern shows that the voltage output is far from being a normal pattern. This pattern indicates serious faults in the rectifier diodes.

3 The first step is to remove the drive pulley. This rebuilder is using an electric impact wrench to accomplish the task.

4 Carefully inspect the drive galley for damage of embedded rubber from the drive belt. The slightest fault can cause a vibration, noise, or possible damage to the alternator.

5 Remove the external fan (if equipped) and then the spacers as shown.

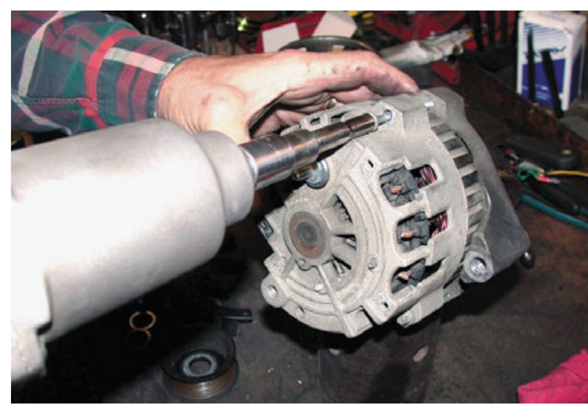
6 Next pop off the plastic cover (shield) covering the stator/rectifier connection.



7 After the cover has been removed, the stator connections to the rectifier can be seen.

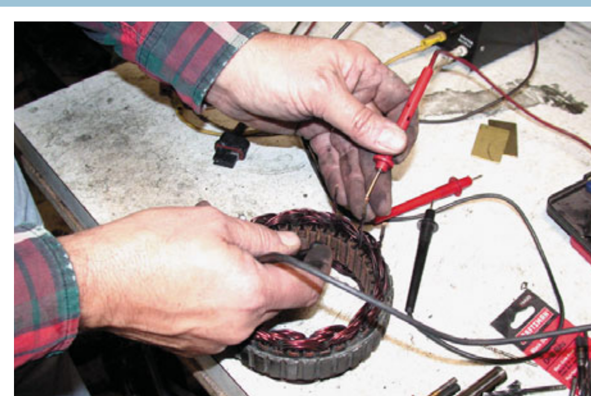
8 Using a diagonal cutter, cut the weld to separate the stator from the rectifier.

9 Before separating the halves of the case, this technician uses a punch to mark both halves.



10 After the case has been marked, the through-bolts are removed.

11 The drive-end housing and the stator are being separated from the rear (slip-ring-end) housing.



12 The stator is checked by visual inspection for discoloration or other physical damage, and then checked with an ohmmeter to see if the windings are shorted-to-ground.

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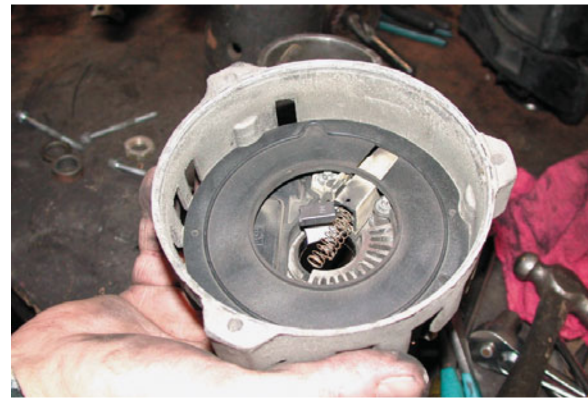
13 The front bearing is removed from the drive-end housing using a press.



14 A view of the slip-ring-end (SRE) housing showing the black plastic shield, which helps direct air flow across the rectifier.

15 A punch is used to dislodge the plastic shield retaining clips.

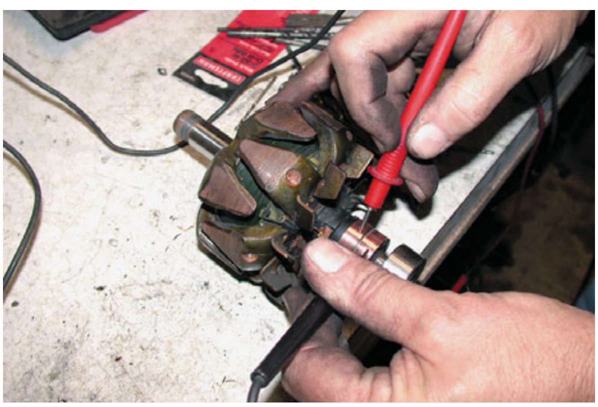
16 After the shield has been removed, the rectifier, regulator, and brush holder assembly can be removed by removing the retaining screws.

17 The hear transfer grease is visible when the rectifier assembly is lifted out of the rear housing.

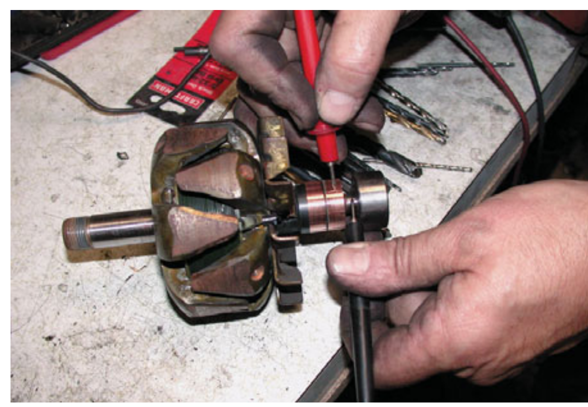
18 The parts are placed into a tumbler where ceramic stones and a water-based solvent are used to clean the parts.

19 This rebuilder is painting the housing using a high-quality industrial grade spray paint to make the rebuilt alternator look like new.

20 The slip rings on the rotor are being machined on a lathe.



21 The rotor is being tested using an ohmmeter. The specifications for the resistance between the slip rings on the CS-130 are 2.2 to 3.5 ohms.



22 The rotor is also tested between the slip ring and the rotor shaft. This reading should be infinity.

23 A new rectifier. This replacement unit is significantly different than the original but is designed to replace the original unit and meets the original factory specifications.

24 Silicone heat transfer compound is applied to the heat sink of the new rectifier.

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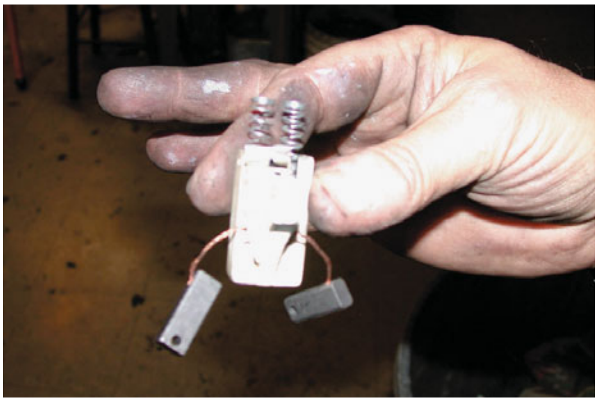


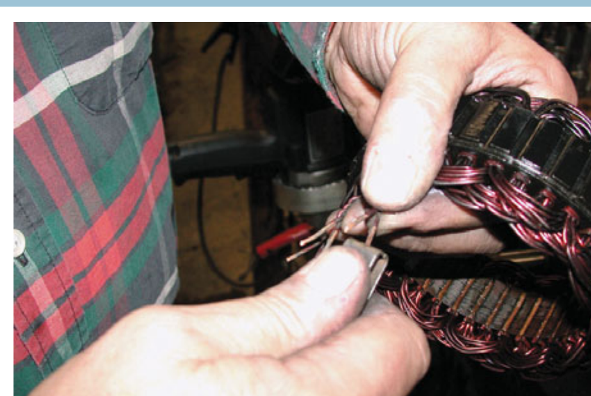
25 Replacement brushes and springs are assembled into the brush holder.

26 The brushes are pushed into the brush holder and retained by a straight wire, which extends through the rear housing of the alternator. This wire is then pulled out when the unit is assembled.

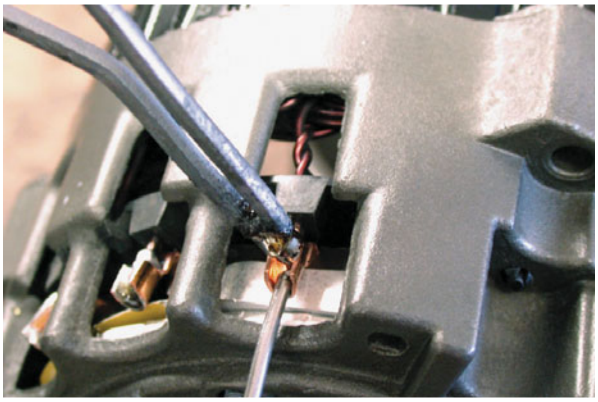
27 Here is what the CS alternator looks like after installing the new brush holder assembly, rectifier bridge, and voltage regulator.

28 The junction between the rectifier bridge and the voltage regulator is soldered.

29 The plastic deflector shield is snapped back into location using a blunt chisel and a hammer. This shield directs the airflow from the fan over the rectifier bridge and voltage regulator.

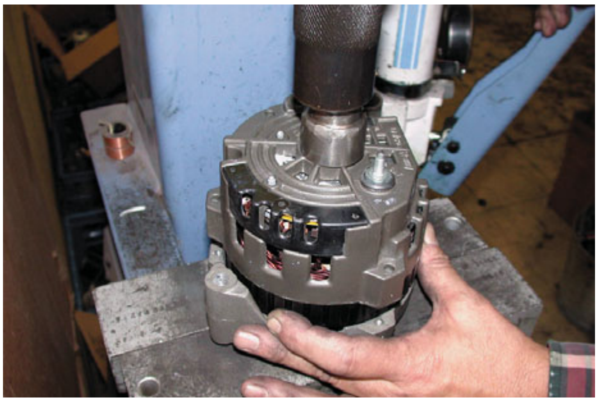


30 Before the stator windings can be soldered to the rectifier bridge, the varnish insulation is removed from the ends of the leads.

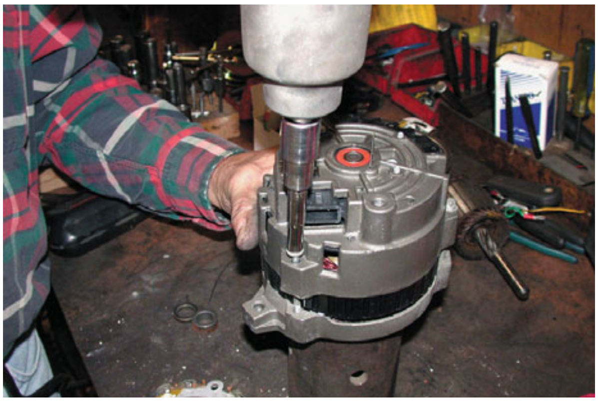


31 After the stator has been inserted into the rear housing the stator leads are soldered to the copper lugs of the rectifier bridge.

32 New bearings are installed. A spacer is placed between the bearing and the slip rings to help prevent the possibility that the bearing could move on the shaft and short against the slip ring.

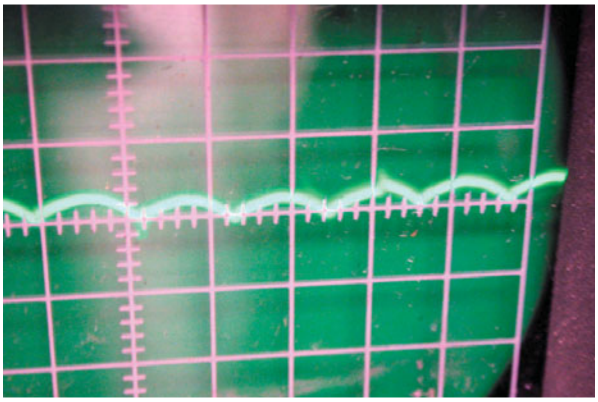


33 The slip-ring-end (SRE) housing is aligned with the marks made during disassembly and is pressed into the drive-end (DE) housing.



34 The retaining bolts, which are threaded into the drive-end housing from the back of the alternator are installed.

35 The external fan and drive pulley are installed and the retaining nut is tightened on the rotor shaft.



36 The scope pattern shows that the diodes and stator are functioning correctly and voltage check indicates that the voltage regulator is also functioning correctly.

SUMMARY

1. Charging system testing requires that the battery be at least 75% charged to be assured of accurate test results. Normal charging voltage (at 2,000 engine RPM) is 13.5 to 15 volts.
2. To check for excessive resistance in the wiring between the alternator and the battery, a voltage drop test should be performed.
3. Alternators do not produce their maximum rated output unless required by circuit demands. Therefore, to test for maximum alternator output, the battery must be loaded to force the alternator to produce its maximum output.
4. Each alternator should be marked across its case before disassembly to ensure proper clock position during reassembly. After disassembly, all alternator internal components should be tested using an ohmmeter. The following components should be tested.
   a. Stator
   b. Rotor
   c. Diodes
   d. Diode trio (if the alternator is so equipped)
   e. Bearings
   f. Brushes (should be more than 1/2 in. long)

REVIEW QUESTIONS

1. How does a technician test the voltage drop of the charging circuit?
2. How does a technician measure the amperage output of an alternator?
3. What tests can be performed to determine whether a diode or stator is defective before removing the alternator from the vehicle?

CHAPTER QUIZ

1. To check the charging voltage, connect a digital multimeter (DMM) to the positive (+) and the negative (−) terminals of the battery and select ________.
   a. DC volts
   b. AC volts
   c. DC amps
   d. AC amps
2. To check for ripple voltage from the alternator, connect a digital multimeter (DMM) and select ________.
   a. DC volts
   b. AC volts
   c. DC amps
   d. AC amps
3. The maximum allowable alternating current (AC) in amperes that is being sent to the battery from the alternator is ________.
   a. 0.4 A
   b. 1 to 3 A
   c. 3 to 4 A
   d. 10% of the rated output of the alternator
4. Why should the lights be turned on when checking for ripple voltage or alternating current from the alternator?
   a. To warm the battery
   b. To check that the battery is fully charged
   c. To create an electrical load for the alternator
   d. To test the battery before conducting other tests
5. An acceptable charging circuit voltage on a 12 volt system is ________.
   a. 13.5 to 15 volts
   b. 12.6 to 15.6 volts
   c. 12 to 14 volts
   d. 14.9 to 16.1 volts
6. Technician A says that the computer can be used to control the output of the alternator by controlling the field current. Technician B says that voltage regulators control the alternator output by controlling the field current through the rotor. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that a voltage drop test of the charging circuit should only be performed when current is flowing through the circuit. Technician B says to connect the leads of a voltmeter to the positive and negative terminals of the battery to measure the voltage drop of the charging system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. When testing an alternator rotor, if an ohmmeter shows zero ohms with one meter lead attached to the slip rings and the other meter lead touching the rotor shaft, the rotor is ________.
   a. Okay (normal)
   b. Defective (shorted-to-ground)
   c. Defective (shorted-to-voltage)
   d. Okay (rotor windings are open)

9. An alternator diode is being tested using a digital multimeter set to the diode-check position. A good diode will read ________ if the leads are connected one way across the diode and ________ if the leads are reversed.
   a. 300/300
   b. 0.475/0.475
   c. OL/OL
   d. 0.551/OL

10. An alternator could test as producing lower-than-normal output, yet be okay, if the ________.
   a. Battery is weak or defective
   b. Engine speed is not high enough during testing
   c. Drive belt is loose or slipping
   d. All of the above

chapter 21

LIGHTING AND SIGNALING CIRCUITS

OBJECTIVES: After studying Chapter 21, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "E" (Lighting System Diagnosis and Repair). • Read and interpret a bulb chart. • Describe how interior and exterior lighting systems work. • Read and interpret a bulb chart. • Discuss troubleshooting procedures for lighting and signaling circuits.

KEY TERMS: AFS 286 • Brake lights 279 • Candlepower 275 • CHMSL 279 • Color shift 286 • Composite headlight 284 • Courtesy lights 288 • DOT 281 • DRL 288 • Feedback 291 • Fiber optics 290 • Hazard warning 282 • HID 284 • Hybrid flasher 281 • Kelvin (K) 285 • LED 279 • Rheostat 282 • Trade number 275 • Troxler effect 291 • Xenon headlights 285

INTRODUCTION

The vehicle has many different lighting and signaling systems, each with its own specific components and operating characteristics. The major light-related circuits and systems covered include:

- Exterior lighting
- Headlights (halogen, HID, and LED)
- Bulb trade numbers
- Brake lights
- Turn signals and flasher units
- Courtesy lights
- Light-dimming rearview mirrors

EXTERIOR LIGHTING

HEADLIGHT SWITCH CONTROL

Exterior lighting is controlled by the headlight switch, which is connected directly to the battery on most vehicles. Therefore, if the light switch is left on manually, the lights could drain the battery. Older headlight switches contained a built-in circuit breaker. If excessive current flows through the headlight circuit, the circuit breaker will momentarily open the circuit, then close it again. The result is headlights that flicker on and off rapidly. This feature allows the headlights to function, as a safety measure, in spite of current overload.

The headlight switch controls the following lights on most vehicles, usually through a module.

1. Headlights
2. Taillights
3. Side-marker lights
4. Front parking lights
5. Dash lights
6. Interior (dome) light(s)

COMPUTER-CONTROLLED LIGHTS

Because these lights can easily drain the battery if accidentally left on, many newer vehicles control these lights through computer modules. The computer module keeps track of the time the lights are on and can turn them off if the time is excessive. The computer can control either the power side or the ground side of the circuit.

For example, a typical computer-controlled lighting system usually includes the following steps.

STEP 1 The driver depresses or rotates the headlight switch.

STEP 2 The signal from the headlight switch is sent to the nearest control module.

STEP 3 The control module then sends a request to the headlight control module to turn on the headlights as well as the front park and side-marker lights.

Through the data BUS, the rear control module receives the lights on signal and turns on the lights at the rear of the vehicle.

STEP 4 All modules monitor current flow through the circuit and will turn on a bulb failure warning light if it detects an open bulb or a fault in the circuit.

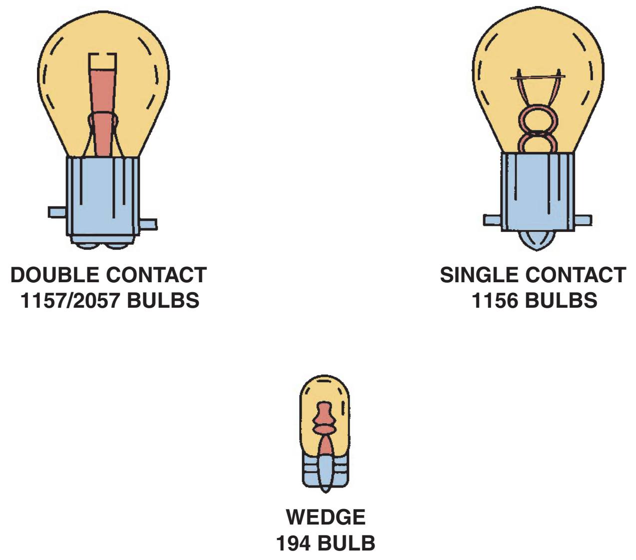


FIGURE 21–1 Dual-filament (double-contact) bulbs contain both a low-intensity filament for taillights or parking lights and a high-intensity filament for brake lights and turn signals. Bulbs come in a variety of shapes and sizes. The numbers shown are the trade numbers.

STEP 5 After the ignition has been turned off, the modules will turn off the lights after a time delay to prevent the battery from being drained.

BULB NUMBERS

TRADE NUMBER The number used on automotive bulbs is called the bulb **trade number,** as recorded with the American National Standards Institute (ANSI). The number is the same regardless of the manufacturer. ● **SEE FIGURE 21–1.**

CANDLEPOWER The trade number also identifies the size, shape, number of filaments, and amount of light produced, measured in **candlepower.** For example, the 1156 bulb, commonly used for backup lights, is 32 candlepower. A 194 bulb, commonly used for dash or side-marker lights, is rated at only 2 candlepower. The amount of light produced by a bulb is determined by the resistance of the filament wire, which also affects the amount of current (in amperes) required by the bulb.

It is important that the correct trade number of bulb always be used for replacement to prevent circuit or component damage. The correct replacement bulb for a vehicle is usually listed in the owner or service manual. ● **REFER TO CHART 21–1** for a listing of common bulbs and their specifications used in most vehicles.

BULB NUMBER SUFFIXES Many bulbs have suffixes that indicate some feature of the bulb, while keeping the same size and light output specifications.

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
Headlights				
1255/H1	1	4.58	55.00	129.00
1255/H3	1	4.58	55.00	121.00
6024	2	2.73/4.69	35.00/60.00	27,000/35,000
6054	2	2.73/5.08	35.00/65.00	35,000/40,000
9003	2	4.58/5.00	55.00/60.00	72.00/120.00
9004	2	3.52/5.08	45.00/65.00	56.00/95.00
9005	1	5.08	65.00	136.00
9006	1	4.30	55.00	80.00
9007	2	4.30/5.08	55.00/65.00	80.00/107.00
9008	2	4.30/5.08	55.00/65.00	80.00/107.00
9011	1	5.08	65.00	163.50
Headlights (HID—Xenon)				
D2R	Air Gap	0.41	35.00	222.75
D2S	Air Gap	0.41	35.00	254.57
Taillights, Stop, and Turn Lamps				
1156	1	2.10	26.88	32.00
1157	2	0.59/2.10	8.26/26.88	3.00/32.00
2057	2	0.49/2.10	6.86/26.88	2.00/32.00
3057	2	6.72/26.88	0.48/2.10	1.50/24.00
3155	1	1.60	20.48	21.00
3157	2	0.59/2.10	8.26/26.88	2.20/24.00
4157	2	0.59/2.10	8.26/26.88	3.00/32.00
7440	1	1.75	21.00	36.60
7443	2	0.42/1.75	5.00/21.00	2.80/36.60
17131	1	0.33	4.00	2.80
17635	1	1.75	21.00	37.00
17916	2	0.42/1.75	5.00/21.00	1.20/35.00
Parking, Daytime Running Lamps				
24	1	0.24	3.36	2.00
67	1	0.59	7.97	4.00
168	1	0.35	4.90	3.00
194	1	0.27	3.78	2.00
889	1	3.90	49.92	43.00
912	1	1.00	12.80	12.00
916	1	0.54	7.29	2.00
1034	2	0.59/1.80	8.26/23.04	3.00/32.00

CHART 21–1

Bulb chart sorted by typical applications. Check the owner's manual, service information, or a bulb manufacturer's application chart for the exact bulb to use.

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
1156	1	2.10	26.88	32.00
1157	2	0.59/2.10	8.26/26.88	3.00/32.00
2040	1	0.63	8.00	10.50
2057	2	0.49/2.10	6.86/26.88	1.50/24.00
2357	2	0.59/2.23	8.26/28.54	3.00/40.00
3157	2	0.59/2.10	8.26/26.88	3.00/32.00
3357	2	0.59/2.23	8.26/28.54	3.00/40.00
3457	2	0.59/2.23	8.26/28.51	3.00/40.00
3496	2	0.66/2.24	8.00/27.00	3.00/45.00
3652	1	0.42	5.00	6.00
4114	2	0.59/2/23	8.26/31.20	3.00/32.00
4157	2	0.59/2.10	8.26/26/88	3.00/32.00
7443	2	0.42/1.75	5.00/21.00	2.80/36.60
17131	1	0.33	4.00	2.80
17171	1	0.42	5.00	4.00
17177	1	0.42	5.00	4.00
17311	1	0.83	10.00	10.00
17916	2	0.42/1.75	5.00/21.00	1.20/35.00
68161	1	0.50	6.00	10.00
Center High-Mounted Stop Lamp (CHMSL)				
70	1	0.15	2.10	1.50
168	1	0.35	4.90	3.00
175	1	0.58	8.12	5.00
211-2	1	0.97	12.42	12.00
577	1	1.40	17.92	21.00
579	1	0.80	10.20	9.00
889	1	3.90	49.92	43.00
891	1	0.63	8.00	11.00
906	1	0.69	8.97	6.00
912	1	1.00	12.80	12.00
921	1	1.40	17.92	21.00
922	1	0.98	12.54	15.00
1141	1	1.44	18.43	21.00
1156	1	2.10	26.88	32.00
2723	1	0.20	2.40	1.50
3155	1	1.60	20.48	21.00
3156	1	2.10	26.88	32.00
3497	1	2.24	27.00	45.00
7440	1	1.75	21.00	36.60
17177	1	0.42	5.00	4.00
17635	1	1.75	21.00	37.00

CONTINUED

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
License Plate, Glove Box, Dome, Side Marker, Trunk, Map, Ashtray, Step/Courtesy, Underhood				
37	1	0.09	1.26	0.50
67	1	0.59	7.97	4.00
74	1	0.10	1.40	.070
98	1	0.62	8.06	6.00
105	1	1.00	12.80	12.00
124	1	0.27	3.78	1.50
161	1	0.19	2.66	1.00
168	1	0.35	4.90	3.00
192	1	0.33	4.29	3.00
194	1	0.27	3.78	2.00
211-1	1	0.968	12.40	12.00
212-2	1	0.74	9.99	6.00
214-2	1	0.52	7.02	4.00
293	1	0.33	4.62	2.00
561	1	0.97	12.42	12.00
562	1	0.74	9.99	6.00
578	1	0.78	9.98	9.00
579	1	0.80	10.20	9.00
PC579	1	0.80	10.20	9.00
906	1	0.69	8.97	6.00
912	1	1.00	12.80	12.00
917	1	1.20	14.40	10.00
921	1	1.40	17.92	21.00
1003	1	0.94	12.03	15.00
1155	1	0.59	7.97	4.00
1210/H2	1	8.33	100.00	239.00
1210/H3	1	8.33	100.00	192.00
1445	1	0.14	2.02	0.70
1891	1	0.24	3.36	2.00
1895	1	0.27	3.78	2.00
3652	1	0.42	5.00	6.00
11005	1	0.39	5.07	4.00
11006	1	0.24	3.36	2.00
12100	1	0.77	10.01	9.55
13050	1	0.38	4.94	3.00
17036	1	0.10	1.20	0.48
17097	1	0.25	3.00	1.76
17131	1	0.33	4.00	2.80
17177	1	0.42	5.00	4.00

CONTINUED

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
17314	1	0.83	10.00	8.00
17916	2	0.42/1.75	5.00/21.00	1.20/35.00
47830	1	0.39	5.00	6.70
Instrument Panel				
37	1	0.09	1.26	0.50
73	1	0.08	1.12	0.30
74	1	0.10	1.40	0.70
PC74	1	0.10	1.40	0.70
PC118	1	0.12	1.68	0.70
124	1	0.27	3.78	1.50
158	1	0.24	3.36	2.00
161	1	0.19	2.66	1.00
192	1	0.33	4.29	3.00
194	1	0.27	3.78	2.00
PC194	1	0.27	3.78	2.00
PC195	1	0.27	3.78	1.80
1210/H1	1	8.33	100.00	217.00
1210/H3	1	8.33	100.00	192.00
17037	1	0.10	1.20	0.48
17097	1	0.25	3.00	1.76
17314	1	0.83	10.00	8.00
Backup, Cornering, Fog/Driving Lamps				
67	1	0.59	7.97	4.00
579	1	0.80	10.20	9.00
880	1	2.10	26.88	43.00
881	1	2.10	26.88	43.00
885	1	3.90	49.92	100.00
886	1	3.90	49.92	100.00
893	1	2.93	37.50	75.00
896	1	2.93	37.50	75.00
898	1	2.93	37.50	60.00
899	1	2.93	37.50	60.00
921	1	1.40	17.92	21.00
1073	1	1.80	23.04	32.00
1156	1	2.10	26.88	32.00
1157	2	0.59/2.10	8.26/26.88	3.00/32.00
1210/H1	1	8.33	100.00	217.00
1255/H1	1	4.58	55.00	129.00
1255/H3	1	4.58	55.00	121.00
1255/H11	1	4.17	55.00	107.00
2057	2	0.49/2.10	6.86/26.88	1.50/24.00

CONTINUED

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
3057	2	0.48/2.10	6.72/26.88	2.00/32.00
3155	1	1.60	20.48	21.00
3156	1	2.10	26.88	32.00
3157	2	0.59/2.10	8.26/26.88	3.00/32.00
4157	2	0.59/2.10	8.26/26/88	3.00/32.00
7440	1	1.75	21.00	36.00
9003	2	4.58/5.00	55.00/60.00	72.00/120.00
9006	1	4.30	55.00	80.00
9145	1	3.52	45.00	65.00
17635	1	1.75	21.00	37.00

FIGURE 21–2 Bulbs that have the same trade number have the same operating voltage and wattage. The NA means that the bulb uses a natural amber glass ampoule with clear turn signal lenses.

Typical bulb suffixes include:

- NA: natural amber (amber glass)
- A: amber (painted glass)
- HD: heavy duty
- LL: long life
- IF: inside frosted
- R: red
- B: blue
- G: green

SEE FIGURE 21–2.

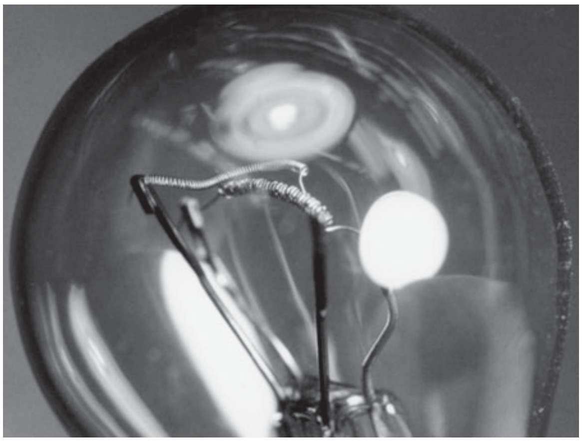


FIGURE 21–3 Close-up a 2057 dual-filament (double-contact) bulb that failed. Notice that the top filament broke from its mounting and melted onto the lower filament. This bulb caused the dash lights to come on whenever the brakes were applied.

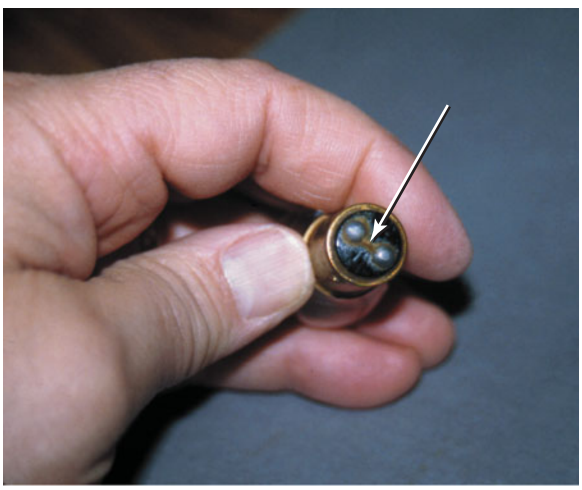


FIGURE 21–4 Corrosion caused the two terminals of this dual-filament bulb to be electrically connected.

FIGURE 21–5 Often the best diagnosis is a thorough visual inspection. This bulb was found to be filled with water, which caused weird problems.

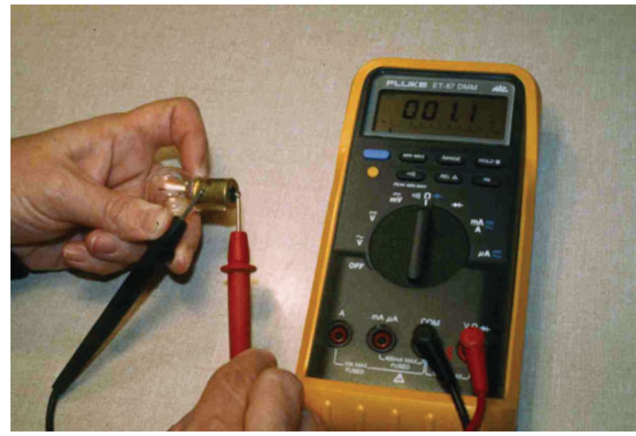


FIGURE 21–6 This single-filament bulb is being tested with a digital multimeter set to read resistance in ohms. The reading of 1.1 ohms is the resistance of the bulb when cold. As soon as current flows through the filament, the resistance increases about 10 times. It is the initial surge of current flowing through the filament when the bulb is cool that causes many bulbs to fail in cold weather as a result of the reduced resistance. As the temperature increases, the resistance increases.

REAL WORLD FIX

Weird Problem—Easy Solution

A General Motors minivan had the following electrical problems.

- The turn signals flashed rapidly on the left side.
- With the ignition key off, the lights-on warning chime sounded if the brake pedal was depressed.
- When the brake pedal was depressed, the dome light came on.

All of these problems were caused by *one* defective 2057 dual-filament bulb, as shown in ● **FIGURE 21–3**.

Apparently, the two filaments were electrically connected when one filament broke and then welded to the other filament. This caused the electrical current to feed back from the brake light filament into the taillight circuit, causing all the problems.

TESTING BULBS

Bulbs can be tested using two basic tests.

1. Perform a visual inspection of any bulb. Many faults, such as a shorted filament, corroded connector, or water, can cause weird problems that are often thought to be wiring issues.

● **SEE FIGURES 21–4 AND 21–5.**

2. Bulbs can be tested using an ohmmeter and checking the resistance of the filaments(s). Most bulbs will read low resistance at room temperature between 0.5 and 20 ohms depending on the bulb. Test results include:
   - **Normal resistance.** The bulb is good. Check both filaments if it is a two-filament bulb. ● **SEE FIGURE 21–6.**

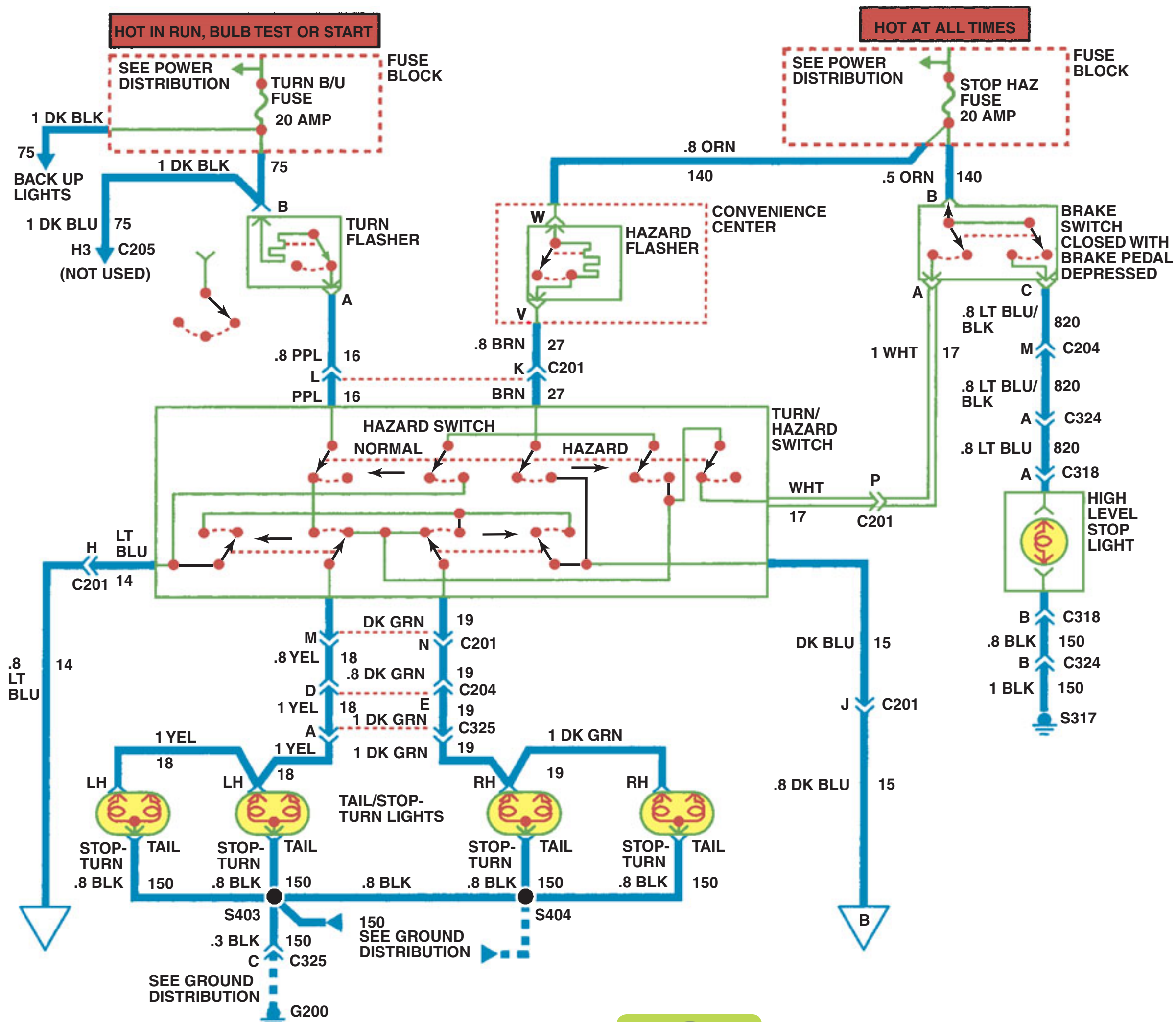


FIGURE 21–7 Typical brake light and taillight circuit showing the brake switch and all of the related circuit components.

- **Zero ohms.** It is unlikely but possible for the bulb filament to be shorted.
- **OL (electrically open).** The reading indicates that the bulb filament is broken.

BRAKE LIGHTS

OPERATION **Brake lights,** also called stop lights, use the high-intensity filament of a double-filament bulb. (The low-intensity filament is for the taillights.) When the brakes are applied, the brake switch is closed and the brake lamps light. The brake switch receives current from a fuse that is hot all the time. The brake light switch is a normally open (N.O.) switch, but is closed when the driver depresses the brake pedal. Since 1986, all vehicles sold in the United States have a third brake light commonly referred to as the **center high-mounted stop light (CHMSL).** ● **SEE FIGURE 21–7.**

? FREQUENTLY ASKED QUESTION

Why Are LEDs Used for Brake Lights?

Light-emitting diode (LED) brake lights are frequently used for high-mounted stop lamps (CHMSLs) for the following reasons.

1. **Faster illumination.** An LED will light up to 200 milliseconds faster than an incandescent bulb, which requires some time to heat the filament before it is hot enough to create light. This faster illumination can mean the difference in stopping distances at 60 mph (100 km/h) by about 18 ft (6 m) due to the reduced reaction time for the driver of the vehicle behind.
2. **Longer service life.** LEDs are solid-state devices that do not use a filament to create light. As a result, they are less susceptible to vibration and will often last the life of the vehicle.

   NOTE: Aftermarket replacement LED bulbs that are used to replace conventional bulbs may require the use of a different type of flasher unit due to the reduced current draw of the LED bulbs. ● **SEE FIGURE 21–8.**

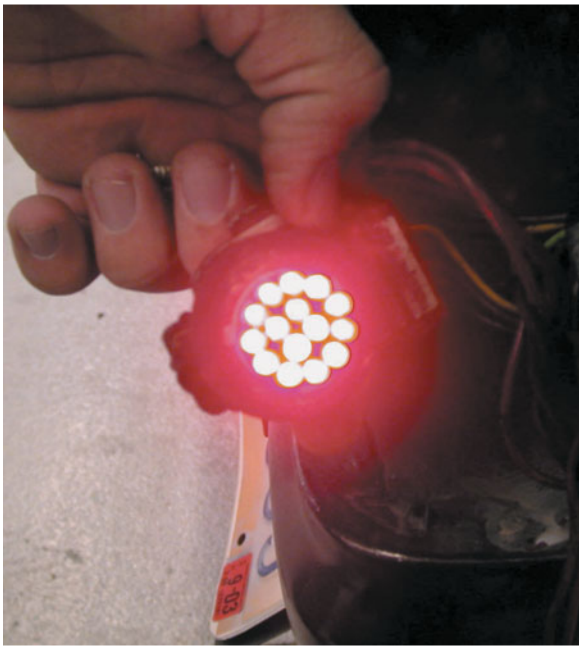


FIGURE 21–8 A replacement LED taillight bulb is constructed of many small, individual light-emitting diodes.

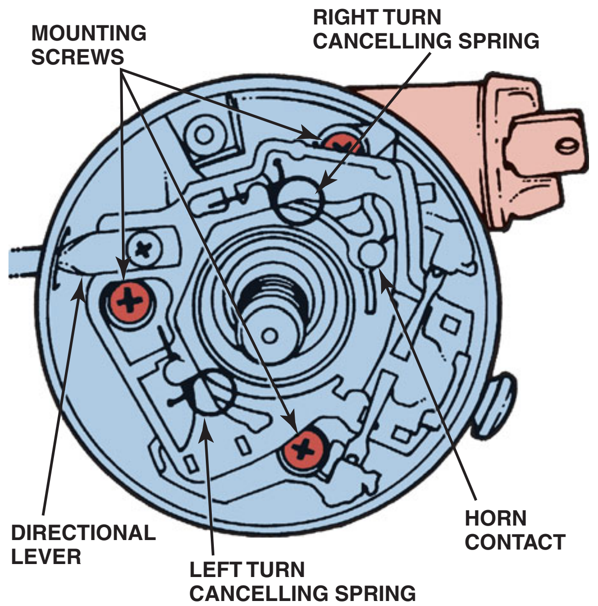


FIGURE 21–9 The typical turn signal switch includes various springs and cams to control the switch and to cause the switch to cancel after a turn has been completed.

The brake switch is also used as an input switch (signal) for the following:

1. Cruise control (deactivates when the brake pedal is depressed)
2. Antilock brakes (ABS)
3. Brake shift interlock (prevents shifting from park position unless the brake pedal is depressed)

TURN SIGNALS

OPERATION The turn signal circuit is supplied power from the ignition switch and operated by a lever and switch. ● **SEE FIGURE 21–9.**

When the turn signal switch is moved in either direction, the corresponding turn signal lamps receive current through the flasher unit. The flasher unit causes the current to start and stop as the turn signal lamp flashes on and off with the interrupted current.

ONE-FILAMENT STOP/TURN BULBS In many vehicles, the stop and turn signals are both provided by one filament. When the turn signal switch is turned on (closed), the filament receives interrupted current through the flasher unit. When the brakes are applied, the current first flows to the turn signal switch, except for the high-mounted stop, which is fed directly from the brake switch. If neither turn signal is on, then current through the turn signal switch flows to both rear brake lights. If the turn signal switch is operated (turned to either left or right), current flows through the flasher unit on the side that was selected and directly to the brake lamp on the opposite side. If the brake pedal is not depressed, then current flows through the flasher and only to one side. ● **SEE FIGURE 21–10.**

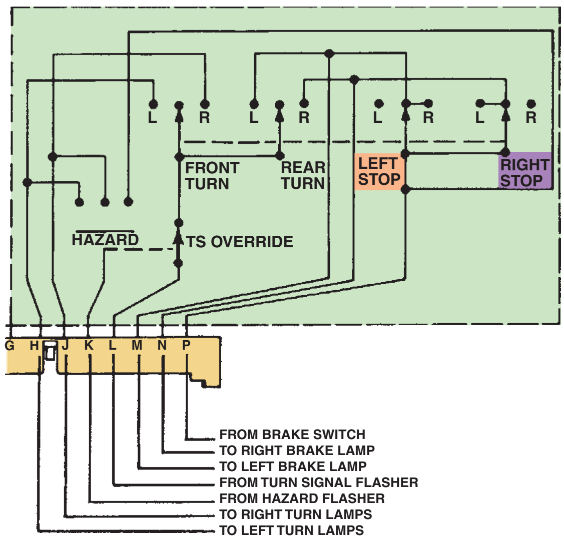


FIGURE 21–10 When the stop lamps and turn signals share a common bulb filament, stop light current flows through the turn signal switch.

Moving the lever up or down completes the circuit through the flasher unit and to the appropriate turn signal lamps. A turn signal switch includes cams and springs that cancel the signal after the turn has been completed. As the steering wheel is turned in the signaled direction and then returns to its normal position, the cams and springs cause the turn signal switch contacts to open and break the circuit.

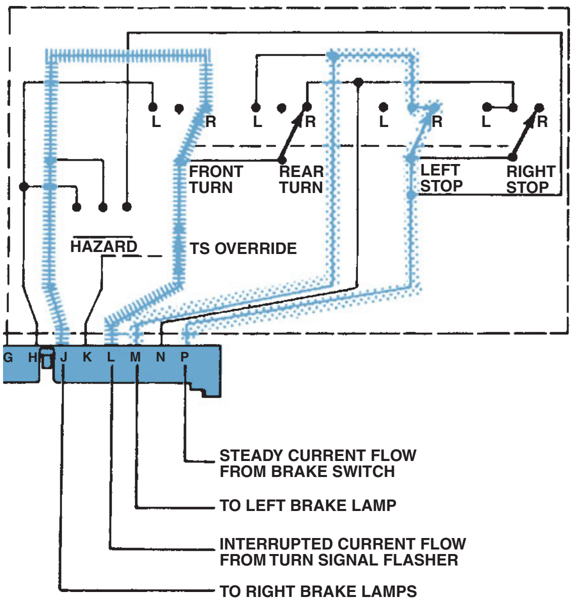


FIGURE 21–11 When a right turn in signaled, the turn signal switch contacts send flasher current to the right-hand filament and brake switch current to the left-hand filament.

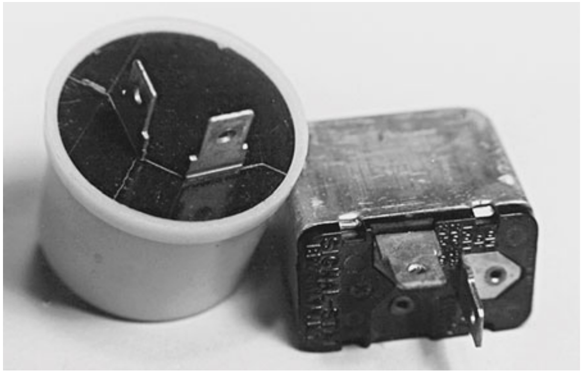


FIGURE 21–12 Two styles of two-prong flasher units.

TWO-FILAMENT STOP/TURN BULBS In systems using separate filaments for the stop and turn lamps, the brake and turn signal switches are not connected. If the vehicle uses the same filament for both purposes, then brake switch current is routed through contacts within the turn signal switch. By linking certain contacts, the bulbs can receive either brake switch current or flasher current, depending upon which direction is being signaled. For example, ● **FIGURE 21–11** shows current flow through the switch when the brake switch is closed and a right turn is signaled.

Steady current through the brake switch is sent to the left brake lamp. Interrupted current from the turn signal is sent to the right turn lamps.

FLASHER UNITS A turn signal flasher unit is a metal or plastic can containing a switch that opens and closes the turn signal circuit. Vehicles can be equipped with many different types of flasher units. ● **SEE FIGURE 21–12.**

- **DOT flashers.** This turn signal flasher unit is often installed in a metal clip attached to the dash panel to allow the "clicking" noise of the flasher to be heard by the driver. The turn signal flasher is designed to transmit the current to light the front and rear bulbs on only one side at a time. The U.S. **Department of Transportation (DOT)** regulation requires that the driver be alerted when a turn signal bulb is not working. This is achieved by using a series-type flasher unit. The flasher unit requires current flow through two bulbs (one in the front and one in the rear) in order to flash. If one bulb burns out, the current flow through only one bulb is not sufficient to make the unit flash; it will be a steady light. These turn signal units are often called DOT flashers.
- **Bimetal flashers.** The bimetal flashers have a lower cost and shorter life expectancy than hybrid or solid-state flashers. The operation of this flasher is current sensitive, which means that the flasher will stop flashing when one of the light bulbs is out and that it will flash at a faster rate when adding additional load, such as a trailer. The bimetal element is a sandwich of two different metals that distorts with temperature changes similar to a circuit breaker. The turn signal lamp current is passed through the bimetal element and causes heating. When the element is hot enough, the bimetal distorts, opening the contacts and turning off the lamps. After the bimetal cools, it returns to the original shape, closing the contacts and turning on the lamps again. This sequence is repeated until the load is removed. If one bulb burns out, the turn signal indicator lamp on the dash will remain lighted. The flasher will not flash because there is not enough current flow through the one remaining bulb to cause the flasher to become heated enough to open.
- **Hybrid flashers.** The **hybrid flashers** have an electronic flasher control circuit to operate the internal electromechanical relay and are commonly called a *flasher relay.* This type of flasher has a stable electronic timing circuitry that enables a wide operating voltage and temperature range with a reasonable cost. The life expectancy is considerably longer compared to bimetal units and is dependent on the load and relay used internally for switching the load. The hybrid flasher has a lamp current-sensing circuit which will cause the flash rate to double when a bulb is burned out.
- **Solid-state flashers.** The solid-state flashers have an internal electronic circuit for timing and solid-state power output devices for load switching. Life expectancy is longer than other flashers because there are no moving parts for mechanical breakdown. The biggest disadvantage of solid state is the higher cost. Solid-state units cause the turn indicator to flash rapidly if a bulb is burned out.

ELECTRONIC FLASHER REPLACEMENT UNITS Older vehicles (and a few newer ones) use thermal (bimetal) flashers that use heat to switch on and off. Most turn signal flasher units are mounted in a metal clip that is attached to the dash. The dash panel acts as a sounding board, increasing the sound of the

FIGURE 21–13 A hazard warning flasher uses a parallel resistor across the contacts to provide a constant flashing rate regardless of the number of bulbs used in the circuit.

flasher unit. Most four-way hazard flasher units are plugged into the fuse panel. Some turn signal flasher units are plugged into the fuse panel. How do you know for sure where the flasher unit is located? With both the turn signal and the ignition on, listen and/or feel for the clicking of the flasher unit. Some service manuals also give general locations for the placement of flasher units.

Newer vehicles have electronic flashers that use microchips to control the on/off function. Electronic flashers are compatible with older systems and are wise to use for the following reasons.

1. Electronic flashers do not burn out, and they provide a faster "flash" of the turn signals.
2. If upgrading to LED tail lamps, or lights, the LED bulbs only work with electronic flashers unless a resistor is added in the circuit.

HAZARD WARNING FLASHER The **hazard warning flasher** is a device installed in a vehicle lighting system with the primary function of causing both the left and right turn signal lamps to flash when the hazard warning switch is activated. Secondary functions may include visible dash indicators for the hazard system and an audible signal to indicate when the flasher is operating. A typical hazard warning flasher is also called a *parallel* or *variable-load* flasher because there is a resistor in parallel with the contacts to provide a control load and, therefore, a constant flash rate, regardless of the number of bulbs being flashed. ● **SEE FIGURE 21–13.**

COMBINATION TURN SIGNAL AND HAZARD WARNING FLASHER The combination flasher is a device that combines the functions of a turn signal flasher and a hazard warning flasher into one package, which often uses three electrical terminals.

? FREQUENTLY ASKED QUESTION

How Do You Tell What Type of Flasher Is Being Used?

The easiest way to know which type of flasher can be used is to look at the type of bulb used in the tail lamps and turn signals. If it is a "wedge" style (plastic base, flat and rectangular), the vehicle has an electronic flasher. If it is a "twist and turn" bayonet-style (brass base) bulb, then either type of flasher can be used.

? FREQUENTLY ASKED QUESTION

Why Does the Side-Marker Light Alternately Flash?

A question that service technicians are asked frequently is why the side-marker light alternately goes out when the turn signal is on, and is on when the turn signal is off. Some vehicle owners think that there is a fault with the vehicle, but this is normal operation. The side-marker light goes out when the lights are on and the turn signal is flashing because there are 12 volts on both sides of the bulb (see points X and Y in ● **FIGURE 21–14**).

Normally, the side-marker light gets its ground through the turn signal bulb.

HEADLIGHTS

HEADLIGHT SWITCHES The headlight switch operates the exterior and interior lights of most vehicles. On noncomputer-controlled lighting systems, the headlight switch is connected directly to the battery through a fusible link, and has continuous power or is "hot" all the time. A circuit breaker is built into most older model headlight switches to protect the headlight circuit. ● **SEE FIGURE 21–15.**

The headlight switch may include the following:

- The interior dash lights can often be dimmed manually by rotating the headlight switch knob or by another rotary knob that controls a variable resistor (called a **rheostat**). The rheostat drops the voltage sent to the dash lights. Whenever there is a voltage drop (increased resistance), there is heat. A coiled resistance wire is built into a ceramic housing that is designed to insulate the rest of the switch from the heat and allow heat to escape.
- The headlight switch also contains a built-in circuit breaker that will rapidly turn the headlights on and off in the event of a short circuit. This prevents a total loss of headlights.

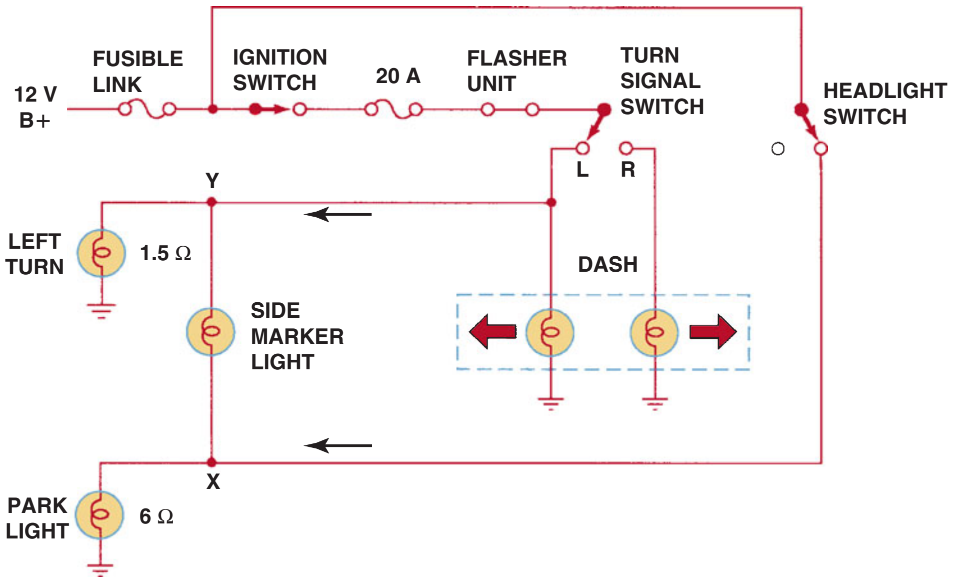


FIGURE 21–14 The side-marker light goes out whenever there is voltage at both points X and Y. These opposing voltages stop current flow through the side-marker light. The left turn light and left park light are actually the same bulb (usually 2057) and are shown separately to help explain how the side-marker light works on many vehicles.

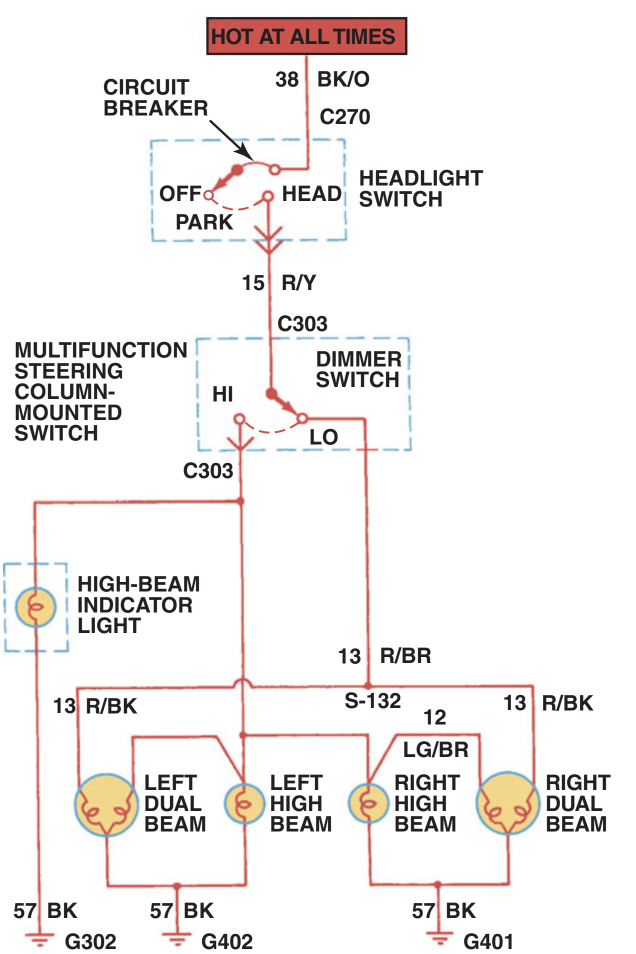


FIGURE 21–15 Typical headlight circuit diagram. Note that the headlight switch is represented by a dotted outline indicating that other circuits (such as dash lights) also operate from the switch.

If the headlights are rapidly flashing on and off, check the entire headlight circuit for possible shorts. The circuit breaker controls only the headlights. The other lights controlled by the headlight switch (taillights, dash lights, and parking lights) are fused separately. Flashing headlights also may be caused by a failure in the built-in circuit breaker, requiring replacement of the switch assembly.

AUTOMATIC HEADLIGHTS Computer-controlled lights use a light sensor that signals when to have the computer turn on the headlights. The sensor is mounted on the dashboard or mirror. Often these systems have a driver-adjusted sensitivity control that allows for the lights to be turned on at various levels of light. Most systems also have a computer module control over the time that the lights remain on after the ignition has been turned off and the last door has been closed. A scan tool is often needed to change this time delay.

SEALED BEAM HEADLIGHTS A sealed beam headlight consists of a sealed glass or plastic assembly containing the bulb, reflective surface, and prism lenses to properly focus the light beam. Low-beam headlights contain two filaments and three electrical terminals.

- One for low beam
- One for high beam
- Common ground

High-beam headlights contain only one filament and two terminals. Because low-beam headlights also contain a high-beam filament, the entire headlight assembly must be replaced if either filament is defective. ● **SEE FIGURE 21–16**.

A sealed beam headlight can be tested with an ohmmeter. A good bulb should indicate low ohms between the ground terminal and both power-side (hot) terminals. If either the high-beam or the low-beam filament is burned out, the ohmmeter will indicate infinity (OL).

FIGURE 21–16 A typical four-headlight system using sealed beam headlights.

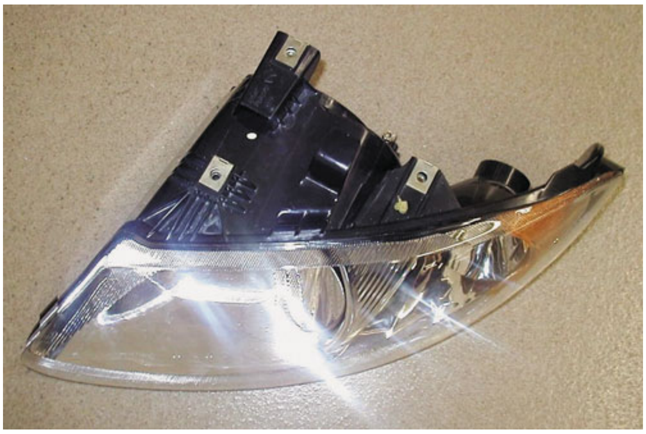


FIGURE 21–17 A typical composite headlamp assembly. The lens, housing, and bulb sockets are usually included as a complete assembly.

HALOGEN SEALED BEAM HEADLIGHTS Halogen sealed beam headlights are brighter and more expensive than normal headlights. Because of their extra brightness, it is common practice to have only two headlights on at any one time, because the candlepower output would exceed the maximum U.S. federal standards if all four halogen headlights were on. Therefore, before trying to repair the problem that only two of the four lamps are on, check the owner or shop manual for proper operation.

CAUTION: Do not attempt to wire all headlights together. The extra current flow could overheat the wiring from the headlight switch through the dimmer switch and to the headlights. The overloaded circuit could cause a fire.

COMPOSITE HEADLIGHTS **Composite headlights** are constructed using a replaceable bulb and a fixed lens cover that is part of the vehicle. Composite headlights are the result of changes in the aerodynamic styling of vehicles where sealed beam lamps could no longer be used. ● **SEE FIGURE 21–17.**

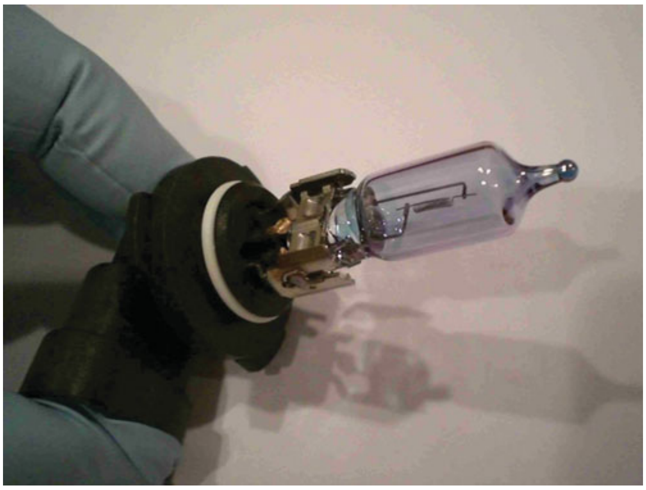


FIGURE 21–18 Handle a halogen bulb by the base to prevent the skin's oil from getting on the glass.

TECH TIP

Diagnose Bulb Failure

Halogen bulbs can fail for various reasons. Some causes for halogen bulb failure and their indications are as follows:

- **Gray color.** Low voltage to bulb (check for corroded socket or connector)
- **White (cloudy) color.** Indication of an air leak
- **Broken filament.** Usually caused by excessive vibration
- **Blistered glass.** Indication that someone has touched the glass

NOTE: *Never touch the glass (called the ampoule) of any halogen bulb.* The oils from your fingers can cause unequal heating of the glass during operation, leading to a shorter-than-normal service life. ● SEE FIGURE 21–18.

The replaceable bulbs are usually bright halogen bulbs. Halogen bulbs get very hot during operation, between 500°F and 1,300°F (260°C and 700°C). It is important never to touch the glass of any halogen bulb with bare fingers because the natural oils of the skin on the glass bulb can cause the bulb to break when it heats during normal operation.

HIGH-INTENSITY DISCHARGE HEADLIGHTS

PARTS AND OPERATION **High-intensity discharge (HID)** headlights produce a distinctive blue-white light that is crisper, clearer, and brighter than light produced by a halogen headlight.

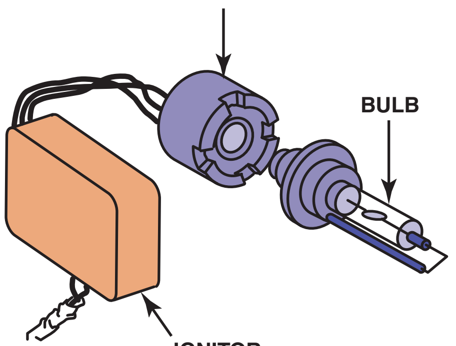


FIGURE 21–19 The igniter contains the ballast and transformer needed to provide high-voltage pulses to the arc tube bulb.

? FREQUENTLY ASKED QUESTION

What Is the Difference Between the Temperature of the Light and the Brightness of the Light?

The temperature of the light indicates the color of the light. The brightness of the light is measured in lumens. A standard 100 watt incandescent light bulb emits about 1,700 lumens. A typical halogen headlight bulb produces about 2,000 lumens, and a typical HID bulb produces about 2,800 lumens.

High-intensity discharge lamps do not use a filament like conventional electrical bulbs, but contain two electrodes about 0.2 in. (5 mm) apart. A high-voltage pulse is sent to the bulb which arcs across the tips of electrodes producing light.

It creates light from an electrical discharge between two electrodes in a gas-filled arc tube. It produces twice the light with less electrical input than conventional halogen bulbs.

The HID lighting system consists of the discharge arc source, igniter, ballast, and headlight assembly. ● **SEE FIGURE 21–19.**

The two electrodes are contained in a tiny quartz capsule filled with xenon gas, mercury, and metal halide salts. HID headlights are also called **xenon headlights.** The lights and support electronics are expensive, but they should last the life of the vehicle unless physically damaged.

HID headlights produce a white light giving the lamp a blue-white color. The color of light is expressed in temperature using the Kelvin scale. **Kelvin (K)** temperature is the Celsius temperature plus 273 degrees. Typical color temperatures include:

- Daylight: 5,400°K
- HID: 4,100°K
- Halogen: 3,200°K
- Incandescent (tungsten): 2,800°K

● **SEE FIGURE 21–20.**

FIGURE 21–20 HID (xenon) headlights emit a whiter light than halogen headlights and usually look blue compared to halogen bulbs.

The HID ballast is powered by 12 volts from the headlight switch on the body control module. The HID headlights operate in three stages or states.

1. Start-up or stroke state
2. Run-up state
3. Steady state

START-UP OR STROKE STATE When the headlight switch is turned to the on position, the ballast may draw up to 20 amperes at 12 volts. The ballast sends multiple high-voltage pulses to the arc tube to start the arc inside the bulb. The voltage provided by the ballast during the start-up state ranges from −600 volts to +600 volts, which is increased by a transformer to about 25,000 volts. The increased voltage is used to create an arc between the electrodes in the bulb.

RUN-UP STATE After the arc is established, the ballast provides a higher than steady state voltage to the arc tube to keep the bulb illuminated. On a cold bulb, this state could last as long as 40 seconds. On a hot bulb, the run-up state may last only 15 seconds. The current requirements during the run-up state are about 360 volts from the ballast and a power level of about 75 watts.

STEADY STATE The steady state phase begins when the power requirement of the bulb drops to 35 watts. The ballast provides a minimum of 55 volts to the bulb during steady state operation.

BI-XENON HEADLIGHTS Some vehicles are equipped with bi-xenon headlights, which use a shutter to block some of the light during low-beam operation and then mechanically move to expose more of the light from the bulb for high-beam operation. Because xenon lights are relatively slow to start working, vehicles equipped with bi-xenon headlights use two halogen lights for the "flash-to-pass" feature.

FAILURE SYMPTOMS The following symptoms indicate bulb failure.

- A light flickers
- Lights go out (caused when the ballast assembly detects repeated bulb restrikes)
- Color changes to a dim pink glow

FIGURE 21–21 LED headlights usually require multiple units to provide the needed light as seen on this Lexus LS600h.

Bulb failures are often intermittent and difficult to repeat. However, bulb failure is likely if the symptoms get worse over time. Always follow the vehicle manufacturer's recommended testing and service procedures.

DIAGNOSIS AND SERVICE High-intensity discharge headlights will change slightly in color with age. This **color shift** is usually not noticeable unless one headlight arc tube assembly has been replaced due to a collision repair, and then the difference in color may be noticeable. The difference in color will gradually change as the arc tube ages and should not be too noticeable by most customers. If the arc tube assembly is near the end of its life, it may not light immediately if it is turned off and then back on immediately. This test is called a "hot restrike" and if it fails, a replacement arc tube assembly may be needed or there is another fault, such as a poor electrical connection, that should be checked.

> **WARNING:**
>
> Always adhere to all warnings because the high-voltage output of the ballast assembly can cause personal injury or death.

LED HEADLIGHTS

Some vehicles, including several Lexus models, use LED headlights either as standard equipment (Lexus LS600h) or optional. ● **SEE FIGURE 21–21**.

Advantages include:

- Long service life
- Reduced electrical power required

Disadvantages include:

- High cost
- Many small LEDs required to create the necessary light output

HEADLIGHT AIMING

According to U.S. federal law, all headlights, regardless of shape, must be able to be aimed using headlight aiming equipment. Older vehicles equipped with sealed beam headlights used a headlight aiming system that attached to the headlight itself. ● **SEE FIGURES 21–22 AND 21–23.** Also see the photo sequence on headlight aiming at the end of the chapter.

ADAPTIVE FRONT LIGHTING SYSTEM

PARTS AND OPERATION A system that mechanically moves the headlights to follow the direction of the front wheels is called **adaptive (**or **advanced) front light system,** or **AFS.** The AFS provides a wide range of visibility during cornering. The headlights are usually capable of rotating 15 degrees to the left and 5 degrees to the right (some systems rotate 14 degrees and 9 degrees, respectively). Vehicles that use AFS include Lexus, Mercedes, and certain domestic models, usually as an extra cost option. ● **SEE FIGURE 21–24.**

NOTE: These angles are reversed on vehicles sold in countries that drive on the left side of the road, such as Great Britain, Japan, Australia, and New Zealand.

The vehicle has to be moving above a predetermined speed, usually above 20 mph (30 km/h) and the lights stop moving when the speed drops below about 3 mph (5 km/h).

AFS is often used in addition to self-leveling motors so that the headlights remain properly aimed regardless of how the vehicle is loaded. Without self-leveling, headlights would shine higher than normal if the rear of the vehicle is heavily loaded. ● **SEE FIGURE 21–25.**

When a vehicle is equipped with an adaptive front lighting system, the lights are moved by the headlight controller outward, and then inward as well as up and down as a test of the system. This action is quite noticeable to the driver, and is normal operation of the system.

DIAGNOSIS AND SERVICE The first step when diagnosing an AFS fault is to perform the following visual inspection.

- Start by checking that the AFS is switched on. Most AFS headlights are equipped with a switch that allows the driver to turn the system on and off. ● **SEE FIGURE 21–26.**
- Check that the system performs a self-test during start-up.

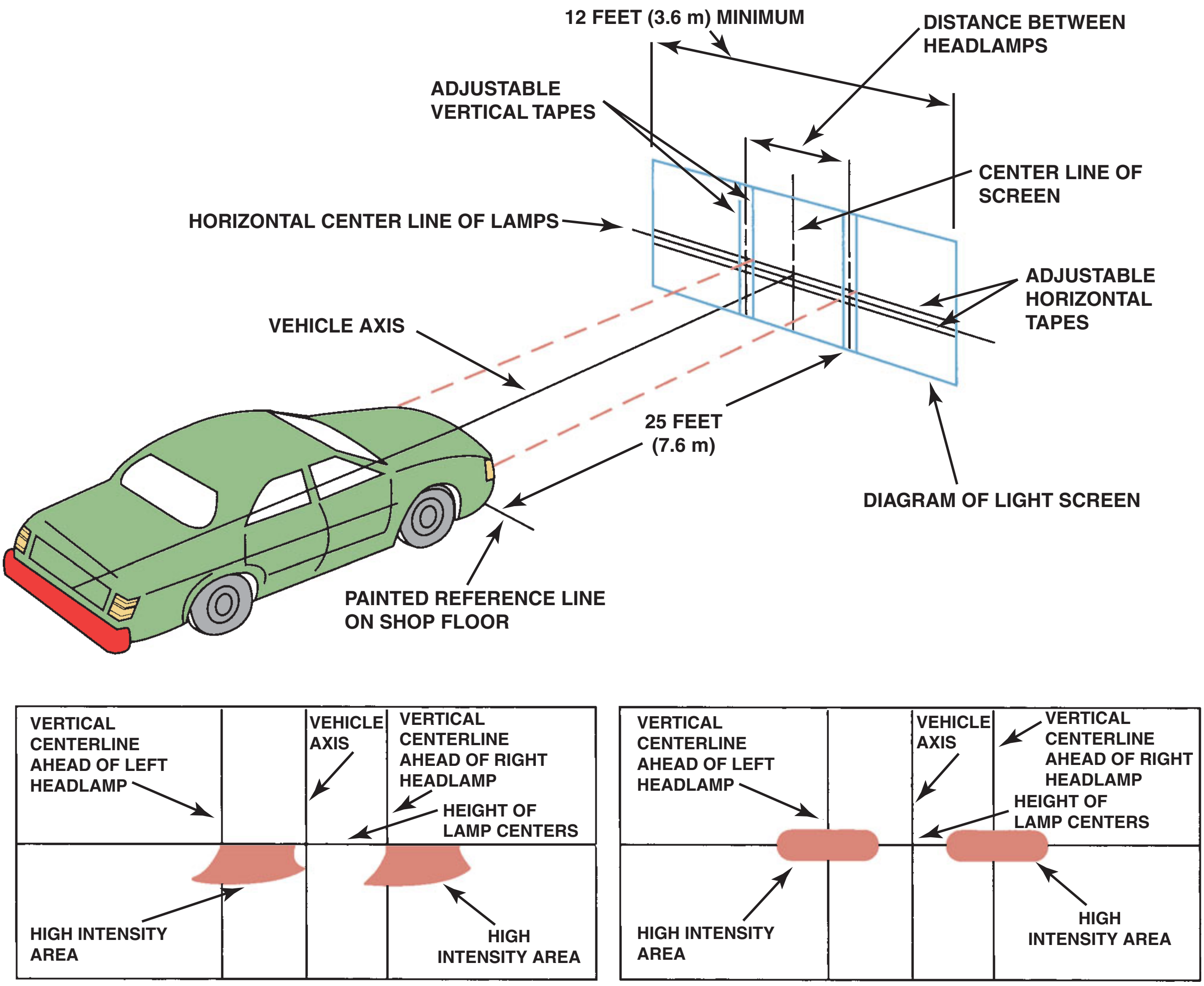


FIGURE 21–22 Typical headlight aiming diagram as found in service information.

FIGURE 21–23 Many composite headlights have a built-in bubble level to make aiming easy and accurate.

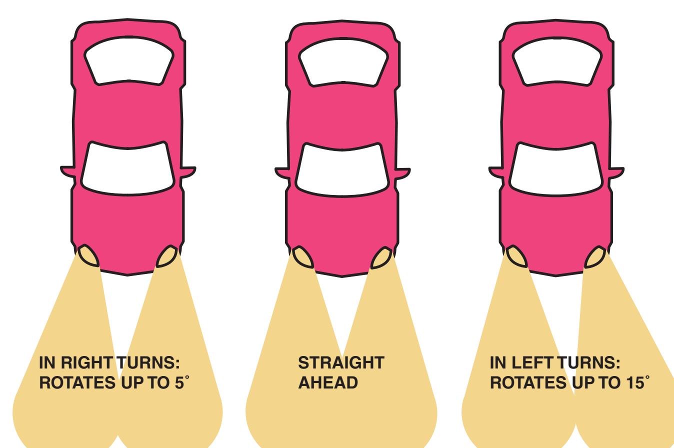


FIGURE 21–24 Adaptive front lighting systems rotate the low-beam headlight in the direction of travel.

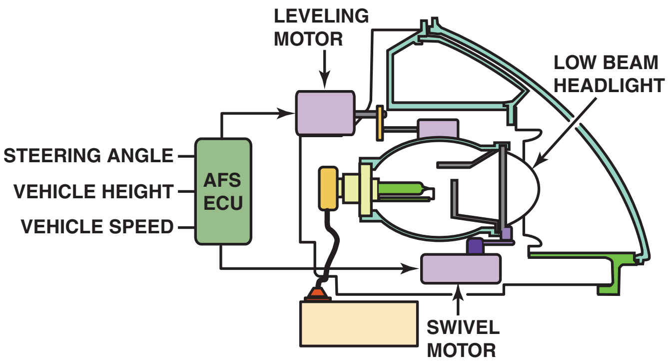


FIGURE 21–25 A typical adaptive front lighting system uses two motors: one for the up and down movement and the other for rotating the low-beam headlight to the left and right.

FIGURE 21–26 Typical dash-mounted switch that allows the driver to disable the front lighting system.

- Verify that both low-beam and high-beam lights function correctly. The system may be disabled if a fault with one of the headlights is detected.
- Use a scan tool to test for any AFS-related diagnostic trouble codes. Some systems allow the AFS to be checked and operated using a scan tool.

Always follow the recommended testing and service procedures as specified by the vehicle manufacturer in service information.

DAYTIME RUNNING LIGHTS

PURPOSE AND FUNCTION **Daytime running lights (DRLs)** involve operation of the following:

- Front parking lights
- Separate DRL lamps
- Headlights (usually at reduced current and voltage) when the vehicle is running

TECH TIP

Checking a Dome Light Can Be Confusing

If a technician checks a dome light with a test light, both sides of the bulb will "turn on the light" if the bulb is good. This will be true if the system's "ground switched" doors are closed and the bulb is good. This confuses many technicians because they do not realize that the ground will not be sensed unless the door is open.

Canada has required daytime running lights on all new vehicles since 1990. Studies have shown that DRLs have reduced accidents where used.

Daytime running lights primarily use a control module that turns on either the low- or high-beam headlights or separate daytime running lights. The lights on some vehicles come on when the engine starts. Other vehicles will turn on the lamps when the engine is running but delay their operation until a signal from the vehicle speed sensor indicates that the vehicle is moving.

To avoid having the lights on during servicing, some systems will turn off the headlights when the parking brake is applied and the ignition switch is cycled off then back on. Others will only light the headlights when the vehicle is in a drive gear. ● **SEE FIGURE 21–27.**

CAUTION: Most factory daytime running lights operate the headlights at reduced intensity. These are *not* designed to be used at night. Normal intensity of the headlights (and operation of the other external lamps) is actuated by turning on the headlights as usual.

DIMMER SWITCHES

The headlight switch controls the power or hot side of the headlight circuit. The current is then sent to the dimmer switch, which allows current to flow to either the high-beam or the low-beam filament of the headlight bulb, as shown in ● **FIGURE 21–28.**

An indicator light illuminates on the dash when the high beams are selected.

The dimmer switch is usually hand operated by a lever on the steering column. Some steering column switches are actually attached to the *outside* of the steering column and are spring loaded. To replace these types of dimmer switches, the steering column needs to be lowered slightly to gain access to the switch itself.

COURTESY LIGHTS

Courtesy light is a generic term primarily used for interior lights, including overhead (dome) and under-the-dash (courtesy) lights. These interior lights are controlled by operating switches

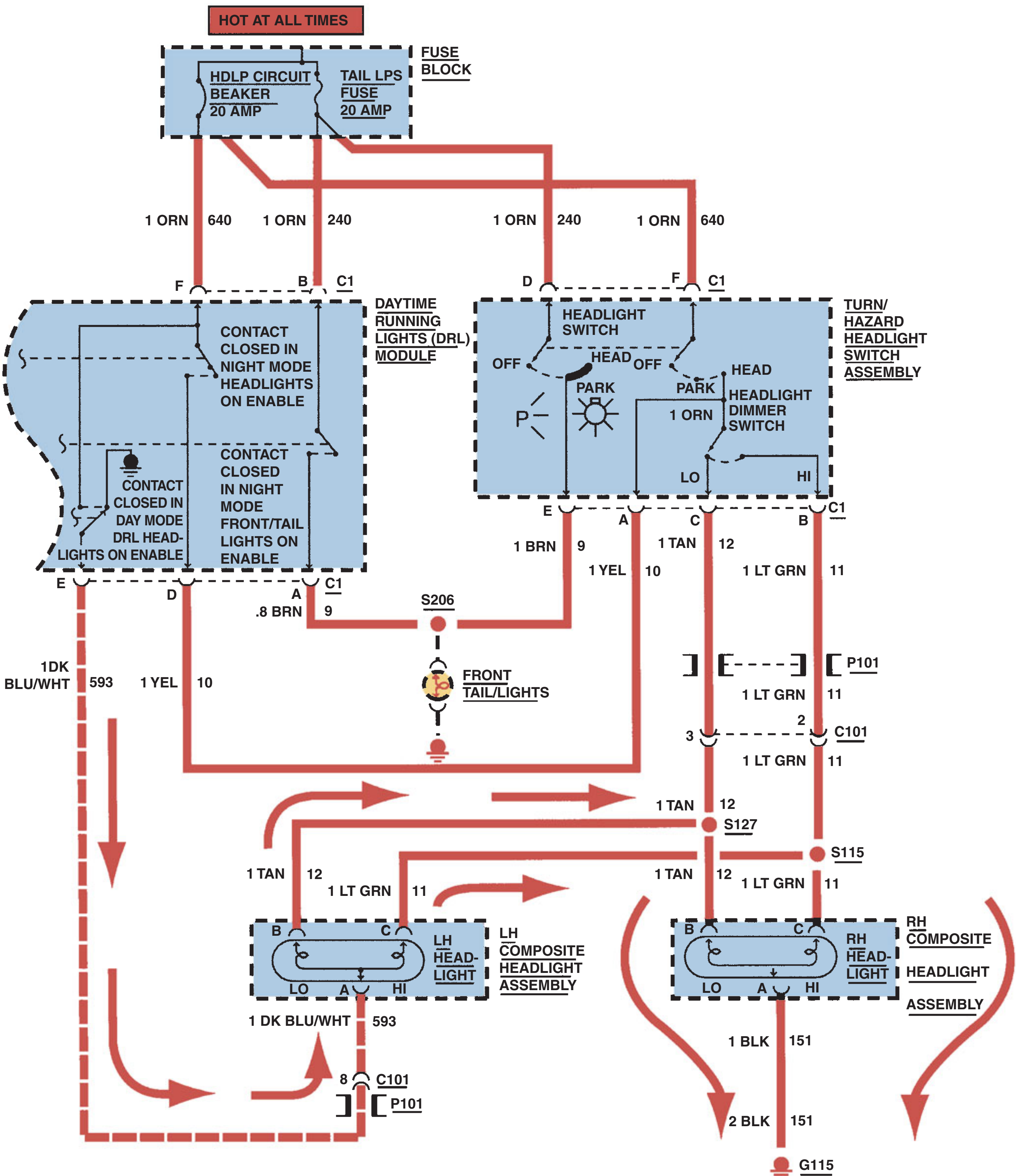


FIGURE 21–27 Typical daytime running light (DRL) circuit. Follow the arrows from the DRL module through both headlights. Notice that the left and right headlights are connected in series, resulting in increased resistance, less current flow, and dimmer than normal lighting. When the normal headlights are turned on, both headlights receive full battery voltage, with the left headlight grounding through the DRL module.

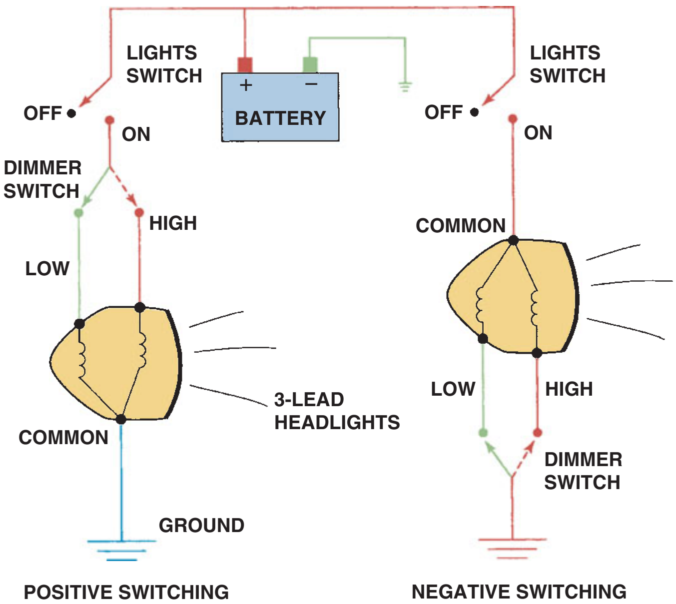


FIGURE 21–28 Most vehicles use positive switching of the high- and low-beam headlights. Notice that both filaments share the same ground connection. Some vehicles use negative switching and place the dimmer switch between the filaments and the ground.

FIGURE 21–29 A typical courtesy light doorjamb switch. Newer vehicles use the door switch as an input to the vehicle computer and the computer turns the interior lights on or off. By placing the lights under the control of the computer, the vehicle engineers have the opportunity to delay the lights after the door is closed and to shut them off after a period of time to avoid draining the battery.

located in the doorjambs of the vehicle doors or by a switch on the dash. ● **SEE FIGURE 21–29.**

Many Ford vehicles use the door switches to open and close the power side of the circuit. Many newer vehicles operate the interior lights through the vehicle computer or through an electronic module. Because the exact wiring and operation of these units differ, consult the service information for the exact model of the vehicle being serviced.

ILLUMINATED ENTRY

Some vehicles are equipped with illuminated entry, meaning the interior lights are turned on for a given amount of time when the outside door handle is operated while the doors are locked. Most vehicles equipped with illuminated entry also light the exterior door keyhole. Vehicles equipped with body computers use the input from the key fob remote to “wake up” the power supply for the body computer.

FIBER OPTICS

Fiber optics is the transmission of light through special plastic (polymethyl methacrylate) that keeps the light rays parallel even if the plastic is tied in a knot. These strands of plastic are commonly used in automotive applications as indicators for the driver that certain lights are functioning. For example, some vehicles are equipped with fender-mounted units that light when the lights or turn signals are operating. Plastic fiber-optic strands, which often look like standard electrical wire, transmit the light at the bulb to the indicator on top of the fender so that the driver can determine if a certain light is operating. Fiber-optic strands also can be run like wires to indicate the operation of all lights on the dash or console. Fiber-optic strands are also commonly used to light ashtrays, outside door locks, and other areas where a small amount of light is required. The source of the light can be any normally operating light bulb, which means that one bulb can be used to illuminate many areas. A special bulb clip is normally used to retain the fiber-optic plastic tube near the bulb.

AUTOMATIC DIMMING MIRRORS

PARTS AND OPERATION Automatic dimming mirrors use electrochromic technology to dim the mirror in proportion to the amount of headlight glare from other vehicles at the rear. The electrochromic technology developed by Gentex Corporation uses a gel that changes with light between two pieces of glass. One piece of glass acts as a reflector and the other has a transparent (clear) electrically conductive coating. The inside rearview mirror also has a forward-facing light sensor that is used to detect darkness and signal the rearward-facing

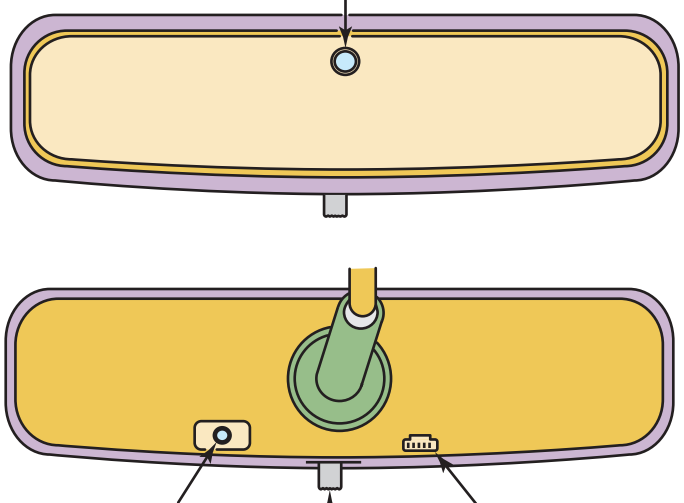


FIGURE 21–30 An automatic dimming mirror compares the amount of light toward the front of the vehicle to the rear of the vehicle and allies a voltage to cause the gel to darken the mirror.

sensor to begin to check for excessive glare from headlights behind the vehicle. The rearward-facing sensor sends a voltage to the electrochromic gel in the mirror that is in proportion to the amount of glare detected. The mirror dims in proportion to the glare and then becomes like a standard rearview mirror when the glare is no longer detected. If automatic dimming mirrors are used on the exterior, the sensors in the interior mirror and electronics are used to control both the interior and exterior mirrors. ● **SEE FIGURE 21–30.**

DIAGNOSIS AND SERVICE If a customer concern states that the mirrors do not dim when exposed to bright headlights from the vehicle behind, the cause could be sensors or the mirror itself. Be sure that the mirror is getting electrical power. Most automotive dimming mirrors have a green light to indicate the presence of electrical power. If no voltage is found at the mirror, follow standard troubleshooting procedures to find the cause. If the mirror is getting voltage, start the diagnosis by placing a strip of tape over the forward-facing light sensor. Turn the ignition key on, engine off (KOEO), and observe the operation of the mirror when a flashlight or trouble light is directed onto the mirror. If the mirror reacts and dims, the forward-facing sensor is defective. Most often, the entire mirror assembly has to be replaced if any sensor or mirror faults are found.

One typical fault with automatic dimming mirrors is a crack can occur in the mirror assembly, allowing the gel to escape from between the two layers of glass. This gel can drip onto the dash or center console and harm these surfaces. The mirror should be replaced at the first sign of any gel leakage.

? FREQUENTLY ASKED QUESTION

What Is the Troxler Effect?

The **Troxler effect,** also called *Troxler fading,* is a visual effect where an image remains on the retina of the eye for a short time after the image has been removed. The effect was discovered in 1804 by Igney Paul Vital Troxler (1780–1866), a Swiss physician. Because of the Troxler effect, headlight glare can remain on the retina of the eye and create a blind spot. At night, this fading away of the bright lights from the vehicle in the rear reflected by the rearview mirror can cause a hazard.

TECH TIP

The Weirder the Problem, the More Likely It Is a Poor Ground Connection

Bad grounds are often the cause for feedback or lamps operating at full or partial brilliance. At first the problem looks weird because often the switch for the lights that are on dimly is not even turned on. When an electrical device is operating and it lacks a proper ground connection, the current will try to find ground and will often cause other circuits to work. Check all grounds before replacing parts.

FEEDBACK

DEFINITION When current that lacks a good ground goes backward along the power side of the circuit in search of a return path (ground) to the battery, this reverse flow is called **feedback,** or *reverse-bias* current flow. Feedback can cause other lights or gauges that should not be working to actually turn on.

FEEDBACK EXAMPLE A customer complained that when the headlights were on, the left turn signal indicator light on the dash remained on. The cause was found to be a poor ground connection for the left front parking light socket. The front parking light bulb is a dual filament: one filament for the parking light (dim) and one filament for the turn signal operation (bright). A corroded socket did not provide a good enough ground to conduct all current required to light the dim filament of the bulb.

The two filaments of the bulb share the same ground connection and are electrically connected. When all the current could not flow through the bulb's ground in the socket, it caused a feedback or reversed its flow through the other filament, looking for ground. The turn signal filament is electrically connected to the dash indicator light; therefore, the reversed current on its path toward ground could light the turn signal indicator light. Cleaning or replacing the socket usually solves the problem if the ground wire for the socket is making a secure chassis ground connection.

LIGHTING SYSTEM DIAGNOSIS

Diagnosing any faults in the lighting and signaling systems usually includes the following steps.

STEP 1 Verify the customer concern.

STEP 2 Perform a visual inspection, checking for collision damage or other possible causes that would affect the operation of the lighting circuit.

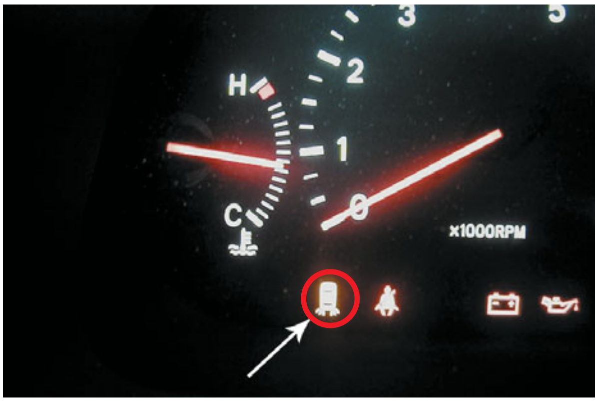
STEP 3 Connect a factory or enhanced scan tool with bidirectional control of the computer modules to check for proper operation of the affected lighting circuit.

STEP 4 Follow the diagnostic procedure as found in service information to determine the root cause of the problem.

LIGHTING SYSTEM SYMPTOM GUIDE

The following list will assist technicians in troubleshooting lighting systems.

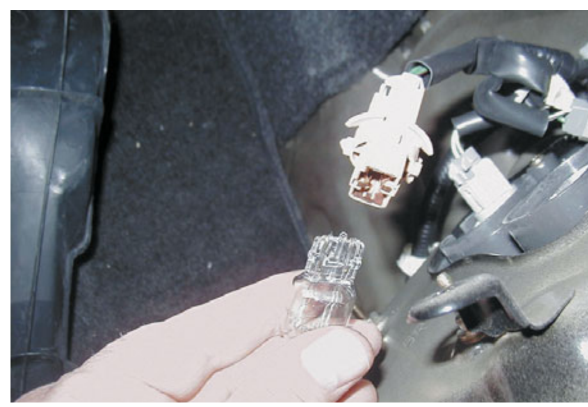
Problem	Possible Causes and/or Solutions
One headlight dim	1. Poor ground connection on body 2. Corroded connector
One headlight out (low or high beam)	1. Burned out headlight filament (Check the headlight with an ohmmeter. There should be a low-ohm reading between the power-side connection and the ground terminal of the bulb.) 2. Open circuit (no 12 volts to the bulb)
Both high- and low-beam headlights out	1. Burned out bulbs (Check for voltage at the wiring connector to the headlights for a possible open circuit to the headlights or open [defective] dimmer switch.) 2. Open circuit (no 12 volts to the bulb)
All headlights inoperative	1. Burned out filaments in all headlights (Check for excessive charging system voltage.) 2. Defective dimmer switch 3. Defective headlight switch
Slow turn signal operation	1. Defective flasher unit 2. High resistance in sockets or ground wire connections 3. Incorrect bulb numbers
Turn signals operating on one side only	1. Burned out bulb on affected side 2. Poor ground connection or defective socket on affected side 3. Incorrect bulb number on affected side 4. Defective turn signal switch
Interior light(s) inoperative	1. Burned out bulb(s) 2. Open in the power-side circuit (blown fuse) 3. Open in doorjamb switch(es)
Interior lights on all the time	1. Shorted doorjamb switch 2. Shorted control switch
Brake lights inoperative	1. Defective brake switch 2. Defective turn signal switch 3. Burned out brake light bulbs 4. Open circuit or poor ground connection 5. Blown fuse
Hazard warning lights inoperative	1. Defective hazard flasher unit 2. Open in hazard circuit 3. Blown fuse 4. Defective hazard switch
Hazard warning lights blinking too rapidly	1. Incorrect flasher unit 2. Shorted wiring to front or rear lights 3. Incorrect bulb numbers



1 The driver noticed that the taillight fault indicator (icon) on the dash was on any time the lights were on.

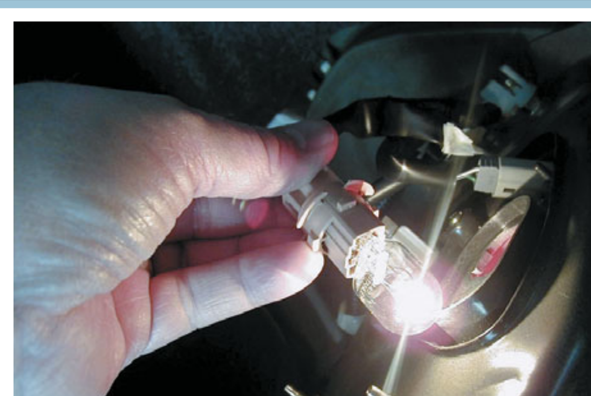
2 A visual inspection at the rear of the vehicle indicated that the right rear taillight bulb did not light. Removing a few screws from the plastic cover revealed the taillight assembly.

3 The bulb socket is removed from the taillight assembly by gently twisting the base of the bulb counterclockwise.



4 The bulb is removed from the socket by gently grasping the bulb and pulling the bulb straight out of the socket. Many bulbs required that you rotate the bulb 90° (1/4 turn) to release the retaining bulbs.

5 The new 7443 replacement bulb is being checked with an ohmmeter to be sure that it is okay before it is installed in the vehicle.

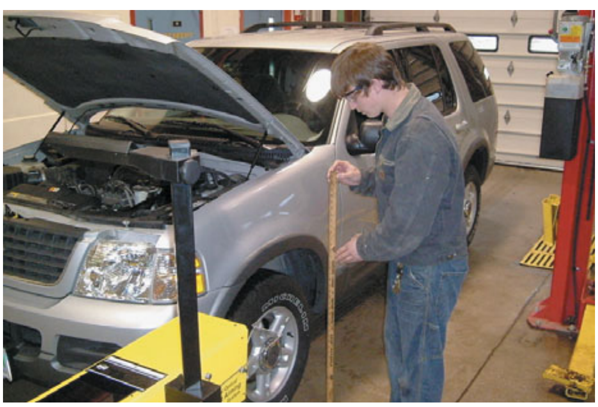


6 The replacement bulb in inserted into the taillight socket and the lights are turned on to verify proper operation before putting the components back together.

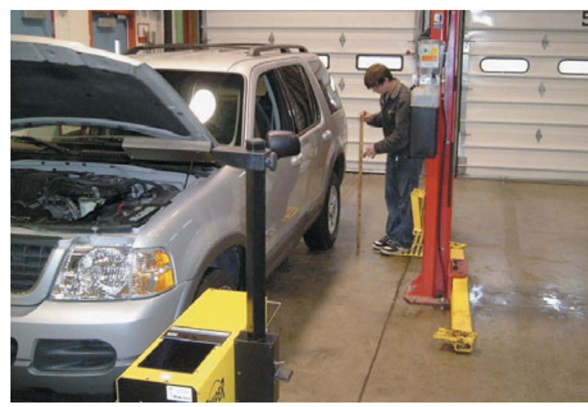
OPTICAL HEADLIGHT AIMING

1 Before checking the vehicle for headlight aim, be sure that all the tires are at the correct inflation pressure, and that the suspension is in good working condition.

2 The headlight aim equipment will have to be adjusted for the slope of the floor in the service bay. Start the process by turning on the laser light generator on the side of the aimer body.



3 Place a yardstick or measuring tape vertically in front of the center of the front wheel, noting the height of the laser beam.



4 Move the yardstick to the center of the rear wheel and measure the height of the laser beam at this point. The height at the front and rear wheels should be the same.

5 If the laser beam height measurements are not the same, the floor slope of the aiming equipment must be adjusted. Turn the floor slope knob until the measurements are equal.

6 Place the aimer in front of the headlight to be checked, at a distance of 10 to 14 inches (25 to 35 cm). Use the aiming pointer to adjust the height of the aimer to the middle of the headlight.

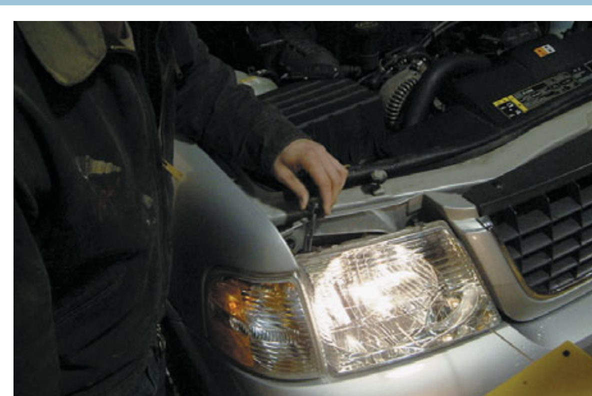
7 Align the aimer horizontally, using the pointer to place the aimer at the center of the headlight.

8 Lateral alignment (aligning the body of the aimer with the body of the vehicle) is done by looking through the upper visor. The line in the upper visor is aligned with symmetrical points on the vehicle body.

9 Turn on the vehicle headlights, being sure to select the correct beam position for the headlight to be aimed.

10 View the light beam through the aimer window. The position of the light pattern will be different for high and low beams.

11 If the first headlight is aimed adequately, move the aimer to the headlight on the opposite side of the vehicle. Follow the previous steps to position the aimer accurately.



12 If adjustment is required, move the headlight adjusting screws using a special tool or a 1/4-in. drive ratchet/socket combination. Watch the light beam through the aimer window to verify the adjustment.

SUMMARY

1. Automotive bulbs are identified by trade numbers.
2. The trade number is the same regardless of manufacturer for the exact same bulb specification.
3. Daytime running lights (DRLs) are used on many vehicles.
4. High-intensity discharge (HID) headlights are brighter and have a blue tint.
5. Turn signal flashers come in many different types and construction.

REVIEW QUESTIONS

1. Why should the exact same trade number of bulb be used as a replacement?
2. Why is it important to avoid touching a halogen bulb with your fingers?
3. How do you diagnose a turn signal operating problem?
4. How do you aim headlights on a vehicle equipped with aerodynamic-style headlights?

CHAPTER QUIZ

1. Technician A says that the bulb trade number is the same for all bulbs of the same size. Technician B says that a dual-filament bulb has different candlepower ratings for each filament. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing flasher units. Technician A says that only a DOT-approved flasher unit should be used for turn signals. Technician B says that a parallel (variable-load) flasher will function for turn signal usage, although it will not warn the driver if a bulb burns out. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Interior overhead lights (dome lights) are operated by door-jamb switches that ________.
   a. Complete the power side of the circuit
   b. Complete the ground side of the circuit
   c. Move the bulb(s) into contact with the power and ground
   d. Either a or b depending on application
4. Electrical feedback is usually a result of ________.
   a. Too high a voltage in a circuit
   b. Too much current (in amperes) in a circuit
   c. Lack of a proper ground
   d. Both a and b
5. According to Chart 21–1, which bulb is brightest?
   a. 194
   b. 168
   c. 194NA
   d. 1157
6. If a 1157 bulb were to be installed in a left front parking light socket instead of a 2057 bulb, what would be the most likely result?
   a. The left turn signal would flash faster.
   b. The left turn signal would flash slower.
   c. The left parking light would be slightly brighter.
   d. The left parking light would be slightly dimmer.
7. A technician replaced a 1157NA with a 1157A bulb. Which is the most likely result?
   a. The bulb is brighter because the 1157A candlepower is higher.
   b. The amber color of the bulb is a different shade.
   c. The bulb is dimmer because the 1157A candlepower is lower.
   d. Both b and c
8. A customer complained that every time he turned on his vehicle's lights, the left-side turn signal indicator light on the dash remained on. The most likely cause is a ________.
   a. Poor ground to the parking light (or taillight) bulb on the *left* side
   b. Poor ground to the parking light (or taillight) bulb on the *right* side, causing current to flow to the left-side lights
   c. Defective (open) parking light (or taillight) bulb on the left side
   d. Both a and c
9. A defective taillight or front park light bulb could cause the ________.
   a. Turn signal indicator on the dash to light when the lights are turned on
   b. Dash lights to come on when the brake lights are on
   c. Lights-on warning chime to sound if the brake pedal is depressed
   d. All of the above
10. A defective brake switch could prevent proper operation of the __________.
   a. Cruise control
   b. ABS brakes
   c. Shift interlock
   d. All of the above

chapter 22

DRIVER INFORMATION AND NAVIGATION SYSTEMS

OBJECTIVES: After studying Chapter 22, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "F" (Gauges, Warning Devices, and Driver Information System Diagnosis and Repair). • Be able to identify the meaning of dash warning symbols. • Discuss how a fuel gauge works. • Explain how to use a service manual to troubleshoot a malfunctioning dash instrument. • Describe how a navigation system works. • List the various types of dash instrument displays.

KEY TERMS: Backup camera 314 • CFL 307 • Combination valve 301 • CRT 307 • EEPROM 310 • GPS 311 • HUD 305 • IP 302 • LCD 306 • LDWS 316 • LED 306 • NVRAM 310 • Phosphor 307 • PM generator 308 • Pressure differential switch 301 • RPA 315 • Stepper motor 302 • VTF 307 • WOW display 307

DASH WARNING SYMBOLS

PURPOSE AND FUNCTION All vehicles are equipped with warning lights that are often confusing to drivers. Because many vehicles are sold throughout the world, symbols instead of words are being used as warning lights. The dash warning lights are often called *telltale* lights as they are used to notify the driver of a situation or fault.

BULB TEST When the ignition is first turned on, all of the warning lights come on as part of a self-test and to help the driver or technician spot any warning light that may be burned out. Technicians or drivers who are familiar with what lights should light may be able to determine if one or more warning lights are not on when the ignition is first turned on. Most factory scan tools can be used to command all of the warning lights on to help determine if one is not working.

ENGINE FAULT WARNING Engine fault warning lights include the following:

- **Engine coolant temperature.** This warning lamp should come on when the ignition is first turned on as a bulb check and if the coolant temperature reaches 248°F to 258°F (120°C to 126°C), depending on the make and model of the vehicle. ● **SEE FIGURE 22–1.**

  If the engine coolant temperature warning lamp comes on while driving, perform the following in an attempt to reduce the temperature.

1. Turn off the air conditioning.
2. Turn on the heater.

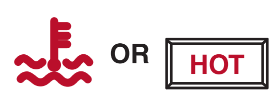


FIGURE 22–1 Engine coolant temperature is too high.

FIGURE 22–2 Engine oil pressure too low.

3. If the hot light remains on, drive to a safe location and shut off the engine and allow it to cool to help avoid serious engine damage.

- **Engine oil pressure.** This warning lamp should light when the ignition is first turned on as a bulb check; or if the engine oil pressure light comes on when driving, perform the following:

1. Pull off the road as soon as possible.
2. Shut off the engine.
3. Check the oil level.
4. Do not drive the vehicle with the engine oil light on or severe engine damage can occur.

● **SEE FIGURE 22–2.**

- **Water in diesel fuel warning.** This warning lamp will light when the ignition is first turned on as a bulb check and if water is detected in the diesel fuel. This lamp is only used or operational in vehicles equipped with a diesel engine. If the water in diesel fuel warning lamp comes on, do the following:

1. Remove the water using the built-in drain, usually part of the fuel filter.
2. Check service information for the exact procedure to follow.

● **SEE FIGURE 22–3.**

FIGURE 22–3 Water detected in fuel. Notice to drain the water from the fuel filter assembly on a vehicle equipped with a diesel engine.

FIGURE 22–4 Maintenance required. This usually means that the engine oil is scheduled to be changed or other routine service items replaced or checked.

FIGURE 22–5 Malfunction indicator lamp (MIL), also called a check engine light. The light means the engine control computer has detected a fault.

- **Maintenance required warning.** The maintenance required lamp comes on when the ignition is first turned on as a bulb check and if the vehicle requires service. The service required could include:

1. Oil and oil filter change
2. Tire rotation
3. Inspection

Check service information for the exact service required. ● **SEE FIGURE 22–4.**

- **Malfunction indicator lamp (MIL), also called a check engine or service engine soon (SES) light.** This warning lamp comes on when the ignition is first turned on as a bulb test and then only if a fault in the powertrain control module (PCM) has been detected. If the MIL comes on when driving, it is not necessary to stop the vehicle, but the cause for why the warning lamp came on should be determined as soon as possible to avoid harming the engine or engine control systems. The MIL could come on if any of the following has been detected.

1. A sensor or actuator is electrically open or shorted.
2. A sensor is out of range for expected values.
3. An emission control system failure occurs, such as a loose gas cap.

If the MIL is on, a diagnostic trouble code has been set. Use a scan tool to retrieve the code(s) and follow service information for the exact procedure to follow. ● **SEE FIGURE 22–5.**

FIGURE 22–6 Charging system fault detected.

FIGURE 22–7 Fasten safety belt warning light.

FIGURE 22–8 Fault detected in the supplemental restraint (airbag) system.

ELECTRICAL SYSTEM–RELATED WARNING LIGHTS

- **Charging system fault.** This warning lamp will come on when the ignition is first turned on as a bulb check and if a fault in the charging system has been detected. The lamp could include a fault with any of the following:

1. Battery state of charge (SOC), electrical connections, or the battery itself
2. Alternator or related wiring

● **SEE FIGURE 22–6.**

If the charge system warning lamp comes on, continue to drive until it is safe to pull over. The vehicle can usually be driven for several miles using battery power alone.

Check the following by visible inspection.

1. Alternator drive belt
2. Loose or corroded electrical connections at the battery
3. Loose or corroded wiring to the alternator
4. Defective alternator

SAFETY-RELATED WARNING LAMPS Safety-related warning lamps include the following

- **Safety belt warning lamp.** The safety belt warning lamp will light and sound an alarm to notify the driver if the driver's side or passenger's side safety belt is not fastened. It is also used to indicate a fault in the safety belt circuit. Check service information for the exact procedure to follow if the safety belt warning light remains on even when the belts are fastened. ● **SEE FIGURE 22–7.**
- **Airbag warning lamp.** The airbag warning lamp comes on and flashes when the ignition is first turned on as part of a self-test of the system. If the airbag warning lamp remains on after the self-test, then the airbag controller has detected a fault. Check service information for the exact procedure to follow if the airbag warning lamp is on. ● **SEE FIGURE 22–8.**

FIGURE 22–9 Fault detected in base brake system.

FIGURE 22–10 Brake light bulb failure detected.

FIGURE 22–11 Exterior light bulb failure detected.

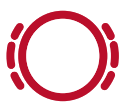


FIGURE 22–12 Worn brake pads or linings detected.

NOTE: The passenger side airbag light may indicate that it is on or off, depending if there is a passenger or an object heavy enough to trigger the seat sensor.

- **Red brake fault warning light.** All vehicles are equipped with a red brake warning (RBW) lamp that lights if a fault in the base (hydraulic) brake system is detected. Three types of sensors are used to light this warning light.
  1. A brake fluid level sensor located in the master cylinder brake fluid reservoir
  2. A pressure switch located in the pressure differential switch, which detects a difference in pressure between the front and rear or diagonal brake systems
  3. The parking brake could be applied. ● **SEE FIGURE 22–9.**

  If the red brake warning light comes on, do not drive the vehicle until the cause is determined and corrected.
- **Brake light bulb failure.** Some vehicles are able to detect if a brake light is burned out. The warning lamp will warn the driver when a situation like this occurs. ● **SEE FIGURE 22–10.**
- **Exterior light bulb failure.** Many vehicles use the body control module (BCM) to monitor current flow through all of the exterior lights and therefore can detect if a bulb is not working. ● **SEE FIGURE 22–11.**
- **Worn brake pads.** Some vehicles are equipped with sensors built into the disc brake pads that are used to trigger a dash warning light. The warning light often comes on when the ignition is first turned on as a bulb check and then goes out. If the brake pad warning lamp is on, check service information for the exact service procedure to follow. ● **SEE FIGURE 22–12.**

FIGURE 22–13 Fault detected in antilock brake system.

FIGURE 22–14 Low tire pressure detected.

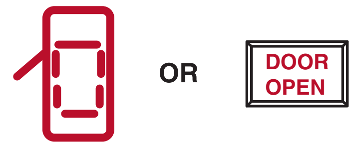


FIGURE 22–15 Door open or ajar.

TECH TIP

Check the Spare

Some vehicles that are equipped with a full-size spare tire also have a sensor in the spare. If the warning lamp is on and all four tires are properly inflated, check the spare.

- **Antilock brake system (ABS) fault.** The amber antilock brake system warning light comes on if the ABS controller detects a fault in the antilock braking system. Examples of what could trigger the warning light include:
  1. Defective wheel speed sensor
  2. Low brake fluid level in the hydraulic control unit assembly
  3. Electrical fault detected anywhere in the system

  ● **SEE FIGURE 22–13.**

  If the amber ABS warning lamp is on, it is safe to drive the vehicle, but the antilock portion may not function.
- **Low tire pressure warning.** A tire pressure monitoring system (TPMS) warns if the inflation pressure of a tire has decreased by 25% (about 8 psi). If the warning lamp or message of a low tire is displayed, check the tire pressures before driving. If the inflation pressure is low, repair or replace the tire. ● **SEE FIGURE 22–14.**

DRIVER INFORMATION SYSTEM

- **Door open or ajar warning light.** If a door is open or ajar, a warning light is used to notify the driver. Check and close all doors and tailgates before driving. ● **SEE FIGURE 22–15.**
- **Windshield washer fluid low.** A sensor in the windshield washer fluid reservoir is used to turn on the low washer fluid warning lamp. ● **SEE FIGURE 22–16.**
- **Low fuel warning.** A low fuel indicator light is used to warn the driver that the fuel level is low. In most vehicles,

FIGURE 22–16 Windshield washer fluid low.

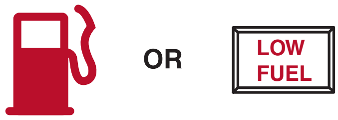


FIGURE 22–17 Low fuel level.

FIGURE 22–18 Headlights on.

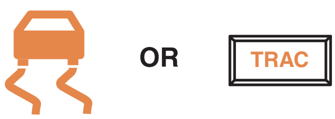


FIGURE 22–19 Low traction detected. Traction control system is functioning to restore traction (usually flashes when actively working to restore traction).

FIGURE 22–20 Vehicle stability control system either off or working if flashing.

the light comes on when there is between 1 and 3 gallons (3.8 and 11 liters) of fuel remaining. ● **SEE FIGURE 22–17.**

- **Headlights on light.** This dash indicator lights whenever the headlights are on. ● **SEE FIGURE 22–18.**

NOTE: This light may or may not indicate that the headlights are on if the headlight switch is set to the automatic position.

- **Low traction detected.** On a vehicle equipped with a traction control system (TCS), a dash indicator light is flashed whenever the system is working to restore traction. If the low traction warning light is flashing, reduce the rate of acceleration to help the system restore traction of the drive wheels with the road surface. ● **SEE FIGURE 22–19.**
- **Electronic stability control.** If a vehicle is equipped with electronic stability control (ESC), also called vehicle stability control (VSC), the dash indicator lamp will flash if the system is trying to restore vehicle stability. ● **SEE FIGURE 22–20.**
- **Traction off.** If the traction control system (TCS) is turned off by the driver, an indicator lamp lights to help remind the driver that this system has been turned off and will not be able to restore traction when lost. The system reverts to on, when the ignition is turned off, and then back on as the traction off button is depressed. ● **SEE FIGURE 22–21.**

FIGURE 22–21 Traction control system has been turned off.

FIGURE 22–22 Indicates that the cruise control is on and able to maintain vehicle speed if set.

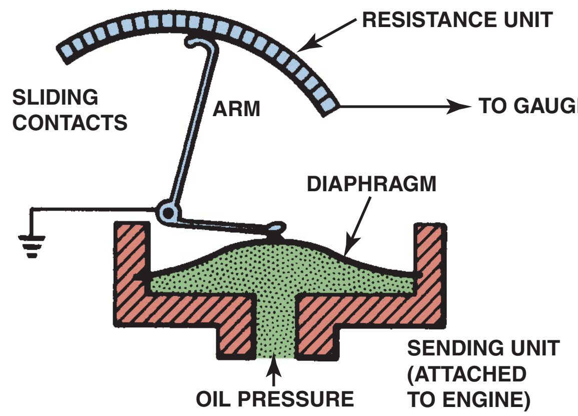


FIGURE 22–23 A typical oil pressure sending unit provides a varying amount of resistance as engine oil pressure changes. The output from the sensor is a variable voltage.

- **Cruise indicator lamp.** Most vehicles are equipped with a switch that turns on the cruise control. The cruise (speed) control system does not work unless it has been turned on to help prevent accidental engagement. When the cruise control has been turned on, the cruise indicator light is on. ● **SEE FIGURE 22–22.**

OIL PRESSURE WARNING DEVICES

OPERATION The oil pressure lamp operates through use of an oil pressure sensor unit, which is screwed into the engine block, and grounds the electrical circuit and lights the dash warning lamp in the event of low oil pressure, that is, 3 to 7 psi (20 to 50 kilopascals [kPa]). Normal oil pressure is generally between 10 and 60 psi (70 and 400 kPa). Some vehicles are equipped with a variable voltage oil pressure sensors rather than a simple pressure switch. ● **SEE FIGURE 22–23.**

OIL PRESSURE LAMP DIAGNOSIS To test the operation of the oil pressure warning circuit, unplug the wire from the oil pressure sending unit, usually located near the oil filter, with the ignition switch on. With the wire disconnected from the sending unit, the warning lamp should be off. If the wire is touched to a ground, the warning lamp should be on. If there is *any* doubt of the operation of the oil pressure warning lamp,

FIGURE 22–24 A temperature gauge showing normal operating temperature between 180°F and 215°F, depending on the specific vehicle and engine.

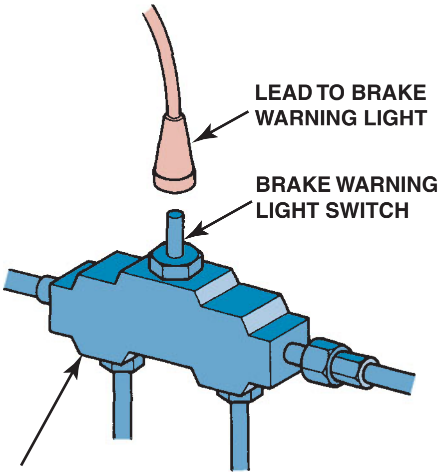


FIGURE 22–25 Typical brake warning light switch located on or near the master brake cylinder.

REAL WORLD FIX

The Low Oil Pressure Story

After replacing valve cover gaskets on a Chevrolet V-8, the technician discovered that the oil pressure warning lamp was on. After checking the oil level and finding everything else okay, the technician discovered a wire pinched under the valve cover.

The wire went to the oil pressure sending unit. The edge of the valve cover had cut through the insulation and caused the current from the oil lamp to go to ground through the engine. Normally the oil lamp comes on when the sending unit grounds the wire from the lamp.

The technician freed the pinched wire and covered the cut with silicone sealant to prevent corrosion damage.

always check the actual engine oil pressure using a gauge that can be screwed into the opening that is left after unscrewing the oil pressure sending unit. For removing the sending unit, special sockets are available at most auto parts stores, or a 1 in. or 1 1/16 in. 6-point socket may be used for most units.

TEMPERATURE LAMP DIAGNOSIS

The "hot" lamp, or engine coolant overheat warning lamp, warns the driver whenever the engine coolant temperature is between 248°F and 258°F (120°C and 126°C). This temperature is slightly below the boiling point of the coolant in a properly operating cooling system. The temperature sensor on older models was separate from the sensor used by the engine computer. However, most vehicles now use the engine coolant temperature (ECT) sensor for engine temperature gauge operation. To test this sensor, use a scan tool to verify proper engine temperature and follow the vehicle manufacturer's recommended testing procedures. ● **SEE FIGURE 22–24.**

BRAKE WARNING LAMP

All vehicles sold in the United States after 1967 must be equipped with a dual braking system and a dash-mounted warning lamp to signal the driver of a failure in one part of the hydraulic brake system. The switch that operates the warning lamp is called a **pressure differential switch**. This switch is usually the center portion of a multipurpose brake part called a **combination valve**. If there is unequal hydraulic pressure in the braking system, the switch usually provides a ground path for the brake warning lamp, and the lamp comes on. ● **SEE FIGURE 22–25.**

Unfortunately, the dash warning lamp is often the same lamp as that used to warn the driver that the parking brake is on. The warning lamp is usually operated by using the parking brake lever or brake hydraulic pressure switch to complete the ground for the warning lamp circuit. If the warning lamp is on, first check if the parking brake is fully released. If the parking brake is fully released, the problem could be a defective parking brake switch or a hydraulic brake problem. To test for which system is causing the lamp to remain on, simply unplug the wire from the valve or switch. If the wire on the pressure differential switch is disconnected and the warning lamp remains on, then the problem is due to a defective or misadjusted parking brake switch. If, however, the warning lamp goes out when the wire is removed from the brake switch, then the problem is due to a hydraulic brake fault that caused the pressure differential switch to complete the warning lamp circuit. The red brake warning

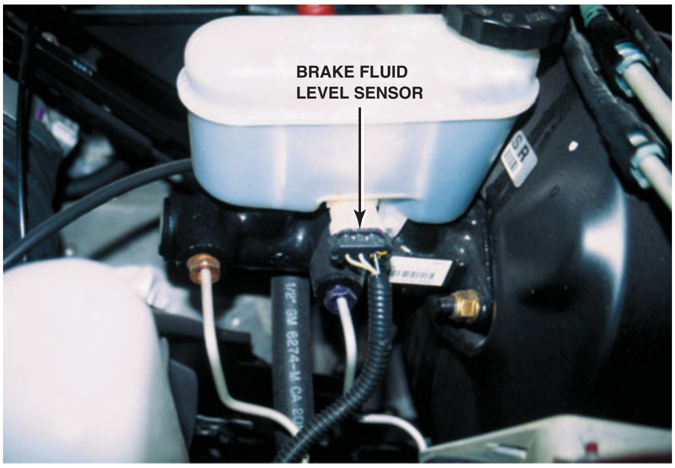


FIGURE 22–26 The red brake warning lamp can be turned on if the brake fluid level is low.

lamp also can be turned on if the brake fluid is low. ● **SEE FIGURE 22–26** for an example of a brake fluid level sensor.

ANALOG DASH INSTRUMENTS

An analog display uses a needle to show the value, whereas a digital display uses numbers. Analog electromagnetic dash instruments use small electromagnetic coils that are connected to a sending unit for such things as fuel level, water temperature, and oil pressure. The sensors are the same regardless of the type of display used. The resistance of the sensor varies with what is being measured. ● **SEE FIGURE 22–27** for typical electromagnetic fuel gauge operation.

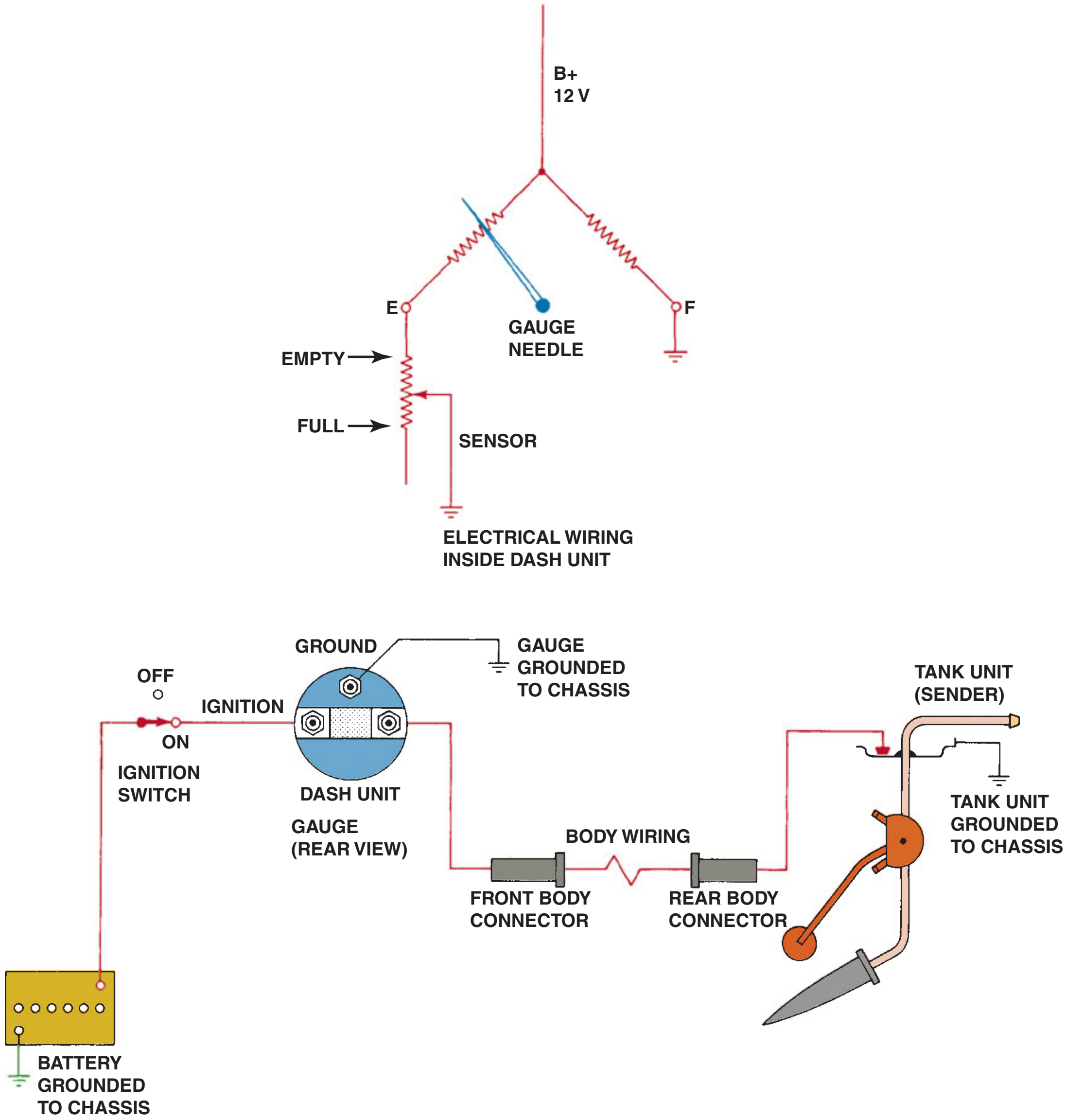


FIGURE 22–27 Electromagnetic fuel gauge wiring. If the sensor wire is unplugged and grounded, the needle should point to “E” (empty). If the sensor wire is unplugged and held away from ground, the needle should point to “F” (full).

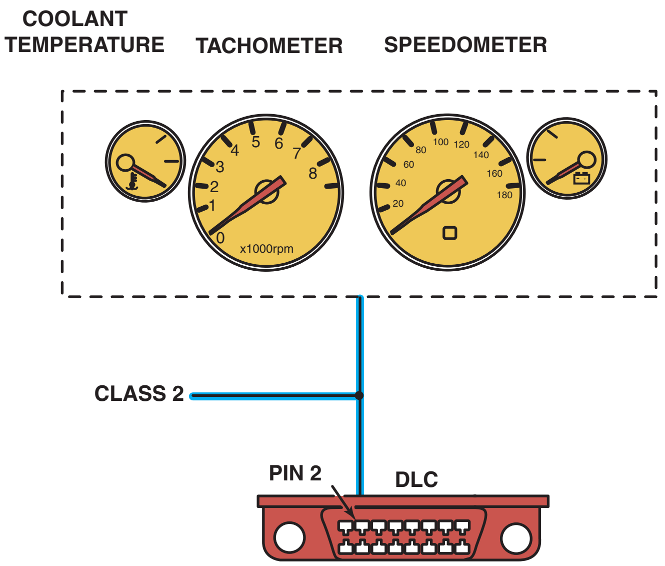


FIGURE 22–28 A typical instrument display uses data from the sensors over serial data lines to the individual gauges.

NETWORK COMMUNICATION

DESCRIPTION Many instrument panels are operated by electronic control units that communicate with the engine control computer for engine data such as revolutions per minute (RPM) and engine temperature. These electronic **instrument panels (IPs)** use the voltage changes from variable-resistance sensors, such as that of the fuel gauge, to determine fuel level. Therefore, even though the sensor in the fuel tank is the same, the display itself may be computer controlled. The data is transmitted to the instrument cluster as well as to the powertrain control module through serial data lines. Because all sensor inputs are interconnected, the technician should always follow the factory recommended diagnostic procedures. ● **SEE FIGURE 22–28.**

STEPPER MOTOR ANALOG GAUGES

DESCRIPTION Most analog dash displays use a stepper motor to move the needle. A **stepper motor** is a type of electric motor that is designed to rotate in small steps based on the signal from a computer. This type of gauge is very accurate.

OPERATION A digital output is used to control stepper motors. Stepper motors are direct current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion. When using a stepper motor that is controlled by the PCM, it is very easy for the PCM to keep track of the stepper motor's position. By counting the number of steps that have been sent to the stepper motor, the PCM can determine its relative position. While the PCM does not actually receive a feedback signal from the stepper motor, it knows how many steps forward or backward the motor should have moved.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate 90 degrees at a time. Each 90-degree pulse is recorded by the computer as a "count" or "step," which explains the name given to this type of motor. ● **SEE FIGURE 22–29.**

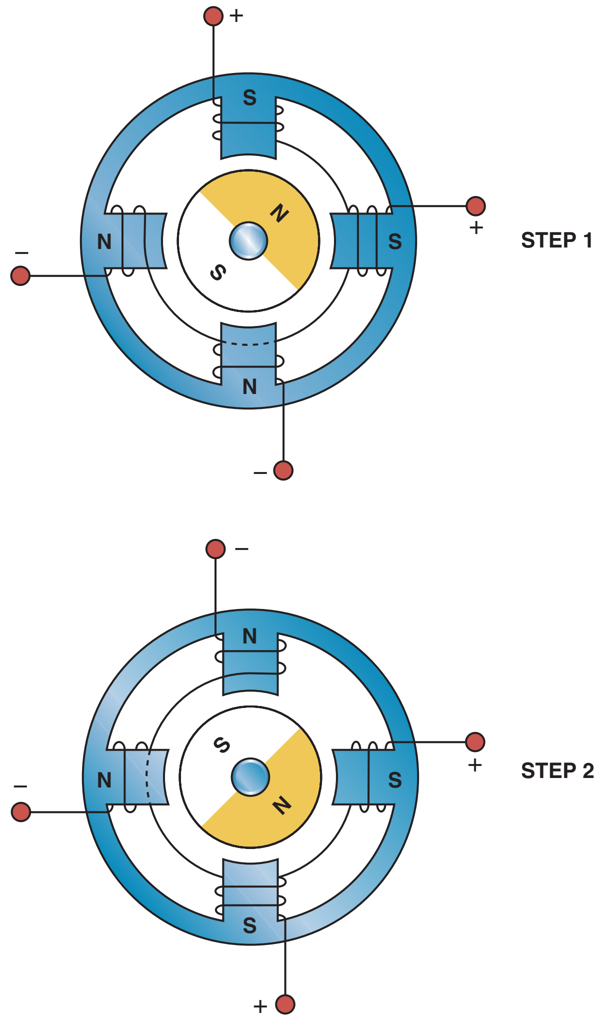


FIGURE 22–29 Most stepper motors use four wires which are pulsed by the computer to rotate the armature in steps.

NOTE: Many electronic gauge clusters are checked at key on where the dash display needles will be commanded to 1/4, 1/2, 3/4, and full positions before returning to their normal readings. This self-test allows the service technician to check the operation of each individual gauge, even though replacing the entire instrument panel cluster is usually necessary to repair an inoperative gauge.

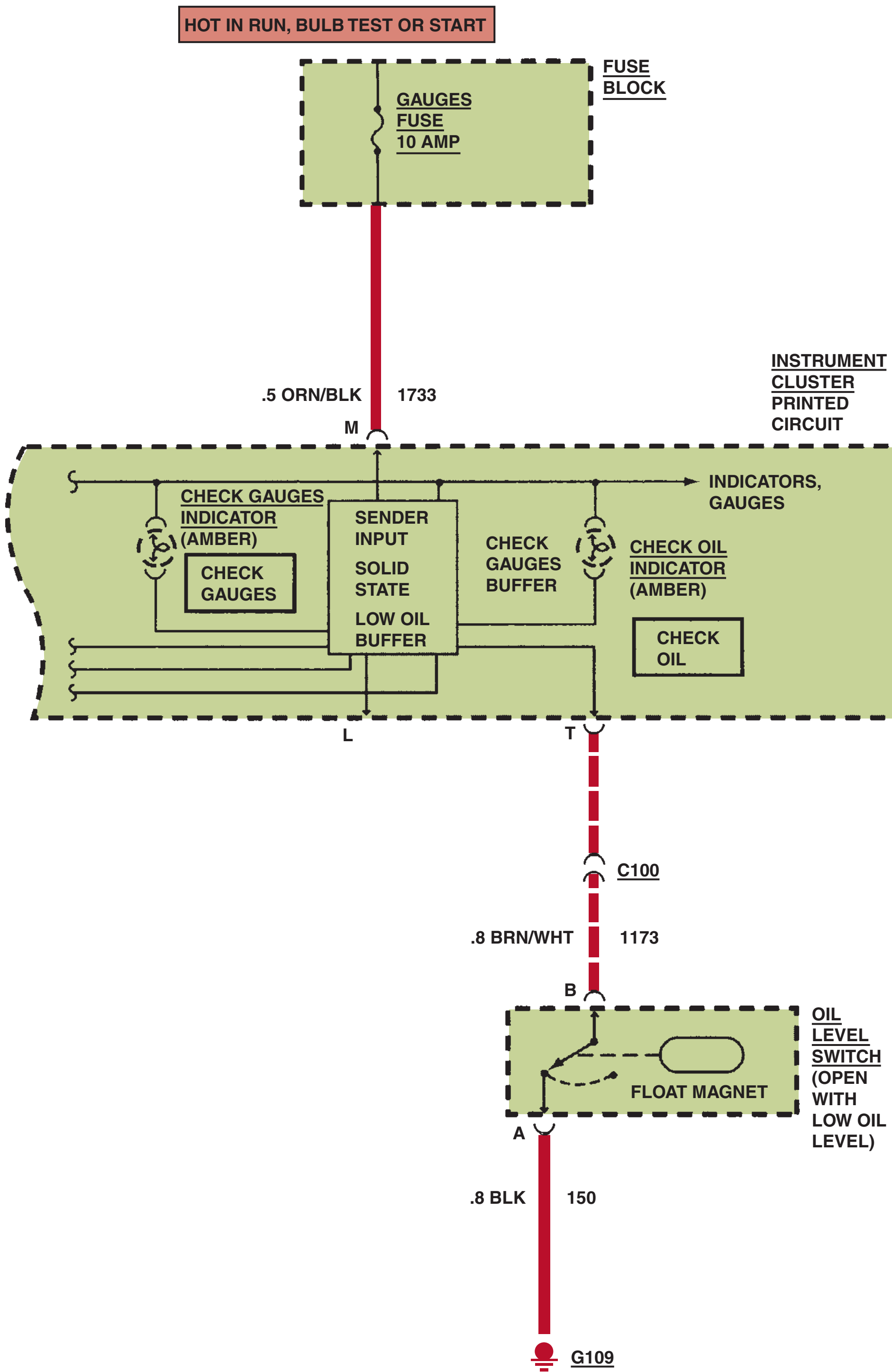


FIGURE 22–30 The ground for the "check oil" indicator lamp is controlled by the electronic low-oil buffer. Even though this buffer is connected to an oil level sensor, the buffer also takes into consideration the amount of time the engine has been stopped and the temperature of the engine. The only way to properly diagnose a problem with this circuit is to use the procedures specified by the vehicle manufacturer. Besides, only the engineer who designed the circuit knows for sure how it is supposed to work.

DIAGNOSIS The dash electronic circuits are often too complex to show on a wiring diagram. Instead, all related electronic circuits are simply indicated as a solid box with "electronic module" printed on the diagram. Even if all the electronic circuits were shown on the wiring diagram, it would require the skill of an electronics engineer to determine exactly how the circuit was designed to work. ● **SEE FIGURE 22–30.**

Note that the grounding for the "check oil" dash indicator lamp is accomplished through an electronic buffer. The exact conditions, such as amount of time since the ignition was shut off, are unknown to the technician. To correctly diagnose problems with this type of circuit, technicians must read, understand, and follow the written diagnostic procedures specified by the vehicle manufacturer.

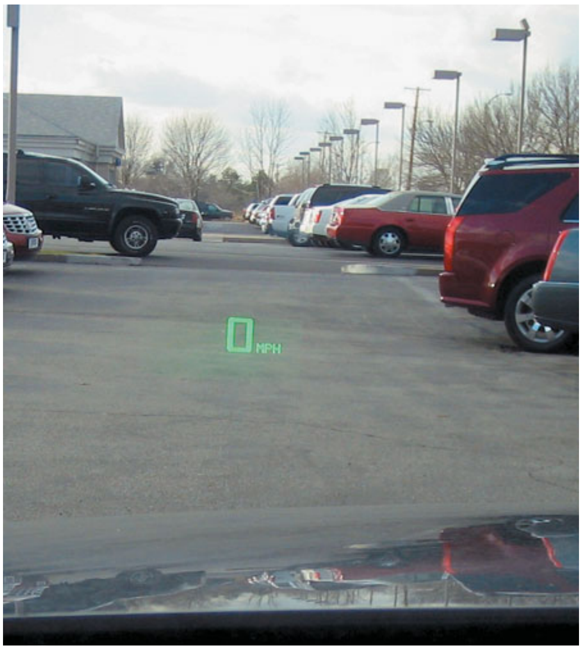


FIGURE 22–31 A typical head-up display showing zero miles per hour, which is actually projected on the windshield from the head-up display in the dash.

HEAD-UP DISPLAY

The **head-up display (HUD)** is a supplemental display that projects the vehicle speed and sometimes other data, such as turn signal information, onto the windshield. The projected image looks as if it is some distance ahead, making it easy for the driver to see without having to refocus on a closer dash display. ● **SEE FIGURES 22–31 AND 22–32.**

The head-up display can also have the brightness controlled on most vehicles that use this type of display. The HUD unit is installed in the instrument panel (IP) and uses a mirror to project vehicle information onto the inside surface of the windshield. ● **SEE FIGURE 22–33.**

Follow the vehicle manufacturer's recommended diagnostic and testing procedures if any faults are found with the head-up display.

NIGHT VISION

PARTS AND OPERATION Night vision systems use a camera that is capable of observing objects in the dark to assist the driver while driving at night. The primary night viewing illumination devices are the headlights. The night vision option uses a head-up display (HUD) to improve the vision of the driver beyond the scope of the headlights. Using a HUD display allows the driver to keep eyes on the road and hands on the wheel for maximum safety.

FIGURE 22–32 The dash-mounted control for the head-up display on this Cadillac allows the driver to move the image up and down on the windshield for best viewing.

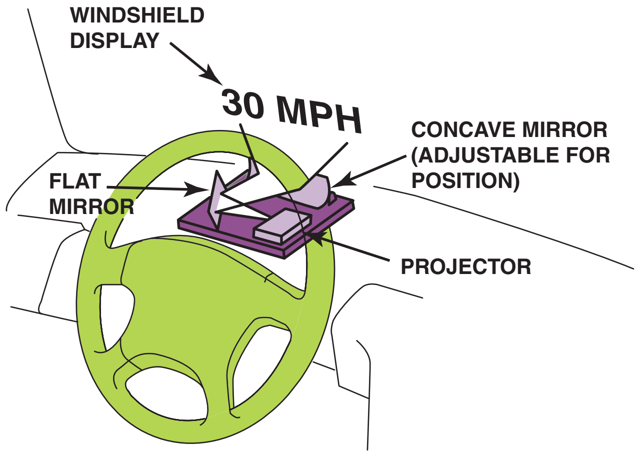


FIGURE 22–33 A typical head-up display (HUD) unit.

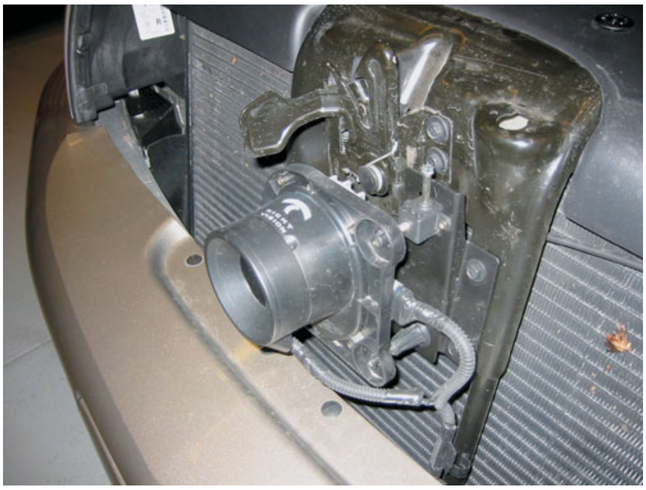


FIGURE 22–34 A night vision camera behind the grille of a Cadillac.

Besides the head-up display, the night vision camera uses a special thermal imaging or infrared technology. The camera is mounted behind the grill in the front of the vehicle. ● **SEE FIGURE 22–34.**

The camera creates pictures based on the heat energy emitted by objects rather than from light reflected on an object as in a normal optical camera. The image looks like a black and white photo negative when hot objects (higher thermal energy) appear light or white, and cool objects appear dark or black. Other parts of the night vision system include:

- **On/off and dimming switch.** This allows the driver to adjust the brightness of the display and to turn it on or off as needed.
- **Up/down switch.** The night vision HUD system has an electric tilt adjust motor that allows the driver to adjust the image up or down on the windshield within a certain image.

CAUTION: Becoming accustomed to night vision can be difficult and may take several nights to get used to looking at the head-up display.

DIAGNOSIS AND SERVICE The first step when diagnosing a fault with the night vision system is to verify the concern. Check the owner manual or service information for proper operation. For example, the Cadillac night vision system requires the following actions to function.

1. The ignition has to be in the on (run) position.
2. The Twilight Sentinel photo cell must indicate that it is dark.
3. The headlights must be on.
4. The switch for the night vision system must be on and the brightness adjusted so the image is properly displayed.

The night vision system uses a camera in the front of the vehicle that is protected from road debris by a grille. However, small stones or other debris can get past the grille and damage the lens of the camera. If the camera is damaged, it must be replaced as an assembly because no separate parts are available. Always follow the vehicle manufacturer's recommended testing and servicing procedures.

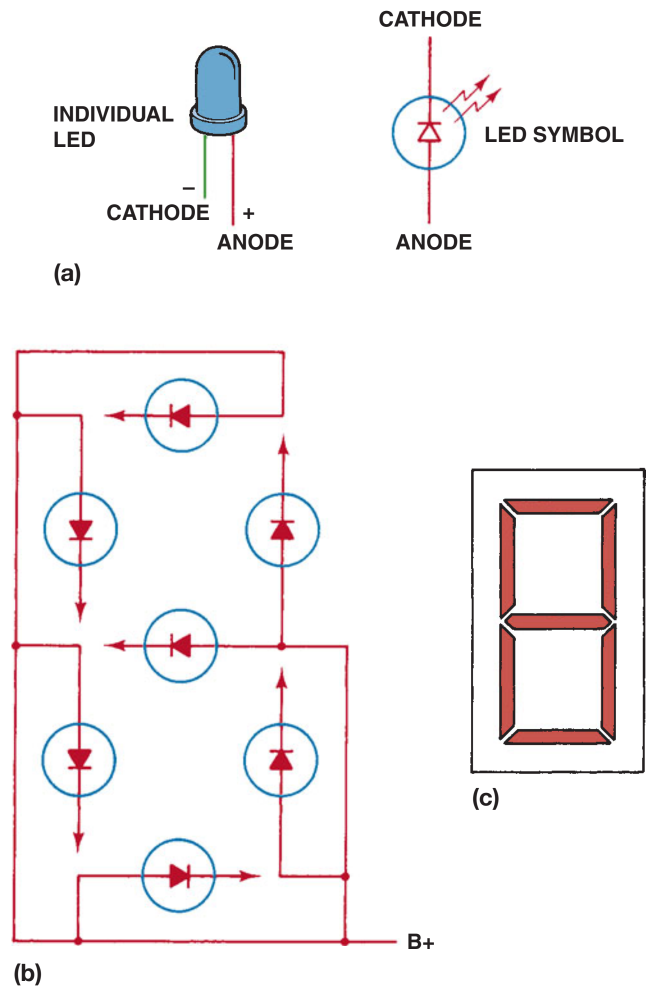


FIGURE 22–35 (a) Symbol and line drawing of a typical light-emitting diode (LED). (b) Grouped in seven segments, this array is called a seven-segment LED display with a common anode (positive connection). The dash computer toggles the cathode (negative) side of each individual segment to display numbers and letters. (c) When all segments are turned on, the number 8 is displayed.

DIGITAL ELECTRONIC DISPLAY OPERATION

TYPES

- Mechanical or electromechanical dash instruments use cables, mechanical transducers, and sensors to operate a particular dash instrument.
- Digital dash instruments use various electric and electronic sensors that activate segments or sections of an electronic display. Most electronic dash clusters use a computer chip and various electronic circuits to operate and control the internal power supply, sensor voltages, and display voltages.
- Electronic dash display systems may use one or more of several types of displays: light-emitting diode (LED), liquid crystal display (LCD), vacuum tube fluorescent (VTF), and cathode ray tube (CRT).

LED DIGITAL DISPLAYS All diodes emit some form of energy during operation; the **light-emitting diode (LED)** is a semiconductor that is constructed to release energy in the form of light. Many colors of LEDs can be constructed, but the most popular are red, green, and yellow. Red is difficult to see in direct sunlight; therefore, if an LED is used, most vehicle manufacturers use yellow. Light-emitting diodes can be arranged in a group of seven, which then can be used to display both numbers and letters. ● **SEE FIGURE 22–35.**

An LED display requires more electrical power than other types of electronic displays. A typical LED display requires 30 mA for each *segment;* therefore, each number or letter displayed could require 210 mA (0.210 A).

LIQUID CRYSTAL DISPLAYS **Liquid crystal displays (LCDs)** can be arranged into a variety of forms, letters, numbers, and bar graph displays.

FIGURE 22–36 A typical navigation system. This Honda/Acura system uses some of the climate control functions as well as the trip information on the display. This particular unit uses a DVD unit in the trunk along with a global positioning satellite (GPS) to display a map and your exact location for the entire country.

- LCD construction consists of a special fluid sandwiched between two sheets of polarized glass. The special fluid between the glass plates will permit light to pass if a small voltage is applied to the fluid through a conductive film laminated to the glass plates.
- The light from a very bright halogen bulb behind the LCD shines through those segments of the LCD that have been polarized to let the light through, which then show numbers or letters. Color filters can be placed in front of the display to change the color of certain segments of the display, such as the maximum engine speed on a digital tachometer.

CAUTION: Be careful, when cleaning an LCD, not to push on the glass plate covering the special fluid. If excessive pressure is exerted on the glass, the display may be permanently distorted. If the glass breaks, the fluid will escape and could damage other components in the vehicle as a result of its strong alkaline nature. Use only a soft, damp cloth to clean these displays.

- The major disadvantage of an LCD digital dash is that the numbers or letters are slow to react or change at low temperatures. ● **SEE FIGURE 22–36.**

VACUUM TUBE FLUORESCENT DISPLAYS The **vacuum tube fluorescent (VTF)** display is a popular automotive and household appliance display because it is very bright and can easily be viewed in strong sunlight. The usual VTF display is green, but white is often used for home appliances.

- The VTF display generates its bright light in a manner similar to that of a TV screen, where a chemical-coated light-emitting element called a **phosphor** is hit with high-speed electrons.
- VTF displays are very bright and must be dimmed by use of dense filters or by controlling the voltage applied to the display. A typical VTF dash is dimmed to 75% brightness whenever the parking lights or headlights are turned on. Some displays use a photocell to monitor and adjust the intensity of the display during daylight viewing. Most VTF displays are green for best viewing under most lighting conditions.

CATHODE RAY TUBE A **cathode ray tube (CRT)** dash display, which is similar to a television tube or LCD display, permits the display of hundreds of controls and diagnostic messages in one convenient location.

Using the touch-sensitive cathode ray tube, the driver or technician can select from many different displays, including those of radio, climate, trip, and dash instrument information. The driver can readily access all of these functions. Further diagnostic information can be displayed on the CRT if the proper combination of air-conditioning controls is touched. The diagnostic procedures for these displays involve pushing two or more buttons at the same time to access the diagnostic menu. Always follow the factory service manual recommendations.

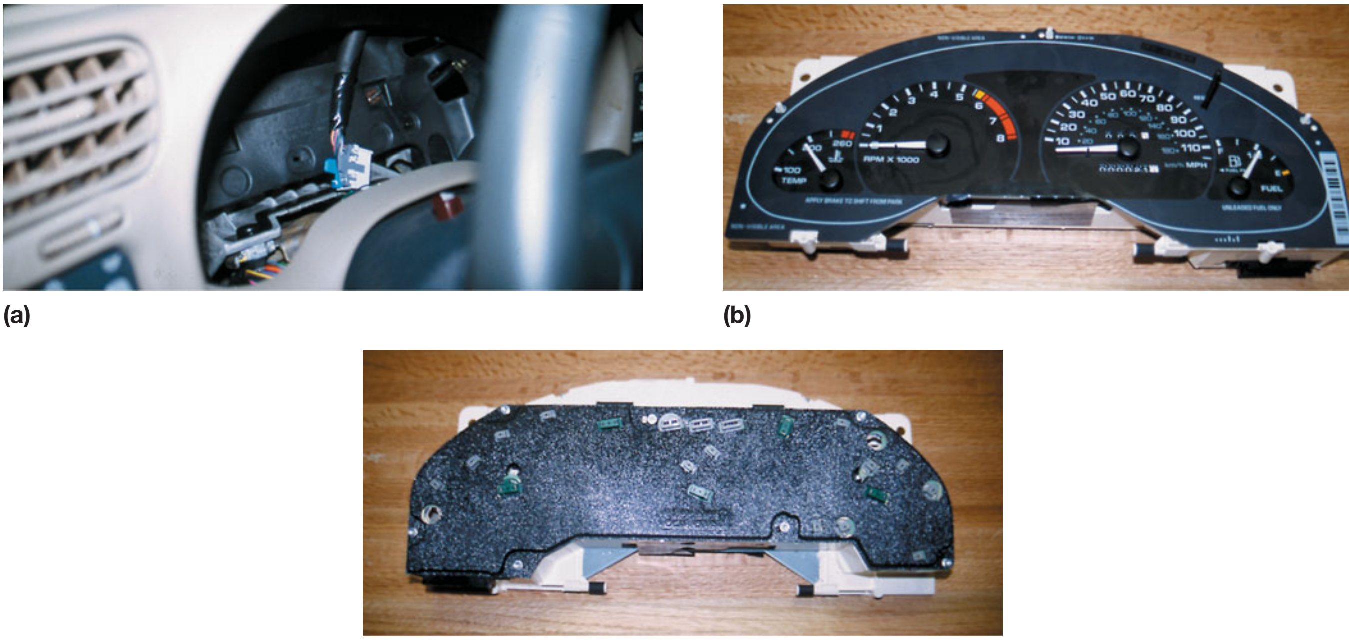
COLD CATHODE FLUORESCENT DISPLAYS Cold **cathode fluorescent lighting (CFL)** models are used by many vehicle manufacturers for backlighting. Current consumption ranges from 3 to 5 mA (0.003 to 0.005 A) with an average life of 40,000 hours. CFL is replacing conventional incandescent light bulbs.

ELECTRONIC ANALOG DISPLAYS Most analog dash displays since the early 1990s are electronically or computer controlled. The sensors may be the same, but the sensor information is sent to the body or vehicle computer through a data BUS, and then the computer controls current through small electromagnets that move the needle of the gauge. ● **SEE FIGURE 22–37.** A scan tool often is needed to diagnosis the operation of a computer-controlled analog dash instrument display.

WOW DISPLAY When a vehicle equipped with a digital dash is started, all segments of the electronic display are turned on at full brilliance for 1 or 2 seconds. This is commonly called the **WOW display,** and is used to show off the brilliance of the display. If numbers are part of the display, the number 8 is shown, because this number uses all segments of a number display. Technicians can also use the WOW display to determine if all segments of the electronic display are functioning correctly.

ELECTRONIC SPEEDOMETERS

OPERATION Electronic dash displays ordinarily use an electric vehicle speed sensor driven by a small gear on the output shaft of the transmission. These speed sensors



(a) (b) (c)

FIGURE 22–37 (a) View of the vehicle dash with the instrument cluster removed. Sometimes the dash instruments can be serviced by removing the padded dash cover (crash pad) to gain access to the rear of the dash. (b) The front view of the electronic analog dash display. (c) The rear view of the dash display showing that there are a few bulbs that can be serviced, but otherwise the unit is serviced as an assembly.

TECH TIP

The Bulb Test

Many ignition switches have six positions. Notice the *bulb test* position (between "on" and "start"). When the ignition is turned to "on" (run), some dash warning lamps are illuminated. When the bulb test position is reached, additional dash warning lamps often are lighted. Technicians use this ignition switch position to check the operation of fuses that protect various circuits. Dash warning lamps are not all powered by the same fuses. If an electrical component or circuit does not work, the power side (fuse) can be quickly checked by observing the operation of the dash lamps that share a common fuse with the problem circuit. Consult a wiring diagram for fuse information on the exact circuit being tested. ● **SEE FIGURES 22–38 AND 22–39.**

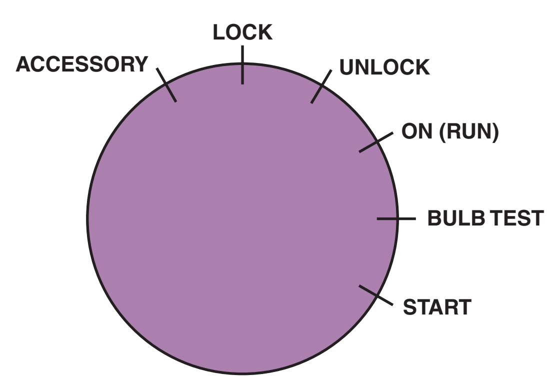


FIGURE 22–38 Typical ignition switch positions. Notice the bulb check position between "on" (run) and "start." These inputs are often just voltage signal to the body control module and can be checked using a scan tool.

contain a permanent magnet and generate a voltage in proportion to the vehicle speed. These speed sensors are commonly called **permanent magnet (PM) generators**. ● **SEE FIGURE 22–40.**

The output of a PM generator speed sensor is an AC voltage that varies in frequency and amplitude with increasing vehicle speed. The PM generator speed signal is sent to the instrument cluster electronic circuits. These specialized electronic circuits include a buffer amplifier circuit that converts the variable sine wave voltage from the speed sensor to an on/off signal that can be used by other electronic circuits to indicate a vehicle's speed. The vehicle speed is then displayed by either an electronic needle-type speedometer or by numbers on a digital display.

FIGURE 22–39 Many newer vehicles place the ignition switch on the dash and incorporate antitheft controls. Note the location of the accessory position.

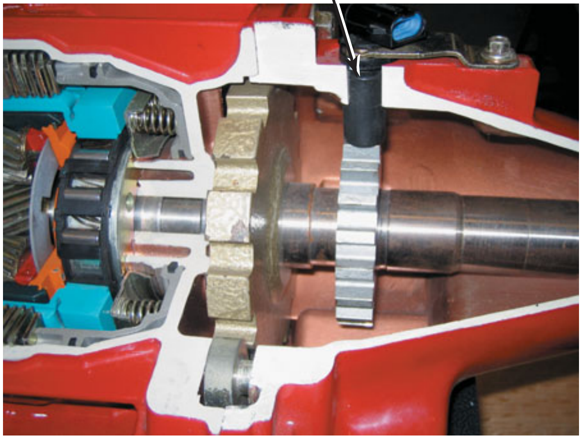


FIGURE 22–40 A vehicle speed sensor located in the extension housing of the transmission. Some vehicles use the wheel speed sensors for vehicle speed information.

REAL WORLD FIX

The Speedometer Works as if It Is a Tachometer

The owner of a Lincoln Town Car complained that all of a sudden the speedometer needle went up and down with engine speed rather than vehicle speed. In fact, the speedometer needle went up and down with engine speed even though the gear selector was in "park" and the vehicle was not moving. After hours of troubleshooting, the service technician went back and started checking the basics and discovered that the alternator had a bad diode. The technician measured over 1 volt AC and over 10 amperes AC ripple current using a clamp-on AC/DC ammeter. Replacing the alternator restored the proper operation of the speedometer.

TECH TIP

The Soldering Gun Trick

Diagnosing problems with digital or electronic dash instruments can be difficult. Replacement parts generally are expensive and usually not returnable if installed in the vehicle. A popular trick that helps isolate the problem is to use a soldering gun near the PM generator.

A PM generator contains a coil of wire. As the magnet inside revolves, a voltage is produced. It is the *frequency* of this voltage that the dash (or engine) computer uses to calculate vehicle speed.

A soldering gun plugged into 110 volts AC will provide a strong *varying* magnetic field around the soldering gun. This magnetic field is constantly changing at the rate of 60 cycles per second. This frequency of the magnetic field induces a voltage in the windings of the PM generator. This induced voltage at 60 hertz (Hz) is converted by the computer circuits to a miles per hour (mph) reading on the dash.

To test the electronic speedometer, turn the ignition to "on" (engine off) and hold a soldering gun near the PM generator.

CAUTION: The soldering gun tip can get hot, so hold it away from wiring or other components that may be damaged by the hot tip.

If the PM generator, wiring, computer, and dash are okay, the speedometer should register a speed, usually 54 mph (87 km/h). If the speedometer does not work when the vehicle is driven, the problem is in the PM generator drive.

If the speedometer does not register a speed when the soldering gun is used, the problem could be caused by the following:

1. Defective PM generator (check the windings with an ohmmeter)
2. Defective (open or shorted) wiring from the PM generator to the computer
3. Defective computer or dash circuit

ELECTRONIC ODOMETERS

PURPOSE AND FUNCTION An odometer is a dash display that indicates the total miles traveled by the vehicle. Some dash displays also include a trip odometer that can be reset and used to record total miles traveled on a trip or the distance traveled between fuel stops. Electronic dash displays can use either an electrically driven mechanical odometer or a digital display odometer to indicate miles traveled. On mechanical

REAL WORLD FIX

The Toyota Truck Story

The owner of a Toyota truck complained that several electrical problems plagued the truck, including the following:

1. The cruise (speed) control would kick out intermittently.
2. The red brake warning lamp would come on, especially during cold weather.

The owner had replaced the parking brake switch, thinking that was the cause of the red brake warning lamp coming on.

An experienced technician checked the wiring diagram in service information. Checking the warning lamp circuit, the technician noticed that the same wire went to the brake fluid level sensor. The brake fluid was at the minimum level. Filling the master cylinder to the maximum level with clean brake fluid solved both problems. The electronics of the cruise control stopped operation when the red brake warning lamp was on as a safety measure.

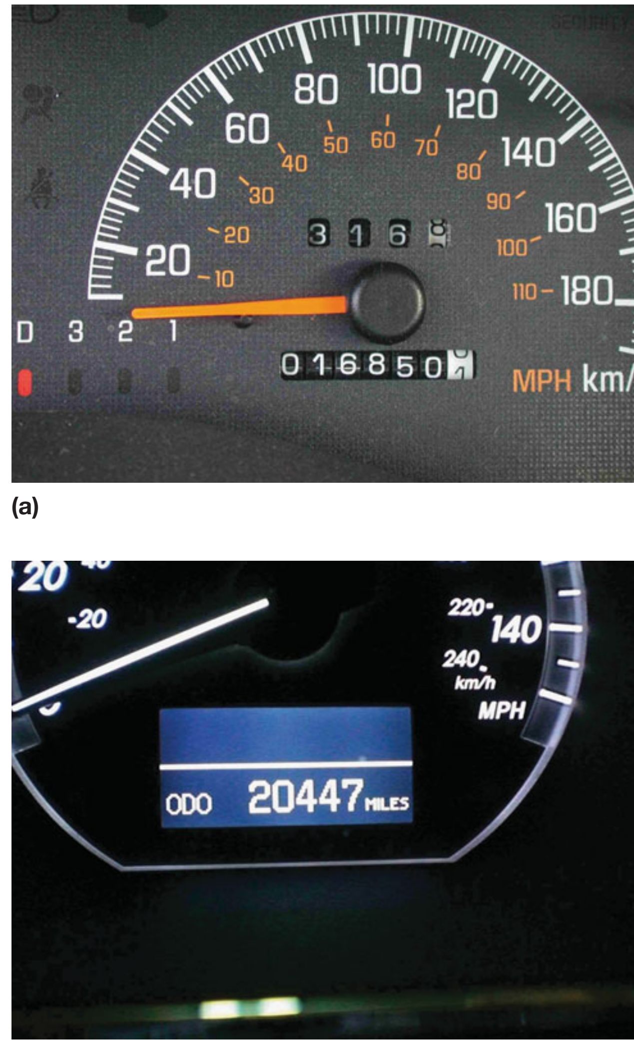
REAL WORLD FIX

Look for Previous Repairs

A technician was asked to fix the speedometer on a Pontiac Grand Am that showed approximately double the actual speed. Previous repairs had included a new vehicle speed (VS) sensor and computer. Nothing made any difference. The customer stated that the problem happened all of a sudden. After hours of troubleshooting, the customer just happened to mention that the automatic transaxle had been repaired shortly before the speedometer problem. The root cause of the problem was discovered when the technician learned that a final drive assembly from a 4T60-E transaxle had been installed on the 3T-40 transaxle. The 4T60-E final drive assembly has 13 reluctor teeth whereas the 3T-40 has 7 teeth. This difference in the number of teeth caused the speedometer to read almost double the actual vehicle speed. After the correct part was installed, the speedometer worked correctly. The technician now always asks if there has been any recent work performed in the vehicle prior to any diagnosis.

type odometers, a small electric motor, called a stepper motor, is used to turn the number wheels of a mechanical-style odometer. A pulsed voltage is fed to this stepper motor, which moves in relation to the miles traveled. ● **SEE FIGURE 22–41.**

Digital odometers use LED, LCD, or VTF displays to indicate miles traveled. Because total miles must be retained when the ignition is turned off or the battery is disconnected, a special electronic chip must be used that will retain the miles traveled.



(a)

(b)

FIGURE 22–41 (a) Some odometers are mechanical and are operated by a stepper motor. (b) Many vehicles are equipped with an electronic odometer.

These special chips are called **nonvolatile random-access memory (NVRAM).** *Nonvolatile* means that the information stored in the electronic chip is not lost when electrical power is removed. Some vehicles use a chip called **electronically erasable programmable read-only memory (EEPROM).** Most digital odometers can read up to 999,999.9 miles or kilometers (km), and then the display indicates error. If the chip is damaged or exposed to static electricity, it may fail to operate and "error" may appear.

SPEEDOMETER/ODOMETER SERVICE If the speedometer and odometer fail to operate, check the following:

- The speed sensor should be the first item checked. With the vehicle safely raised off the ground and supported, check vehicle speed using a scan tool. If a scan tool is not available, disconnect the wires from the speed sensor near the output shaft of the transmission. Connect a multimeter

REAL WORLD FIX

Electronic Devices Cannot Swim

The owner of a Dodge minivan complained that after the vehicle was cleaned inside and outside, the temperature gauge, fuel gauge, and speedometer stopped working. The vehicle speed sensor was checked and found to be supplying a square wave signal that changed with vehicle speed. A scan tool indicated a speed, yet the speedometer displayed zero all the time. Finally, the service technician checked the body computer to the right of the accelerator pedal and noticed that it had been wet, from the interior cleaning. Drying the computer did not fix the problem, but a replacement body computer fixed all the problems. The owner discovered that electronic devices do not like water and that computers cannot swim.

set on AC volts to the terminals of the speed sensor and rotate the drive wheels with the transmission in neutral. A good speed sensor should indicate approximately 2 volts AC if the drive wheels are rotated by hand.

- If the speed sensor is working, check the wiring from the speed sensor to the dash cluster. If the wiring is good, the instrument panel (IP) should be sent to a specialty repair facility.
- If the speedometer operates correctly but the mechanical odometer does not work, the odometer stepper motor, the number wheel assembly, or the circuit controlling the stepper motor is defective. If the digital odometer does not operate but the speedometer operates correctly, then the dash cluster must be removed and sent to a specialized repair facility. A replacement chip is available only through authorized sources; if the odometer chip is defective, the original number of miles must be programmed into the replacement chip.

ELECTRONIC FUEL LEVEL GAUGES

OPERATION Electronic fuel level gauges ordinarily use the same fuel tank sending unit as that used on conventional fuel gauges. The tank unit consists of a float attached to a variable resistor. As the fuel level changes, the resistance of the sending unit changes. As the resistance of the tank unit changes, the dash-mounted gauge also changes. The only difference between a digital fuel level gauge and a conventional needle type is in the display. Digital fuel level gauges can be either numerical (indicating gallons or liters remaining in the tank) or a bar graph display. ● **SEE FIGURE 22–42.**

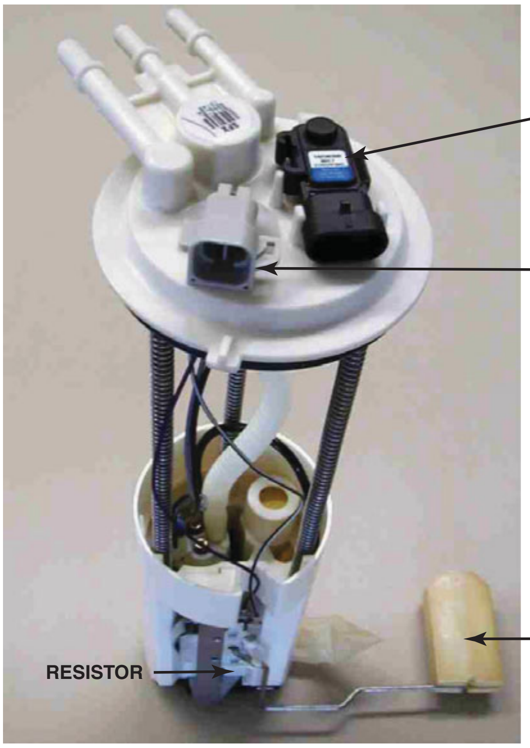


FIGURE 22–42 A fuel tank module assembly that contains the fuel pump and fuel level sensor in one assembly.

The diagnosis of a problem is the same as that described earlier for conventional fuel gauges. If the tests indicate that the dash unit is defective, usually the *entire* dash gauge assembly must be replaced.

NAVIGATION AND GPS

PURPOSE AND FUNCTION The **global positioning system (GPS)** uses 24 satellites in orbit around the earth to provide signals for navigation devices. GPS is funded and controlled by the U.S. Department of Defense (DOD). While the system can be used by anyone with a GPS receiver, it was designed for and is operated by the U.S. military. ● **SEE FIGURE 22–43.**

BACKGROUND The current global positioning system was developed after a civilian airplane from Korean Airlines, Flight 007, was shot down as it flew over Soviet territory in 1983. The system became fully operational in 1991. Civilians were granted use of GPS that same year, but with less accuracy than the system used by the military.

Until 2000, the nonmilitary use of GPS was purposely degraded by a computer program called selection availability (S/A) built into the satellite transmission signals. After 2000, the S/A has been officially turned off, allowing nonmilitary users more accurate position information from the GPS receivers.

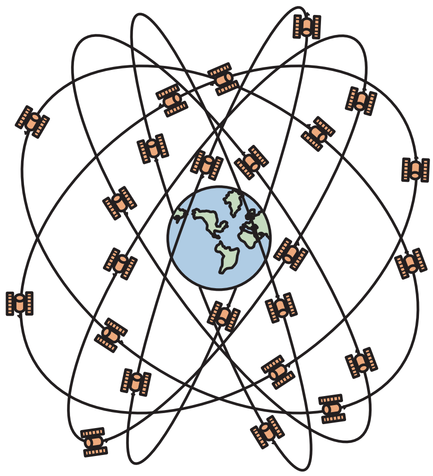


FIGURE 22–43 Global positioning systems use 24 satellites in high earth orbit whose signals are picked up by navigation systems. The navigation system computer then calculates the location based on the position of the satellite overhead.

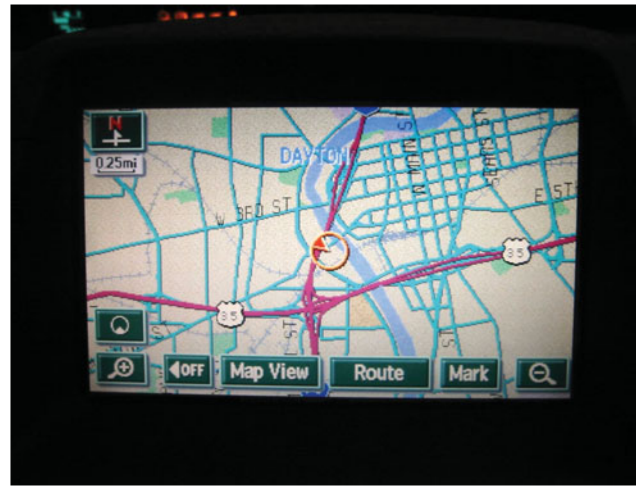


FIGURE 22–44 A typical GPS display screen showing the location of the vehicle.

? FREQUENTLY ASKED QUESTION

Does the Government Know Where I Am?

No. The navigation system uses signals from the satellites and uses the signals from three or more to determine position. If the vehicle is equipped with OnStar, then the vehicle position can be monitored by the use of the cellular telephone link to OnStar call centers. Unless the vehicle has a cellular phone connection to the outside world, the only people who will know the location of the vehicle are the persons inside the vehicle viewing the navigation screen.

NAVIGATION SYSTEM PARTS AND OPERATION

Navigation systems use the GPS satellites for basic location information. The navigation controller located in the rear of the vehicle uses other sensors, including a digitized map to display the location of the vehicle.

- **GPS satellite signals.** These signals from at least three satellites are needed to locate the vehicle.
- **Yaw sensor.** This sensor is often used inside the navigation unit to detect movement of the vehicle during cornering. This sensor is also called a "g" sensor because it measures force; 1 g is the force of gravity.
- **Vehicle speed sensor.** This sensor input is used by the navigation controller to determine the speed and distance the vehicle travels. This information is compiled and compared to the digital map and GPS satellite inputs to locate the vehicle.
- **Audio output/input.** Voice-activated factory units use a built-in microphone at the center top of the windshield and the audio speakers speech output.

Navigation systems include the following components.

1. Screen display ● **SEE FIGURE 22–44.**
2. GPS antenna
3. Navigation control unit, usually with map information on a DVD

The DVD includes street names and the following information.

1. Points of interest (POI), including automated teller machines (ATMs), restaurants, schools, colleges, museums, shopping, and airports, as well as vehicle dealer locations.
2. Business addresses and telephone numbers, including hotels and restaurants (If the telephone number is listed in the business telephone book, it can usually be displayed on the navigation screen. If the telephone number of the business is known, the location can be displayed.)

NOTE: Private residences or cellular telephone numbers are not included in the database of telephone numbers stored on the navigation system DVD.

3. Turn-by-turn directions to addresses that are selected by:
   - Points of interest (POI)
   - Typed in using a keyboard shown on the display

The navigation unit then often allows the user to select the fastest way to the destination, as well as the shortest way, or how to avoid toll roads. ● **SEE FIGURE 22–45**.

DIAGNOSIS AND SERVICE

For the correct functioning of the navigation system, three inputs are needed.

- Location
- Direction
- Speed

The navigation system uses the GPS satellite and map data to determine a location. Direction and speed are determined by the navigation computer from inputs from the satellite, plus the yaw sensor and vehicle speed sensor. The following symptoms may occur and be a customer complaint. Knowing how the system malfunctions helps to determine the most likely cause.

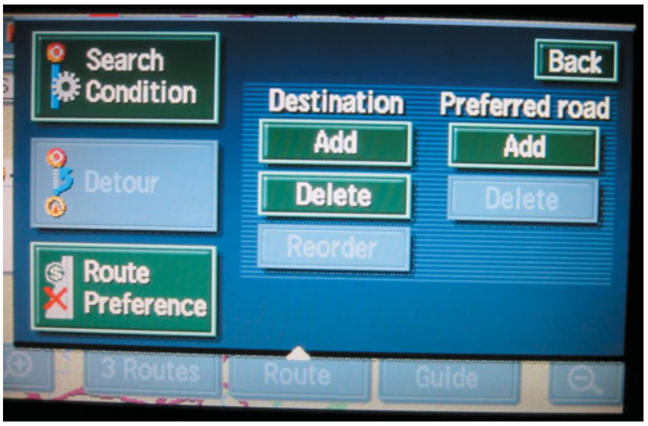


FIGURE 22–45 A typical navigation display showing various options. Some systems do not allow access to these functions if the vehicle is in gear and/or moving.

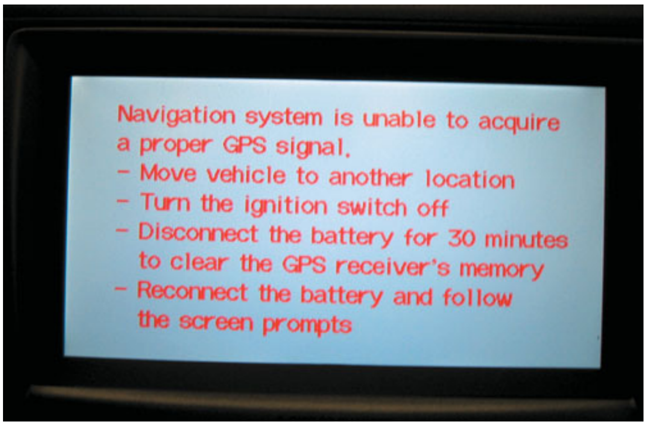


FIGURE 22–46 A screen display of a navigation system that is unable to acquire usable signals from GPS satellites.

TECH TIP

Window Tinting Can Hurt GPS Reception

Most factory-installed navigation systems use a GPS antenna inside the rear back glass or under the rear package shelf. If a metalized window tint is applied to the rear glass, the signal strength from the GPS satellites can be reduced. If the customer concern includes inaccurate or nonfunctioning navigation, check for window tint.

TECH TIP

Touch Screen Tip

Most vehicle navigation systems use a touch screen for use by the driver (or passenger) to input information or other on-screen prompts. Most touch screens use infrared beams projected from the top and bottom plus across the screen to form a grid. The system detects where on the screen a finger is located by the location of the beams that are cut. Do not push harder on the display if the unit does not respond, or damage to the display unit may occur. If no response is detected when lightly depressing the screen, rotate the finger to cause the infrared beams to be cut.

- If the vehicle icon jumps down the road, a fault with the vehicle speed (VS) sensor input is usually indicated.
- If the icon rotates on the screen, but the vehicle is not being driven in circles, a fault with the yaw sensor or yaw sensor input to the navigation controller is likely.
- If the icon goes off course and shows the vehicle on a road that it is not on, a fault with the GPS antenna is the most common reason for this situation.

? FREQUENTLY ASKED QUESTION

What Is Navigation Enhanced Climate Control?

Some vehicles, such as the Acura RL, use data from the navigation system to help control the automatic climate control system. Data about the location of the vehicle includes:

- **Time and date.** This information allows the automatic climate control system to determine where the sun is located.
- **Direction of travel.** The navigation system can also help the climate control system determine the direction of travel.

As a result of the input from the navigation system, the automatic climate control system can control cabin temperature in addition to various other sensors in the vehicle. For example, if the vehicle was traveling south in the late afternoon in July, the climate control system could assume that the passenger side of the vehicle would be warmed more by the sun than the driver's side and could increase the airflow to the passenger side to help compensate for the additional solar heating.

Sometimes the navigation system itself will display a warning that views from the satellite are not being received. Always follow the displayed instructions. ● **SEE FIGURE 22–46.**

ONSTAR

PARTS AND OPERATION OnStar is a system that includes the following functions.

1. Cellular telephone
2. Global positioning antenna and computer

FIGURE 22–47 The three-button OnStar control is located on the inside rearview mirror. The left button (telephone handset icon) is pushed if a hands-free cellular call is to be made. The center button is depressed to contact an OnStar advisor and the right emergency button is used to request that help be sent to the vehicle's location.

OnStar is standard or optional on most General Motors vehicles and selected other brands and models, to help the driver in an emergency or to provide other services. The cellular telephone is used to communicate with the driver from advisors at service centers. The advisor at the service center is able to see the location of the vehicle as transmitted from the GPS antenna and computer system in the vehicle on a display. OnStar does not display the location of the vehicle to the driver unless the vehicle is also equipped with a navigation system.

Unlike most navigation systems, the OnStar system requires a monthly fee. OnStar was first introduced in 1996 as an option on some Cadillac models. Early versions used a hand-held cellular telephone while later units used a group of three buttons mounted on the inside rearview mirror and a hands-free cellular telephone. ● **SEE FIGURE 22–47.**

The first version used analog cellular service while later versions used a dual mode (analog and digital) service until 2007. Since 2007, all OnStar systems use digital cellular service, which means that older systems that were analog only need to be upgraded.

The OnStar system includes the following features, which can vary depending on the level of service desired and cost per month.

- **Automatic notification of airbag deployment.** If the airbag is deployed, the advisor is notified immediately and attempts to call the vehicle. If there is no reply, or if the occupants report an emergency, the advisor will contact emergency services and give them the location of the vehicle.
- **Emergency services.** If the red button is pushed, OnStar immediately locates the vehicle and contacts the nearest emergency service agency.
- **Stolen vehicle location assistance.** If a vehicle is reported stolen, a call center advisor can track the vehicle.
- **Remote door unlock.** An OnStar advisor can send a cellular telephone message to the vehicle to unlock the vehicle if needed.
- **Roadside assistance.** When called, an OnStar advisor can locate a towing company or locate a provider who can bring gasoline or change a flat tire.
- **Accident assistance.** An OnStar advisor is able to help with the best way to handle an accident. The advisor can supply a step-by-step checklist of the things that should be done plus call the insurance company, if desired.
- **Remote horn and lights.** The OnStar system is tied into the lights and horn circuits so an advisor can activate them if requested to help the owner locate the vehicle in a parking lot or garage.
- **Vehicle diagnosis.** Because the OnStar system is tied to the PCM, an OnStar advisor can help with diagnosis if there is a fault detected. The system works as follows:
  - The malfunction indicator light (MIL) (check engine) comes on to warn the driver that a fault has been detected.
  - The driver can depress the OnStar button to talk to an advisor and ask for a diagnosis.
  - The OnStar advisor will send a signal to the vehicle requesting the status from the powertrain control module (PCM), as well as the controller for the antilock brakes and the airbag module.
  - The vehicle then sends any diagnostic trouble codes to the advisor. The advisor can then inform the driver about the importance of the problem and give advice as to how to resolve the problem.

DIAGNOSIS AND SERVICE The OnStar system can fail to meet the needs of the customer if any of the following conditions occur.

1. Lack of cellular telephone service in the area
2. Poor global positioning system (GPS) signals, which can prevent an OnStar advisor from determining the position of the vehicle
3. Transport of the vehicle by truck or ferry so that it is out of contact with the GPS satellite in order for an advisor to properly track the vehicle

If all of the above are okay and the problem still exists, follow service information diagnostic and repair procedures. If a new vehicle communication interface module (VCIM) is installed in the vehicle, the electronic serial number (ESN) must be tied to the vehicle. Follow service information instructions for the exact procedures to follow.

BACKUP CAMERA

PARTS AND OPERATION A **backup camera** is used to display the area at the rear of the vehicle in a screen display on the dash when the gear selector is placed in reverse. Backup cameras are also called *reversing cameras* or *rearview cameras.*

Backup cameras are different from normal cameras because the image displayed on the dash is flipped so it is a

FIGURE 22–48 A typical view displayed on the navigation screen from the backup camera.

FIGURE 22–49 A typical fisheye-type backup camera usually located near the center on the rear of the vehicle near the license plate.

mirror image of the scene at the rear of the vehicle. This reversing of the image is needed because the driver and the camera are facing in opposite directions. Backup cameras were first used in large vehicles with limited rearward visibility, such as motor homes. Many vehicles equipped with navigation systems today include a backup camera for added safety while backing. ● **SEE FIGURE 22–48.**

The backup camera contains a wide-angle or fisheye lens to give the largest viewing area. Most backup cameras are pointed downward so that objects on the ground, as well as walls, are displayed. ● **SEE FIGURE 22–49.**

DIAGNOSIS AND SERVICE Faults in the backup camera system can be related to the camera itself, the display, or the connecting wiring. The main input to the display unit comes from the transmission range switch which signals the backup camera when the transmission is shifted into reverse.

To check the transmission range switch, perform the following:

1. Check if the backup (reverse) lights function when the gear selector is placed in reverse with the key on, engine off (KOEO).

FIGURE 22–50 A typical backup sensor display located above the rear window inside the vehicle. The warning lights are visible in the inside rearview mirror.

2. Check that the transmission/transaxle is fully engaged in reverse when the selector is placed in reverse.

Most of the other diagnosis involves visual inspection, including:

1. Check the backup camera for damage.
2. Check the screen display for proper operation.
3. Check that the wiring from the rear camera to the body is not cut or damaged.

Always follow the vehicle manufacturer's recommended diagnosis and repair procedures.

BACKUP SENSORS

COMPONENTS Backup sensors are used to warn the driver if there is an object behind the vehicle while backing. The system used in General Motors vehicles is called **rear park assist (RPA),** and includes the following components.

- Ultrasonic object sensors built into the rear bumper assembly
- A display with three lights usually located inside the vehicle above the rear window and visible to the driver in the rearview mirror
- An electronic control module that uses an input from the transmission range switch and lights the warning lamps needed when the vehicle gear selector is in reverse

OPERATION The three-light display includes two amber lights and one red light. The following lights are displayed depending on the distance from the rear bumper.

- One amber lamp will light when the vehicle is in reverse and traveling at less than 3 mph (5 km/h) and the sensors detect an object 40 to 60 in. (102 to 152 cm) from the rear bumper. A chime also sounds once when an object is detected, to warn the driver to look at the rear parking assist display. ● **SEE FIGURE 22–50.**

FIGURE 22–51 The small round buttons in the rear bumper are ultrasonic sensors used to sense distance to an object.

TECH TIP

Check for Repainted Bumper

The ultrasonic sensors embedded in the bumper are sensitive to paint thickness because the paint covers the sensors. If the system does not seem to be responding to objects, and if the bumper has been repainted, measure the paint thickness using a nonferrous paint thickness gauge. The maximum allowable paint thickness is 6 mils (0.006 inch or 0.15 mm).

- Two amber lamps light when the distance between the rear bumper and an object is between 20 and 40 in. (50 and 100 cm) and the chime will sound again.
- Two amber lamps and the red lamp light and the chime sounds continuously when the distance between the rear bumper and the object is between 11 and 20 in. (28 and 50 cm).

If the distance between the rear bumper and the object is less than 11 in. (28 cm), all indicator lamps flash and the chime will sound continuously.

The ultrasonic sensors embedded in the rear bumper "fire" individually every 150 milliseconds (27 times per second). ● **SEE FIGURE 22–51.**

The sensors fire and then receive a return signal and arm to fire again in sequence from the left sensor to the right sensor.

Each sensor has the following three wires.

1. An 8 volt supply wire from the RPA module, used to power the sensor
2. A reference low or ground wire
3. A signal line, used to send and receive commands to and from the RPA module

DIAGNOSIS The rear parking assist control module is capable of detecting faults and storing diagnostic trouble codes (DTCs). If a fault has been detected by the control module, the red lamp flashes and the system is disabled. Follow service information diagnostic procedures because the rear parking assist module cannot usually be accessed using a scan tool. Most systems use the warning lights to indicate trouble codes.

LANE DEPARTURE WARNING SYSTEM

PARTS AND OPERATION The **lane departure warning system (LDWS)** uses cameras to detect if the vehicle is crossing over lane marking lines on the pavement. Some systems use two cameras, one mounted on each outside rearview mirror. Some systems use infrared sensors located under the front bumper to monitor the lane markings on the road surface.

The system names also vary according to vehicle manufacturer, including:

Honda/Acura: lane keep assist system (LKAS)
Toyota/Lexus: lane monitoring system (LMS)
General Motors: lane departure warning (LDW)
Ford: lane departure warning (LDW)
Nissan/Infinity: lane departure prevention (LDP) system

If the cameras detect that the vehicle is starting to cross over a lane dividing line, a warning chime will sound or a vibrating mechanism mounted in the driver's seat cushion is triggered on the side where the departure is being detected. This warning will not occur if the turn signal is on in the same direction as detected. ● **SEE FIGURE 22–52.**

DIAGNOSIS AND SERVICE Before attempting to service or repair a lane departure warning system fault, check service information for an explanation on how the system is supposed to work. If the system is not working as designed, perform a visual inspection of the sensors or cameras, checking for damage from road debris or evidence of body damage, which could affect the sensors. After a visual inspection, follow the vehicle manufacturer's recommended diagnosis procedures to locate and repair the fault in the system.

ELECTRONIC DASH INSTRUMENT DIAGNOSIS AND TROUBLESHOOTING

If one or more electronic dash gauges do not work correctly, first check the WOW display that lights all segments to full brilliance whenever the ignition switch is first switched on. If *all* segments of the display do *not* operate, then the entire electronic cluster

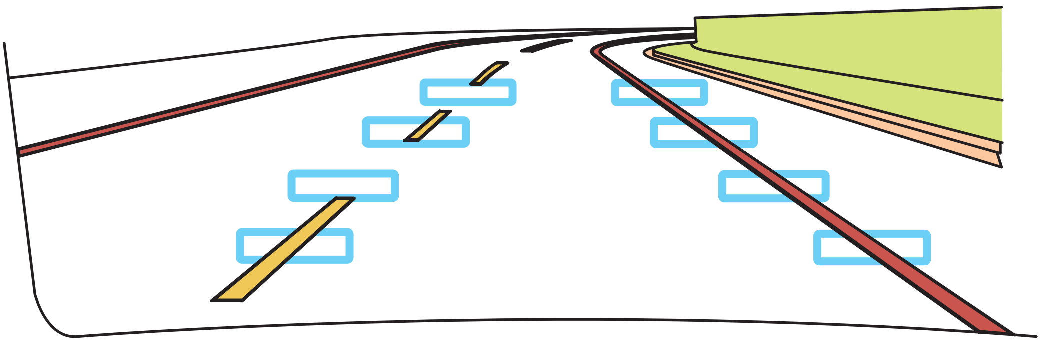


FIGURE 22–52 A lane departure warning system often uses cameras to sense the road lines and warns the driver if the vehicle is not staying within the lane, unless the turn signal is on.

TECH TIP

Keep Stock Overall Tire Diameter

Whenever larger (or smaller) wheels or tires are installed, the speedometer and odometer calibration are also thrown off. This can be summarized as follows:

- **Larger diameter tires.** The speed showing on the speedometer is slower than the actual speed. The odometer reading will show fewer miles than actual.
- **Smaller diameter tires.** The speed showing on the speedometer is faster than the actual speed. The odometer reading will show more miles than actual.

General Motors trucks can be recalibrated with a recalibration kit (1988–1991) or with a replacement controller assembly called a digital ratio adapter controller (DRAC) located under the dash. It may be possible to recalibrate the speedometer and odometer on earlier models, before 1988, or vehicles that use speedometer cables by replacing the drive gear in the transmission. Check service information for the procedure on the vehicle being serviced.

must be replaced in most cases. If all segments operate during the WOW display but do not function correctly afterwards, the problem is most often a defective sensor or defective wiring to the sensor.

All dash instruments except the voltmeter use a variable-resistance unit as a sensor for the system being monitored. Most new-vehicle dealers are required to purchase essential test equipment, including a test unit that permits the technician to insert various fixed-resistance values in the suspected circuit. For example, if a 45 ohm resistance is put into the fuel gauge circuit that reads from 0 to 90 ohms, a properly operating dash unit should indicate one-half tank. The same tester can produce a fixed signal to test the operation of the speedometer and tachometer. If this type of special test equipment is not available, the electronic dash instruments can be tested using the following procedure.

1. With the ignition switched off, unplug the wire(s) from the sensor for the function being tested. For example, if the oil pressure gauge is not functioning correctly, unplug the wire connector at the oil pressure sending unit.
2. With the sensor wire unplugged, turn the ignition switch on and wait until the WOW display stops. The display for the affected unit should show either fully lighted segments or no lighted segments, depending on the make of the vehicle and the type of sensor.
3. Turn the ignition switch off. Connect the sensor wire lead to ground and turn the ignition switch on. After the WOW display, the display should be the opposite (either fully on or fully off) of the results in step 2.

TESTING RESULTS If the electronic display functions fully on and fully off with the sensor unplugged and then grounded, the problem is a defective sensor. If the electronic display fails to function fully on and fully off when the sensor wire(s) are opened and grounded, the problem is usually in the wiring from the sensor to the electronic dash or it is a defective electronic cluster.

CAUTION: Whenever working on or *near* any type of electronic dash display, always wear a wire attached to your wrist (wrist strap) connected to a good body ground to prevent damaging the electronic dash with static electricity.

MAINTENANCE REMINDER LAMPS

Maintenance reminder lamps indicate that the oil should be changed or that other service is required. There are numerous ways to extinguish a maintenance reminder lamp. Some require the use of a special tool. Always check the owner manual or service information for the exact procedure for the vehicle being serviced. For example, to reset the oil service reminder light on many General Motors vehicles, you have to perform the following:

STEP 1 Turn the ignition key on (engine off).

STEP 2 Depress the accelerator pedal three times and hold it down on the fourth.

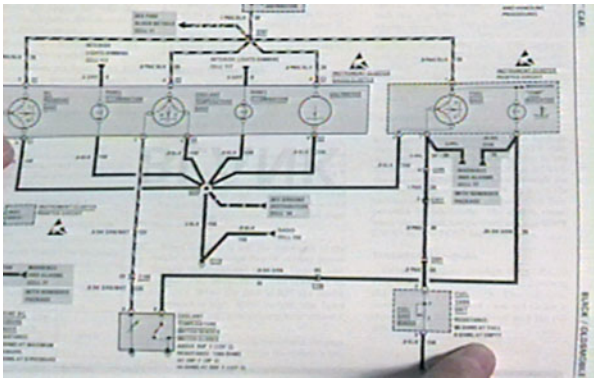
STEP 3 When the reminder light flashes, release the accelerator pedal.

STEP 4 Turn the ignition key to the off position.

STEP 5 Start the engine and the light should be off.

FUEL GAUGE DIAGNOSIS

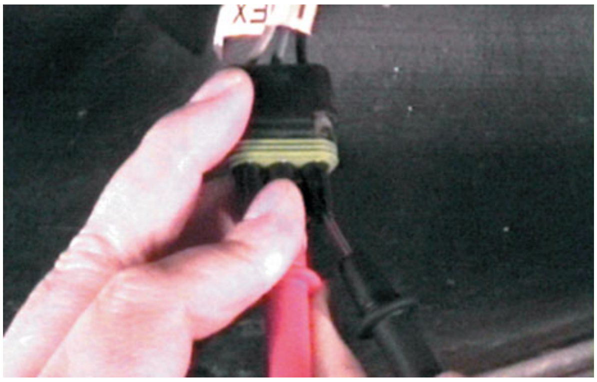
1 Observe the fuel gauge. This General Motors vehicle shows an indicated reading of slightly above one-half tank.



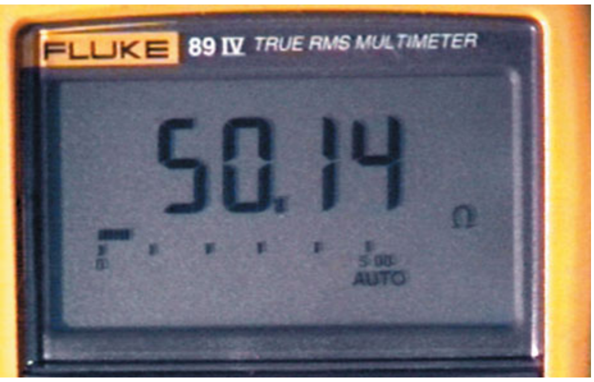
2 Consult the factory service manual for the specifications, wire color, and recommended test procedure.

3 From the service manual, the connector for the fuel gauge-sending unit was located under the vehicle near the rear. A visual inspection indicated that the electrical wiring and connector were not damaged or corroded.

4 To test resistance of the sending unit (tank unit) use a digital multimeter and select ohms (Ω).



5 Following the schematic in the service manual the sending unit resistance can be measured between the pink and the black wires in the connector.



6 The meter displays 50 ohms or slightly above the middle of the normal resistance value for the vehicle of 0 Ω (empty) to 90 Ω (full).

7 To check if the dash unit can move, the connector is unplugged with the ignition key on (engine off).

8 As the connector is disconnected, the needle of the dash unit moves toward full.

9 After a couple of seconds, the needle disappears above the full reading. The open connector represented infinity ohms and normal maximum reading occurs when the tank unit reads 90 ohms. If the technician does not realize that the needle could disappear, an incorrect diagnosis could be made.

10 To check if the dash unit is capable of reading empty, a fuse jumper wire is connected between the signal wire at the dash end of the connector and a good chassis ground.

11 A check of a dash unit indicated that the needle does accurately read empty.

12 After testing, reconnect the electrical connectors and verify for proper operation of the fuel level gauge.

SUMMARY

1. Most digital and analog (needle-type) dash gauges use variable-resistance sensors.
2. Dash warning lamps are called telltale lamps.
3. Many electronically operated or computer-operated dash indicators require that a service manual be used to perform accurate diagnosis.
4. Permanent magnet (PM) generators produce an AC signal and are used for vehicle speed and wheel speed sensors.
5. Navigation systems and warning systems are part of the driver information system on many vehicles.

REVIEW QUESTIONS

1. How does a stepper motor analog dash gauge work?
2. What are LED, LCD, VTF, and CRT dash displays? Describe each.
3. How do you diagnose a problem with a red brake warning lamp?
4. How do you test the dash unit of a fuel gauge?
5. How does a navigation system determine the location of the vehicle?

CHAPTER QUIZ

1. Two technicians are discussing a fuel gauge on a General Motors vehicle. Technician A says that if the ground wire connection to the fuel tank sending unit becomes rusty or corroded, the fuel gauge will read lower than normal. Technician B says that if the power lead to the fuel tank sending unit is disconnected from the tank unit and grounded (ignition on), the fuel gauge should go to empty. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. If an oil pressure warning lamp on a General Motors vehicle is on all the time, yet the engine oil pressure is normal, the problem could be a ________.
   - **a.** Defective (shorted) oil pressure sending unit (sensor)
   - **b.** Defective (open) oil pressure sending unit (sensor)
   - **c.** Wire shorted-to-ground between the sending unit (sensor) and the dash warning lamp
   - **d.** Both a and c
3. When the oil pressure drops to between 3 and 7 psi, the oil pressure lamp lights by ________.
   - **a.** Opening the circuit
   - **b.** Shorting the circuit
   - **c.** Grounding the circuit
   - **d.** Conducting current to the dash lamp by oil
4. A brake warning lamp on the dash remains on whenever the ignition is on. If the wire to the pressure differential switch (usually a part of a combination valve or built into the master cylinder) is unplugged, the dash lamp goes out. Technician A says that this is an indication of a fault in the hydraulic brake system. Technician B says that the problem is probably due to a stuck parking brake cable switch. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. A customer complains that every time the lights are turned on in the vehicle, the dash display dims. What is the most probable explanation?
   - **a.** Normal behavior for LED dash displays
   - **b.** Normal behavior for VTF dash displays
   - **c.** Poor ground in lighting circuit causing a voltage drop to the dash lamps
   - **d.** Feedback problem most likely caused by a short-to-voltage between the headlights and dash display
6. Technician A says that LCDs may be slow to work at low temperatures. Technician B says that an LCD dash display can be damaged if pressure is exerted on the front of the display during cleaning. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

7. Technician A says that backup sensors use LEDs to detect objects. Technician B says that a backup sensor will not work correctly if the paint is thicker than 0.006 in. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. Technician A says that metal-type tinting can affect the navigation system. Technician B says most navigation systems require a monthly payment for use of the GPS satellite. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Technician A says that the data displayed on the dash can come from the engine computer. Technician B says that the entire dash assembly may have to be replaced even if just one unit fails. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. How does changing the size of the tires affect the speedometer reading?
   a. A smaller diameter tire causes the speedometer to read faster than actual speed and more than actual mileage on the odometer.
   b. A smaller diameter tire causes the speedometer to read slower than the actual speed and less than the actual mileage on the odometer.
   c. A larger diameter tire causes the speedometer to read faster than the actual speed and more than the actual mileage on the odometer.
   d. A larger diameter tire causes the speedometer to read slower than the actual speed and more than the actual mileage on the odometer.

chapter 23

HORN, WIPER, AND BLOWER MOTOR CIRCUITS

OBJECTIVES: **After studying Chapter 23, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "G" (Horn and Wiper/Washer Diagnosis and Repair) and content area "H" (Accessories Diagnosis and Repair). • Describe how the horn operates. • List the components of a wiper circuit. • Explain how the blower motor can run at different speeds. • Discuss how to diagnosis faults in the horn, wiper, and blower motor circuits.

KEY TERMS: Horns 322 • Pulse wipers 324 • Rain sense wipers 331 • Series-wound field 324 • Shunt field 324 • Variable-delay wipers 324 • Windshield wipers 324

HORNS

PURPOSE AND FUNCTION **Horns** are electric devices that emit a loud sound used to alert other drivers or persons in the area. Horns are manufactured in several different tones ranging from 1,800 to 3,550 Hz. Vehicle manufacturers select from various horn tones for a particular vehicle sound. ● **SEE FIGURE 23–1.**

When two horns are used, each has a different tone when operated separately, yet the sound combines when both are operated.

FIGURE 23–1 Two horns are used on this vehicle. Many vehicles use only one horn, often hidden underneath the vehicle.

HORN CIRCUITS Automotive horns usually operate on full battery voltage wired from the battery, through a fuse, switch, and then to the horns. Most vehicles use a horn *relay.* With a relay, the horn button on the steering wheel or column completes a circuit to ground that closes a relay, and the heavy current flow required by the horn then travels from the relay to the horn. Without a horn relay, the high current of the horns must flow through the steering wheel horn switch. ● **SEE FIGURE 23–2.**

The horn relay is also connected to the body control module, which "beeps" the horn when the vehicle is locked or unlocked, using the key fob remote.

HORN OPERATION A vehicle horn is an actuator that converts an electrical signal to sound. The horn circuit includes an armature (a coil of wire) and contacts that are attached to a diaphragm. When energized, the armature causes the diaphragm to move up which then opens a set of contact points that de-energize the armature circuit. As the diaphragm moves down, the contact points close, re-energize the armature circuit, and the diaphragm moves up again. This rapid opening and closing of the contact points causes the diaphragm to vibrate at an audible frequency. The sound created by the diaphragm is magnified as it travels through a trumpet attached to the diaphragm chamber. Most horn systems typically use one or two horns, but some have up to four. Those with multiple horns use both high- and low-pitch units to achieve a harmonious tone. Only a high-pitched unit is used in single-horn applications. The horn assembly is marked with an "H" or "L" for pitch identification.

HORN SYSTEM DIAGNOSIS There are three types of horn failure.

- No horn operation
- Intermittent operation
- Constant operation
- Weak or low volume sound

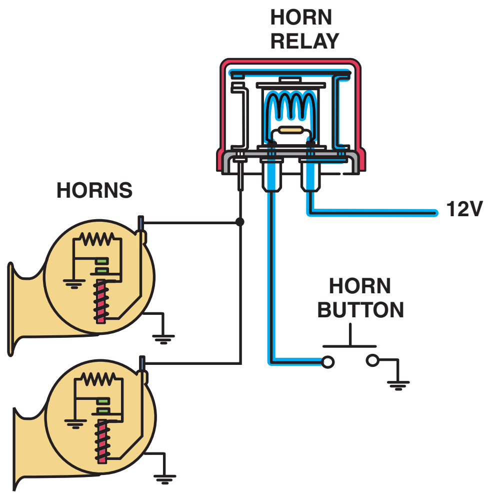


FIGURE 23–2 A typical horn circuit. Note that the horn button completes the ground circuit for the relay.

If a horn does not operate at all, check for the following:

- Burned fuse or fusible link
- Open circuit
- Defective horn
- Faulty relay
- Defective horn switch
- Poor ground (horn mounting)
- Corroded or rusted electrical connector

If a horn operates intermittently, check for the following:

- Loose contact at the switch
- Loose, frayed, or broken wires
- Defective relay

HORN SOUNDS CONTINUOUSLY A horn that sounds continuously and cannot be shut off is caused by horn switch contacts that are stuck closed, or a short-to-ground on the control circuit. This may be the result of a defective horn switch or a faulty relay. Stuck relay contacts keep the circuit complete so the horn sounds constantly. Disconnect the horn and check continuity through the horn switch and relay to locate the source of the problem.

INOPERATIVE HORN To help determine the cause of an inoperative horn, use a fused jumper wire and connect one end to the positive post of the battery and the other end to the wire terminal of the horn itself. Also use a fused jumper wire to substitute a ground path to test or confirm a potential bad ground circuit. If the horn works with jumper wires connected, check ground wires and connections.

- If the horn works, the problem is in the circuit supplying current to the horn.
- If the horn does not work, the horn itself could be defective or the mounting bracket may not be providing a good ground.

HORN SERVICE When a horn malfunctions, circuit tests are made to determine if the horn, relay, switch, or wiring is the source of the failure. Typically, a digital multimeter (DMM) is used to perform voltage drop and continuity checks to isolate the failure.

- **Switch and relay.** A momentary contact switch is used to sound the horn. The horn switch is mounted to the steering wheel in the center of the steering column on some models, and is part of a multifunction switch installed on the steering column.

  CAUTION: If steering wheel removal is required for diagnosis or repair of the horn circuit, follow service information procedures for disarming the airbag circuit prior to steering wheel removal, and for the specified test equipment to use.

  On most late-model vehicles, the horn relay is located in a centralized power distribution center along with other relays, circuit breakers, and fuses. The horn relay bolts onto an inner fender or the bulkhead in the engine compartment of older vehicles. Check the relay to determine if the coil is being energized and if current passes through the power circuit when the horn switch is depressed.

  Obtain an electrical schematic of the horn circuit and use a voltmeter to test input, output, and control voltage.

- **Circuit testing.** Circuit testing involves the following steps.

  STEP 1 Make sure the fuse or fusible link is good before attempting to troubleshoot the circuit.

  STEP 2 Check that the ground connections for the horn are clean and tight. Most horns ground to the chassis through the mounting bolts. High ground circuit resistance due to corrosion, road dirt, or loose fasteners may cause no, or intermittent, horn operation.

  STEP 3 On a system with a relay, test the power output circuit and the control circuit. Check for voltage available at the horn, voltage available at the relay, and continuity through the switch. When no relay is used, there are two wires leading to the horn switch, and a connection to the steering wheel is made with a double contact slip ring. Test points on this system are similar to those of a system with a relay, but there is no control circuit.

HORN REPLACEMENT Horns are generally mounted on the radiator core support by bolts and nuts or sheet metal screws. It may be necessary to remove the grille or other parts to access the horn mounting screws. If a replacement horn is required, attempt to use a horn of the same tone as the original. The tone is usually indicated by a number or letter stamped on the body of the horn. To replace a horn, simply remove the fasteners and lift the old horn from its mounting bracket.

Clean the attachment area on the mounting bracket and chassis before installing the new horn. Some models use a corrosion-resistant mounting bolt to ensure a ground connection. ● **SEE FIGURE 23–3.**

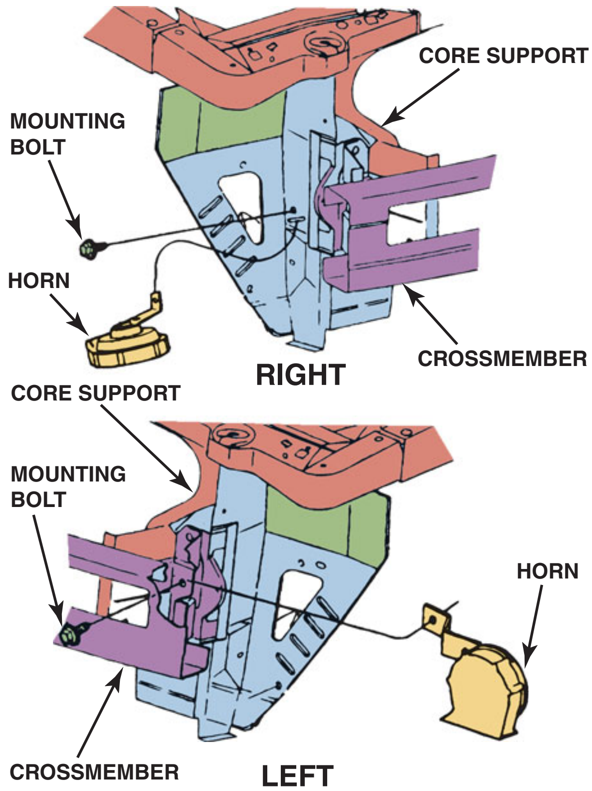


FIGURE 23–3 Horns typically mount to the radiator core support or bracket at the front of the vehicle.

WINDSHIELD WIPER AND WASHER SYSTEM

PURPOSE AND FUNCTION **Windshield wipers** are used to keep the viewing area of the windshield clean of rain. Windshield wiper systems and circuits vary greatly between manufacturers as well as between models. Some vehicles combine the windshield wiper and windshield washer functions into a single system. Many minivans and sport utility vehicles (SUVs) also have a rear window wiper and washer system that works independently of the windshield system. In spite of the design differences, all windshield and rear window wiper and washer systems operate in a similar fashion.

COMPUTER CONTROLLED Most wipers since the 1990s have used the body computer to control the actual operation of the wiper. The wiper controls are simply a command to the computer. The computer may also turn on the headlights whenever the wipers are on, which is the law in some states. ● **SEE FIGURE 23–4.**

WIPER AND WASHER COMPONENTS A typical combination wiper and washer system consists of the following:

- Wiper motor
- Gearbox
- Wiper arms and linkage
- Washer pump
- Hoses and jets (nozzles)
- Fluid reservoir
- Combination switch
- Wiring and electrical connectors
- Electronic control module

The motor and gearbox assembly is wired to the wiper switch on the instrument panel or steering column or to the wiper control module. ● **SEE FIGURE 23–5.**

Some systems use either a one- or two-speed wiper motor, whereas others have a variable-speed motor.

WINDSHIELD WIPER MOTORS The windshield wipers ordinarily use a special two-speed electric motor. Most are compound-wound motors, a motor type, which provides for two different speeds.

- **Series-wound field**
- **Shunt field**

One speed is achieved in the series wound field and the other speed in the shunt wound field. The wiper switch provides the necessary electrical connections for either motor speed. Switches in the mechanical wiper motor assembly provide the necessary operation for "parking" and "concealing" of the wipers. ● **SEE FIGURE 23–6** for a typical wiper motor assembly.

- **Wiper motor operation.** Most wiper motors use a permanent magnet motor with a low speed + brush and a high speed + brush. The brushes connect the battery to the internal windings of the motor, and the two brushes provide for two different motor speeds.

  The ground brush is directly opposite the low-speed brush. The high-speed brush is off to the side of the low-speed brush. When current flows through the high-speed brush, there are fewer turns on the armature between the hot and ground brushes, and therefore the resistance is less. With less resistance, more current flows and the armature revolves faster. ● **SEE FIGURES 23–7 AND 23–8.**
- **Variable wipers.** The **variable-delay wipers** (also called **pulse wipers**) use an electronic circuit with a variable resistor that controls the time of the charge and discharge of a capacitor. The charging and discharging of the capacitor controls the circuit for the operation of the wiper motor. ● **SEE FIGURE 23–9.**

HIDDEN WIPERS Some vehicles are equipped with wipers that become hidden when turned off. These wipers are also called *depressed wipers.* The gearbox has an additional linkage arm to provide depressed parking for hidden wipers. This link extends to move the wipers into the park position when the motor turns in reverse of operating direction. With depressed park, the motor assembly includes an internal park switch. The park switch completes a circuit to reverse armature polarity in the motor when the windshield wiper switch is turned off. The park circuit opens once the wiper arms are in the park position.

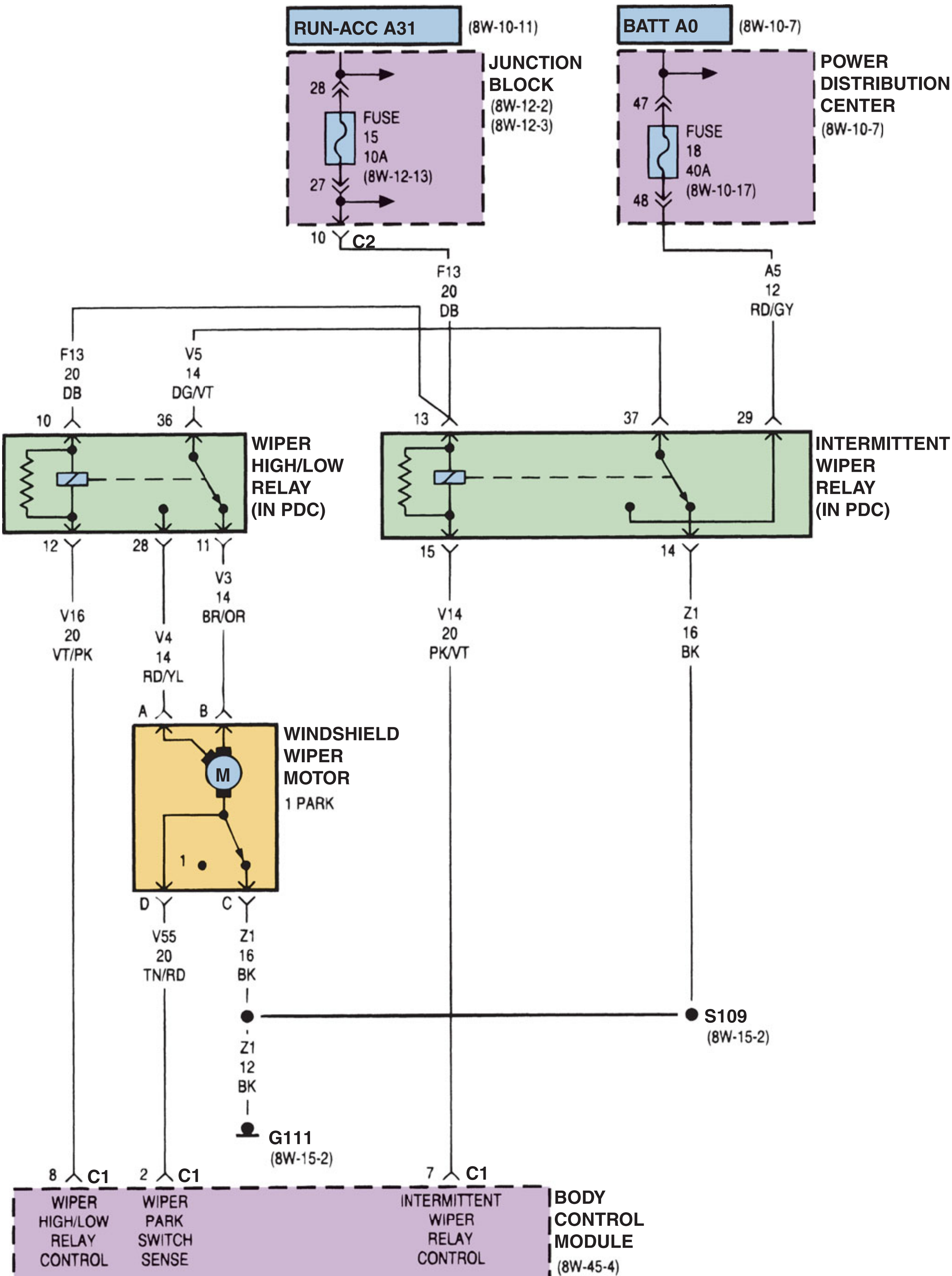


FIGURE 23–4 A circuit diagram is necessary to troubleshoot a windshield wiper problem.

Instead of a depressed park feature, some systems simply extend the cleaning arc below the level of the hood line.

WINDSHIELD WIPER DIAGNOSIS Windshield wiper failure may be the result of an electrical fault or a mechanical problem, such as binding linkage. Generally, if the wipers operate at one speed setting but not another, the problem is electrical.

To determine if there is an electrical or mechanical problem, access the motor assembly and disconnect the wiper arm linkage from the motor and gearbox. Depending on the type of vehicle, this procedure may involve:

- Removing body trim panels from the covered areas at the base of the windshield to gain access to the linkage connectors
- Switching the motor on to each speed (If the motor operates at all speeds, the problem is mechanical. If the motor still does not operate, the problem is electrical.)

If the wiper motor does not run at all, check for the following:

- Grounded or inoperative switch
- Defective motor
- Circuit wiring fault
- Poor electrical ground connection

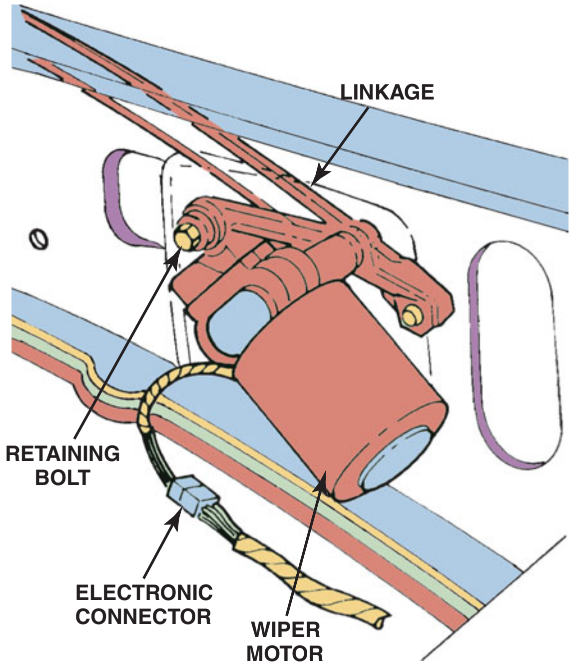


FIGURE 23–5 The motor and linkage bolt to the body and connect to the switch with a wiring harness.

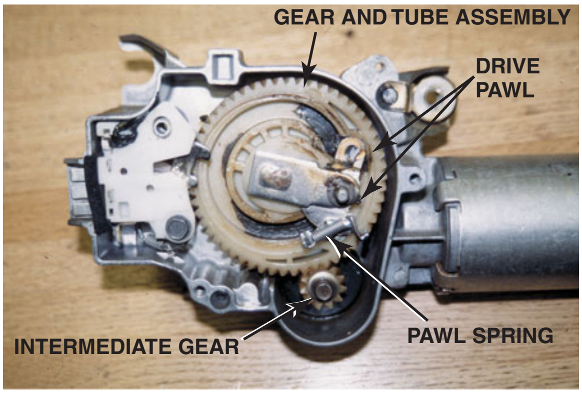


FIGURE 23–6 A typical wiper motor with the housing cover removed. The motor itself has a worm gear on the shaft that turns the small intermediate gear, which then rotates the gear and tube assembly, which rotates the crank arm (not shown) that connects to the wiper linkage.

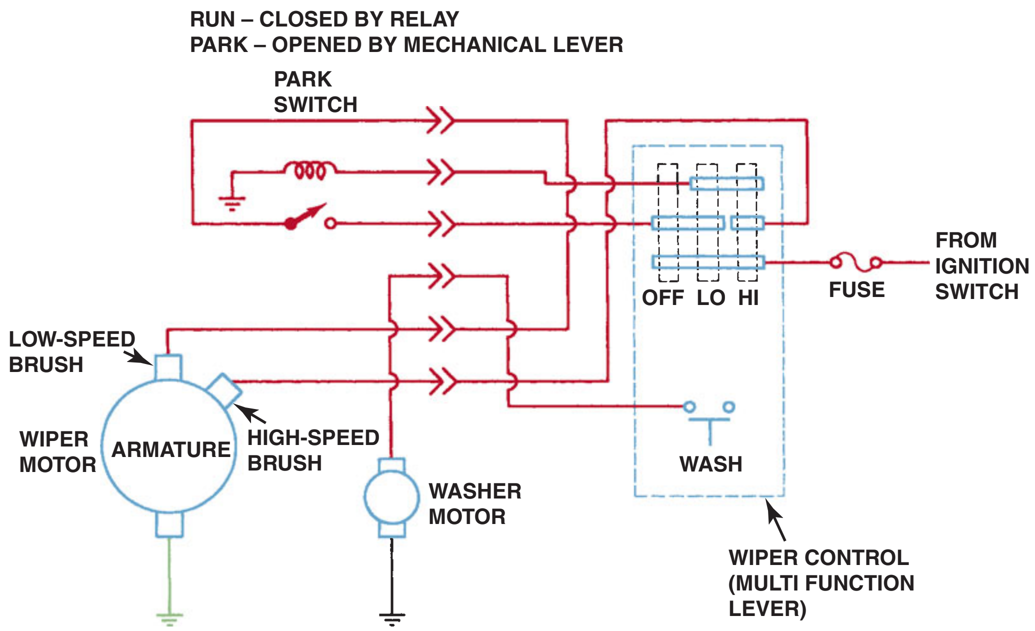


FIGURE 23–7 A wiring diagram of a two-speed windshield wiper circuit using a three-brush, two-speed motor. The dashed line for the multifunction lever indicates that the circuit shown is only part of the total function of the steering column lever.

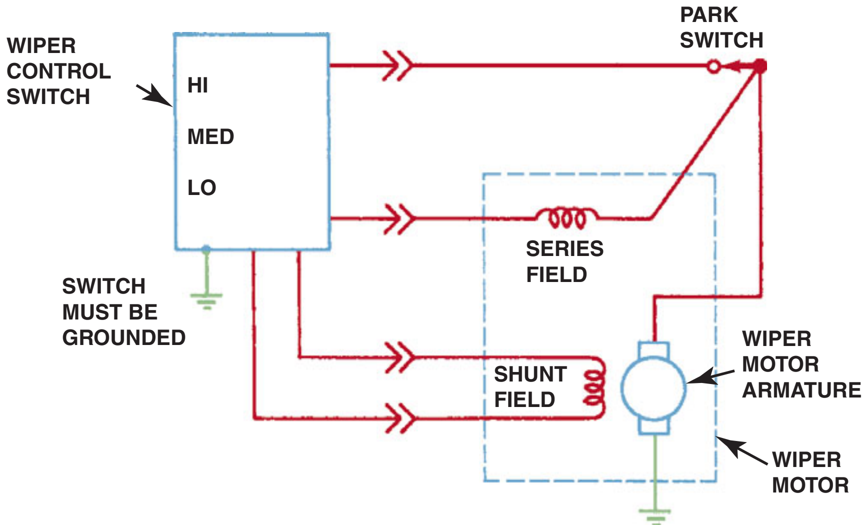


FIGURE 23–8 A wiring diagram of a three-speed windshield wiper circuit using a two-brush motor, but both a series-wound and a shunt field coil.

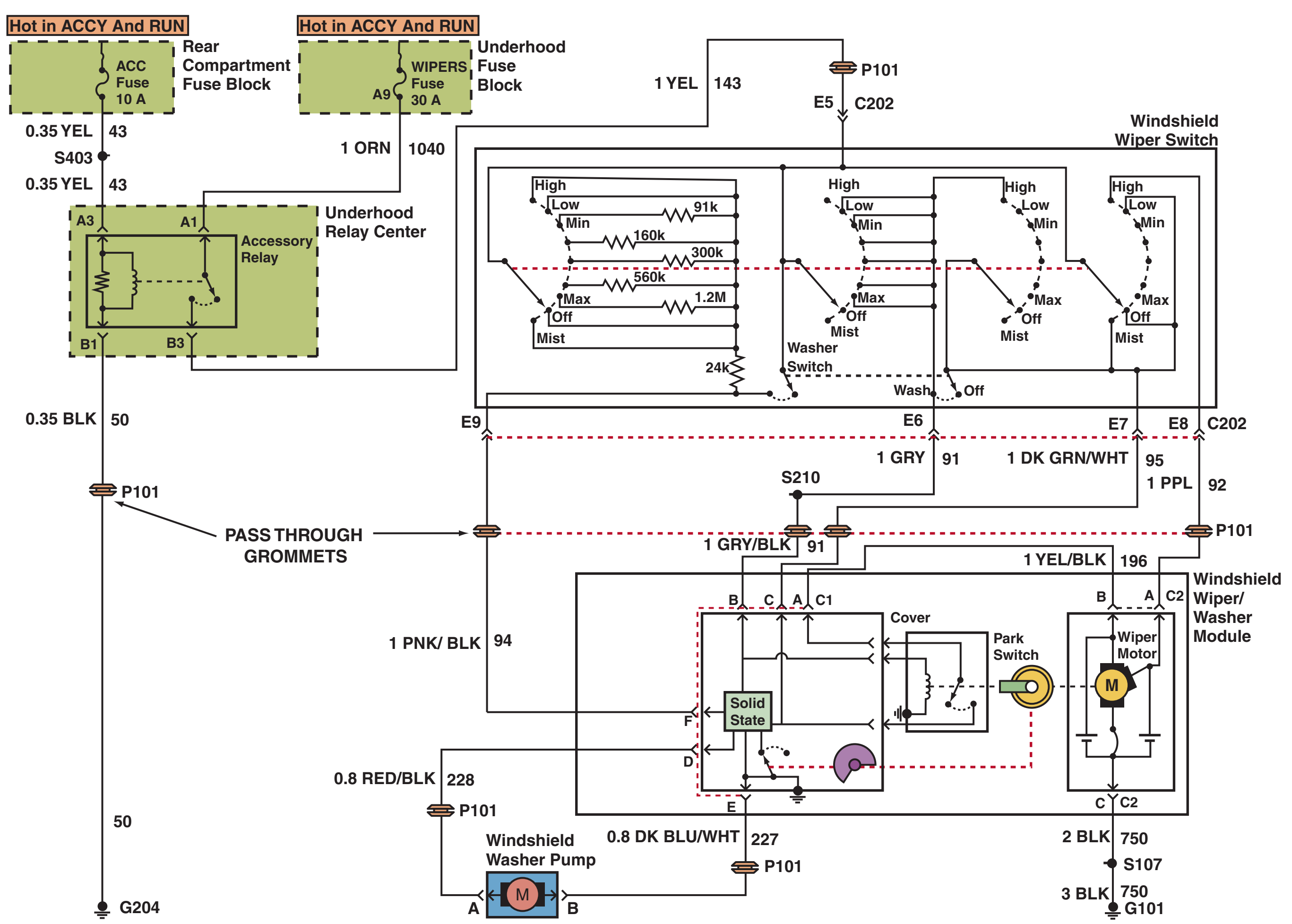
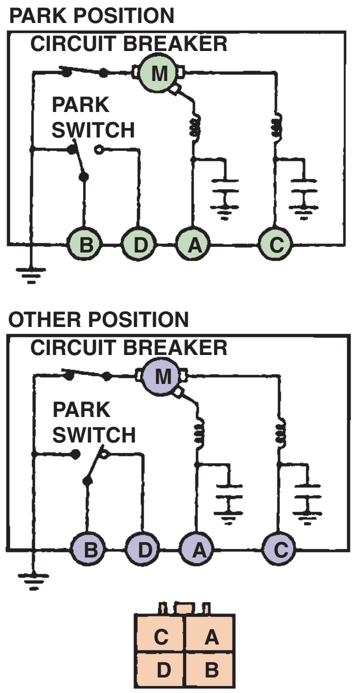


FIGURE 23–9 A variable pulse rate windshield wiper circuit. Notice that the wiring travels from the passenger compartment through pass-through grommets to the underhood area.



TERMINAL	OPERATION SPEED
C	LOW
A	HIGH

FIGURE 23–10 A wiper motor connector pin chart.

If the motor operates but the wipers do not, check for the following:

- Stripped gears in the gearbox or stripped linkage connection
- Loose or separated motor-to-gearbox connection
- Loose linkage to the motor connection

If the motor does not shut off, check for the following:

- Defective park switch inside the motor
- Defective wiper switch
- Poor ground connection at the wiper switch

WINDSHIELD WIPER TESTING When the wiper motor does not operate with the linkage disconnected, perform the following steps to determine the fault. ● **SEE FIGURE 23–10.**

To test the wiper system, perform the following steps.

STEP 1 Refer to the circuit diagram or a connector pin chart for the vehicle being serviced to determine the test points for voltage measurements.

STEP 2 Switch the ignition on and set the wiper switch to a speed at which the motor does not operate.

STEP 3 Check for battery voltage available at the appropriate wiper motor terminal for the selected speed. If voltage is available to the motor, an internal motor problem is indicated. No voltage available indicates a switch or circuit failure.

STEP 4 Check for proper ground connections.

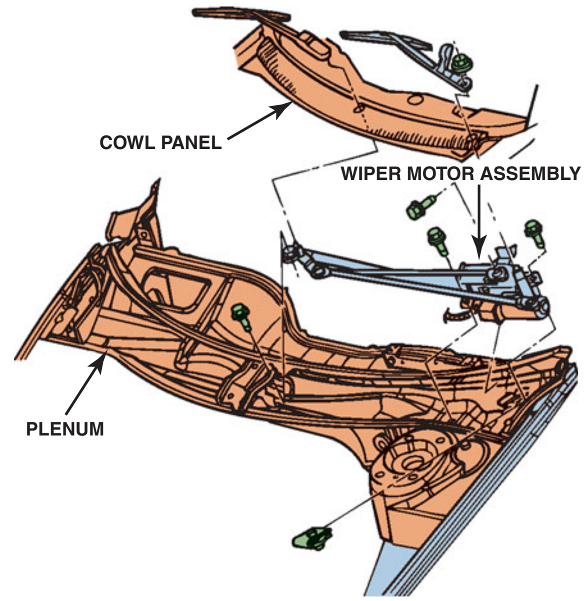


FIGURE 23–11 The wiper motor and linkage mount under the cowl panel on many vehicles.

? FREQUENTLY ASKED QUESTION

How Do Wipers Park?

Some vehicles have wiper arms that park lower than the normal operating position so that they are hidden below the hood when not in operation. This is called a *depressed park position.* When the wiper motor is turned off, the park switch allows the motor to continue to turn until the wiper arms reach the bottom edge of the windshield. Then the park switch reverses the current flow through the wiper motor, which makes a partial revolution in the opposite direction. The wiper linkage pulls the wiper arms down below the level of the hood and the park switch is opened, stopping the wiper motor.

STEP 5 Check that battery voltage is available at the motor side of the wiper switch. If battery voltage is available, the circuit is open between the switch and motor. No voltage available indicates either a faulty switch or a power supply problem.

STEP 6 Check for battery voltage available at the power input side of the wiper switch. If voltage is available, the switch is defective. Replace the switch. No voltage available to the switch indicates a circuit problem between the battery and switch.

WINDSHIELD WIPER SERVICE Wiper motors are replaced if defective. The motor usually mounts on the bulkhead (firewall). Bulkhead-mounted units are accessible from under the hood, while the cowl panel needs to be removed to service a motor mounted in the cowl. ● **SEE FIGURE 23–11.**

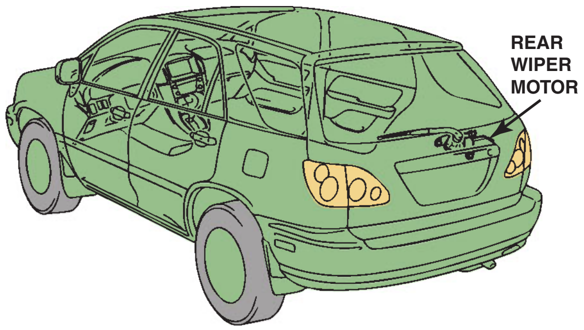


FIGURE 23–12 A single wiper arm mounts directly to the motor on most rear wiper applications.

After gaining access to the motor, removal is simply a matter of disconnecting the linkage, unplugging the electrical connectors, and unbolting the motor. Move the wiper linkage through its full travel by hand to check for any binding before installing the new motor.

Rear window wiper motors are generally located inside the rear door panel of station wagons, or the rear hatch panel on vehicles with a hatchback or liftgate. ● **SEE FIGURE 23–12.**

After removing the trim panel covering the motor, replacement is essentially the same as replacing the front wiper motor.

Wiper control switches are either installed on the steering column or on the instrument panel.

Steering column wiper switches, which are operated by controls on the end of a switch stalk (usually called a *multifunction switch*), require partial disassembly of the steering column for replacement.

PULSE WIPE SYSTEMS Windshield wipers may also incorporate a delay, or intermittent operation, feature commonly called pulse wipe. The length of the delay, or the frequency of the intermittent operation, is adjustable on some systems. Pulse wipe systems may rely on simple electrical controls, such as a variable-resistance switch, or be controlled electronically through a control module.

With any electronic control system, it is important to follow the diagnosis and test procedures recommended by the manufacturer for that specific vehicle.

A typical pulse, or interval, wiper system uses either a governor or a solid-state module that contains either a variable resistor or rheostat and capacitor. The module connects into the electrical circuitry between the wiper switch and wiper motor. The variable resistor or rheostat controls the length of the interval between wiper pulses. A solid-state pulse wipe timer regulates the control circuit of the pulse relay to direct current to the motor at the prescribed interval. ● **SEE FIGURE 23–13.**

The following troubleshooting procedure applies to most models.

STEP 1 If the wipers do not run at all, check the wiper fuse, fusible link, or circuit breaker and verify that voltage is available to the switch.

STEP 2 Refer to a wiring diagram of the switch to determine how current is routed through it to the motor in the different positions.

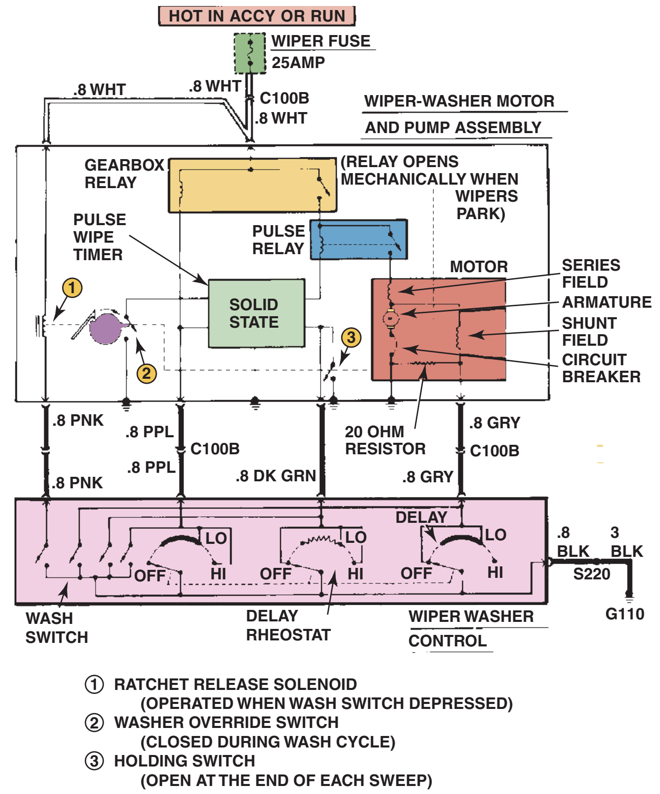


FIGURE 23–13 Circuit diagram of a rheostat-controlled, electronically timed interval wiper.

STEP 3 Disconnect the switch and use fused jumper wires to apply power directly to the motor on the different speed circuits.
- If the motor now runs, the problem is in the switch or module.
- Check for continuity in the circuit for each speed through the control-to-ground if the wiper motor runs at some, but not all, speeds.

WINDSHIELD WASHER OPERATION Most vehicles use a positive-displacement or centrifugal-type washer pump located in the washer reservoir. A momentary contact switch, which is often part of a steering column–mounted combination switch assembly, energizes the washer pump. Washer pump switches are installed either on the steering column or on the instrument panel. The nozzles can be located on the bulkhead or in the hood depending on the vehicle.

WINDSHIELD WASHER DIAGNOSIS Inoperative windshield washers may be caused by the following:

- Blown fuse or open circuit
- Empty reservoir
- Clogged nozzle
- Broken, pinched, or clogged hose
- Loose or broken wire
- Blocked reservoir screen
- Leaking reservoir
- Defective pump

TECH TIP

Use a Scan Tool to Check Accessories

Most vehicles built since 2000 can have the lighting and accessory circuits checked using a scan tool. A technician can use the following:

- Factory scan tool, such as:
  - Tech 2 or Multiple Diagnostic Interface (MDI) (General Motors vehicle)
  - DRB III or Star Scan or Star Mobile or WiTech (Chrysler-Jeep vehicles)
  - New Generation Star or IDS (Ford)
  - Honda Diagnostic System (HDS)
  - TIS Tech Stream (Toyota/Lexus)
- Enhanced aftermarket scan tool that has body bidirectional control capability, including:
  - Snap-on Modis, Solus, or Verus
  - OTC Genisys
  - Autoengenuity

Using a bidirectional scan tool allows the technician to command the operation of electrical accessories such as windows, lights, and wipers. If the circuit operates correctly when commanded by the scan tool and does not function using the switche(s), follow service information instructions to diagnose the switch circuits.

To diagnose the washer system, follow service information procedures that usually include the following steps.

STEP 1 To quick check any washer system, make sure the reservoir has fluid and is not frozen, and then disconnect the pump hose and operate the washer switch.

NOTE: Always use good-quality windshield washer fluid from a closed container to prevent contaminated fluid from damaging the washer pump. Radiator antifreeze (ethylene glycol) should never be used in any windshield wiper system.

● **SEE FIGURE 23–14.**

STEP 2 If fluid squirts from the pump, the delivery system is at fault, not the motor, switch, or circuitry.

STEP 3 If no fluid squirts from the pump, the problem is most likely a circuit failure, defective pump, or faulty switch.

STEP 4 A clogged reservoir screen also may be preventing fluid from entering the pump.

WINDSHIELD WASHER SERVICE When a fluid delivery problem is indicated, check for:

- Blocked, pinched, broken, or disconnected hose
- Clogged nozzles
- Blocked washer pump outlet

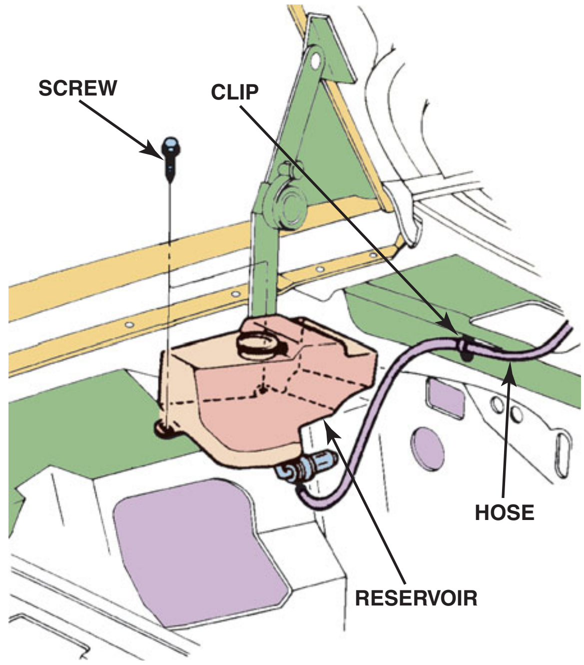


FIGURE 23–14 Disconnect the hose at the pump and operate the switch to check a washer pump.

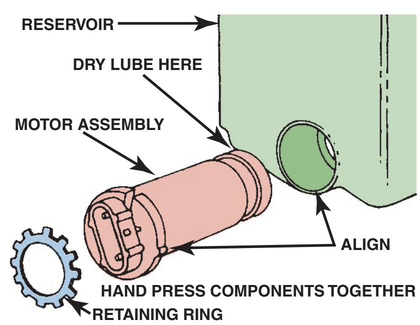


FIGURE 23–15 Washer pumps usually install into the reservoir and are held in place with a retaining ring.

If the pump motor does not operate, check for battery voltage available at the pump while operating the washer switch. If voltage is available and the pump does not run, check for continuity on the pump ground circuit. If there is no voltage drop on the ground circuit, replace the pump motor.

If battery voltage is not available at the motor, check for power through the washer switch. If voltage is available at and through the switch, there is a problem in the wiring between the switch and pump. Perform voltage drop tests to locate the fault. Repair the wiring as needed and retest.

Washer motors are not repairable and are simply replaced if defective. Centrifugal or positive-displacement pumps are located on or inside the washer reservoir tank or cover and secured with a retaining ring or nut. ● **SEE FIGURE 23–15.**

FIGURE 23–16 A typical rain sensing module located on the inside of the windshield near the inside rearview mirror.

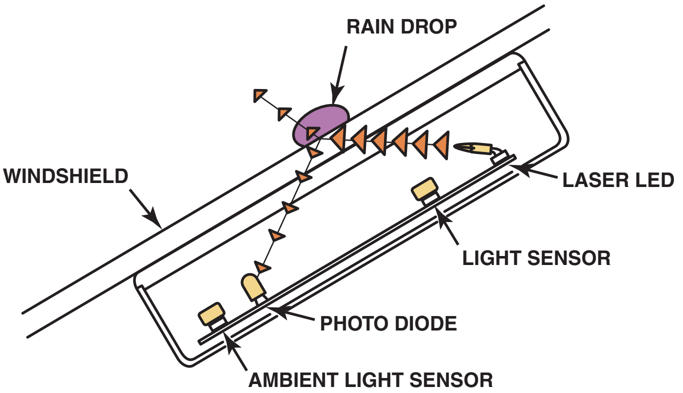


FIGURE 23–17 The electronics in the rain sense wiper module can detect the presence of rain drops under various lighting conditions.

RAIN SENSE WIPER SYSTEM

PARTS AND OPERATION **Rain sense wiper** systems use a sensor located at the top of the windshield on the inside to detect rain droplets. This sensor is called the *rain sense module (RSM)* by General Motors. It determines and adjusts the time delay of the wiper based on how much moisture it detects on the windshield. The wiper switch can be left on the sense position all of the time and if no rain is sensed, the wipers will not swipe. ● **SEE FIGURES 23–16 AND 23–17.**

The control knob is rotated to the desired wiper sensibility level.

The microprocessor in the RSM sends a command to the body control module (BCM). RSM is a triangular-shaped black plastic housing. Fine openings on the windshield side of the housing are fitted with eight convex clear plastic lenses. The unit contains four infrared (IR) diodes, two photocells, and a microprocessor.

The IR diodes generate IR beams that are aimed by four of the convex optical lenses near the base of the module through the windshield glass. Four additional convex lenses near the top of the RSM are focused on the IR light beam on the outside of the windshield glass and allow the two photocells to sense changes in the intensity of the IR light beam. When sufficient moisture accumulates, the RSM detects a change in the monitored IR light beam intensity. The RSM processes the signal BCM over the data BUS to command a swipe of the wiper.

DIAGNOSIS AND SERVICE If there is a complaint about the rain sense wipers not functioning correctly, check the owner manual to be sure that they are properly set and adjusted. Also, verify that the windshield wipers are functioning correctly on all speeds before diagnosing the rain sensor circuits. Always follow the vehicle manufacturer's recommended diagnosis and testing procedures.

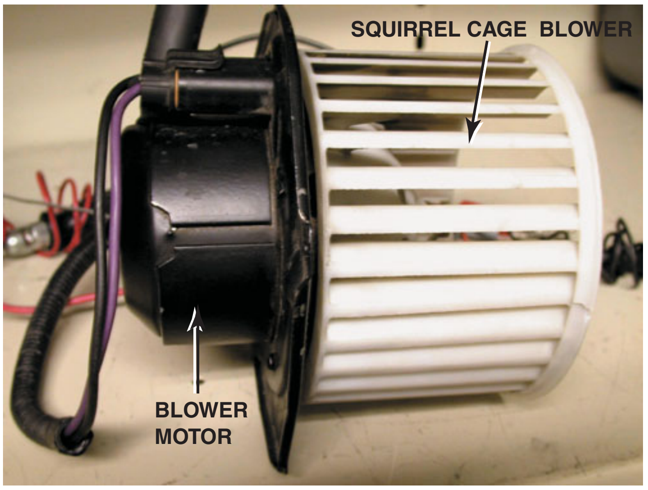


FIGURE 23–18 A squirrel cage blower motor. A replacement blower motor usually does not come equipped with the squirrel cage blower, so it has to be switched from the old motor.

BLOWER MOTOR

PURPOSE AND FUNCTION The same blower motor moves air inside the vehicle for:

1. Air conditioning
2. Heat
3. Defrosting
4. Defogging
5. Venting of the passenger compartment

The motor turns a squirrel cage-type fan. A squirrel cage-type fan is able to move air without creating a lot of noise. The fan switch controls the path that the current follows to the blower motor. ● **SEE FIGURE 23–18.**

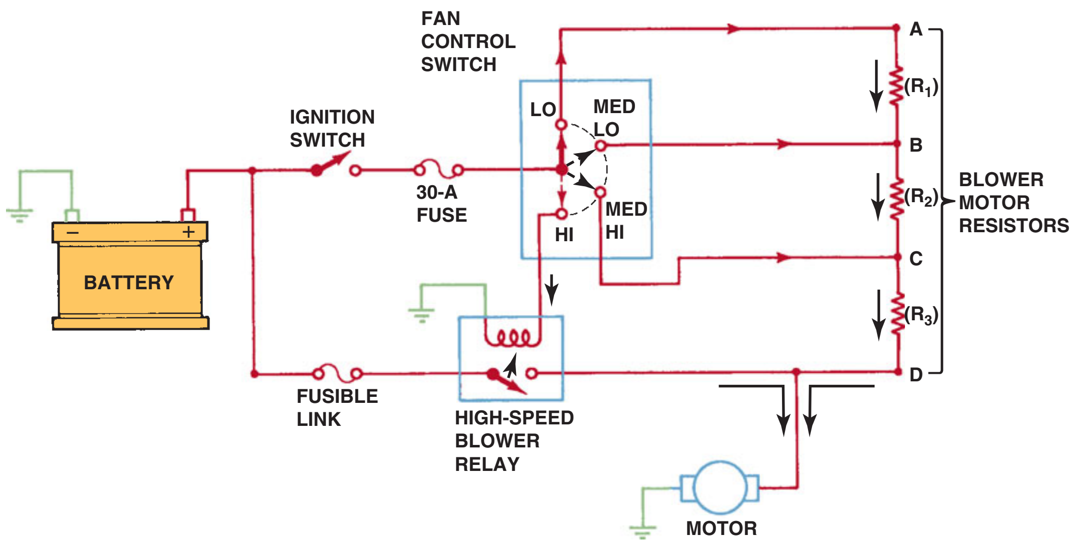


FIGURE 23–19 A typical blower motor circuit with four speeds. The three lowest fan speeds (low, medium-low, and medium-high) use the blower motor resistors to drop the voltage to the motor and reduce current to the motor. On high, the resistors are bypassed. The "high" position on the fan switch energizes a relay, which supplies the current for the blower on high through a fusible link.

PARTS AND OPERATION The motor is usually a permanent magnet, one-speed motor that operates at its maximum speed with full battery voltage. The switch gets current from the fuse panel with the ignition switch on, and then directs full battery voltage to the blower motor for high speed and to the blower motor through resistors for lower speeds.

VARIABLE SPEED CONTROL The fan switch controls the path of current through a resistor pack to obtain different fan speeds of the blower motor. The electrical path can be:

- Full battery voltage for high-speed operation
- Through one or more resistors to reduce the voltage and the current to the blower motor which then rotates at a slower speed

The resistors are located near the blower motor and mounted in the duct where the airflow from the blower can cool the resistors. The current flow through the resistor is controlled by the switch and often uses a relay to carry the heavy current (10 to 12 amperes) needed to power the fan. Normal operation includes:

- **Low speed.** Current flows through three resistors in series to drop the voltage to about 4 volts and 4 amperes.
- **Medium speed.** Current is directed through two resistors in series to lower the voltage to about 6 volts and 6 amperes.
- **Medium-high speed.** Current is directed through one resistor resulting in a voltage of about 9 volts and 9 amperes.
- **High speed.** Full battery voltage, usually through a relay, is applied to the blower motor resulting in a current of about 12 amperes.

● **SEE FIGURES 23–19 AND 23–20.**

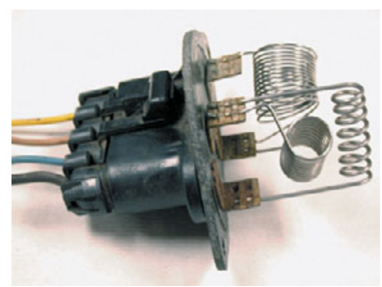


FIGURE 23–20 A typical blower motor resistor pack used to control blower motor speed. Some blower motor resistors are flat and look like a credit card and are called "credit card resistors".

NOTE: Most Ford and some other vehicles place the blower motor resistors on the ground side of the motor circuit. The location of the resistors does not affect the operation because they are connected in series.

Some blower motors are electronically controlled by the body control module (BCM) and include electronic circuits to achieve a variable speed. ● **SEE FIGURE 23–21.**

BLOWER MOTOR DIAGNOSIS If the blower motor does not operate at any speed, the problem could be any of the following:

1. Defective ground wire or ground wire connection
2. Defective blower motor (not repairable; must be replaced)
3. Open circuit in the power-side circuit, including fuse, wiring, or fan switch

If the blower works on lower speeds but not on high speed, the problem is usually an inline fuse or high-speed relay that

TECH TIP

The 20 Ampere Fuse Test

Most blower motors operate at about 12 A on high speed. If the bushings (bearings) on the armature of the motor become worn or dry, the motor turns more slowly. Because a motor also produces counterelectromotive force (CEMF) as it spins, a slower-turning motor will actually draw more amperes than a fast-spinning motor.

If a blower motor draws too many amperes, the resistors or the electronic circuit controlling the blower motor can fail. Testing the actual current draw of the motor is sometimes difficult because the amperage often exceeds the permissible amount for most digital meters.

One test recommended by General Motors Co. is to unplug the power lead to the motor (retain the ground on the motor) and use a fused jumper lead with one end connected to the battery's positive terminal and the other end to the motor terminal. Use a 20 A fuse in the test lead, and operate the motor for several minutes. If the blower motor is drawing more than 20 A, the fuse will blow. Some experts recommend using a 15 A fuse. If the 15 A fuse blows and the 20 A fuse does not, then you know the approximate blower motor current draw.

controls the heavy current flow for high-speed operation. The high-speed fuse or relay usually fails as a result of internal blower motor bushing wear, which causes excessive resistance to motor rotation. At slow blower speeds, the resistance is not as noticeable and the blower operates normally. The blower motor is a sealed unit, and if defective, must be replaced as a unit. The squirrel cage fan usually needs to be removed from the old motor and attached to the replacement motor. If the blower motor operates normally at high speed but not at any of the lower speeds, the problem could be melted wire resistors or a defective switch.

FIGURE 23–21 A brushless DC motor that uses the body computer to control the speed. *(Courtesy of Sammy's Auto Service, Inc.)*

FIGURE 23–22 Using a mini AC/DC clamp-on multimeter to measure the current draw of a blower motor.

The blower motor can be tested using a clamp-on DC ammeter. ● **SEE FIGURE 23–22.**

Most blower motors do not draw more than 15 A on high speed. A worn or defective motor usually draws more current than normal and could damage the blower motor resistors or blow a fuse if not replaced.

ELECTRICAL ACCESSORY SYMPTOM GUIDE

The following list will assist technicians in troubleshooting electrical accessory systems.

Blower Motor Problem	Possible Causes and/or Solutions
Blower motor does not operate.	1. Blown fuse 2. Poor ground connection on blower motor 3. Defective motor (Use a fused jumper wire connected between the positive terminal of the battery and the blower motor power lead connection [lead disconnected] to check for blower motor operation.) 4. Defective control switch 5. Resistor block open or defective blower motor control module
Blower motor operates only on high speed.	1. Open in the resistors located in the air box near the blower motor 2. Stuck or defective high-speed relay 3. Defective blower motor control switch
Blower motor operates in lower speed(s) only, no high speed.	1. Defective high-speed relay or blower high-speed fuse **NOTE: If the high-speed fuse blows a second time, check the current draw of the motor and replace the blower motor if the current draw is above specifications. Check for possible normal operation if the rear window defogger is not in operation; some vehicles electrically prevent simultaneous operation of the high-speed blower and rear window defogger to help reduce the electrical loads.**
Windshield Wiper or Washer Problem	**Possible Causes and/or Solutions**
Windshield wipers are inoperative.	1. Blown fuse 2. Poor ground on the wiper motor or the control switch 3. Defective motor or linkage problem
Windshield wipers operate on high speed or low speed only.	1. Defective switch 2. Defective motor assembly 3. Poor ground on the wiper control switch
Windshield washers are inoperative.	1. Defective switch 2. Empty reservoir or clogged lines or discharge nozzles 3. Poor ground on the washer pump motor
Horn Problem	**Possible Causes and/or Solutions**
Horn(s) are inoperative.	1. Poor ground on horn(s) 2. Defective relay (if used); open circuit in the steering column 3. Defective horn (Use a fused jumper wire connected between the positive terminal of the battery and the horn [horn wire disconnected] to check for proper operation of the horn.)
Horn(s) produce low volume or wrong sound.	1. Poor ground at horn 2. Incorrect frequency of horn
Horn blows all the time.	1. Stuck horn relay (if used) 2. Short-to-ground in the wire to the horn button

SUMMARY

1. Horn frequency can range from 1,800 to 3,550 Hz.
2. Most horn circuits use a relay, and the current through the relay coil is controlled by the horn switch.
3. Most windshield wipers use a three-brush, two-speed motor.
4. Windshield washer diagnosis includes checking the pump both electrically and mechanically for proper operation.
5. Many blower motors use resistors wired in series to control blower motor speed.
6. A good blower motor should draw less than 20 A.

REVIEW QUESTIONS

1. What are the three types of horn failure?
2. How is the horn switch used to operate the horn?
3. How do you determine if a windshield wiper problem is electrical or mechanical?
4. Why does a defective blower motor draw more current (amperes) than a good motor?

CHAPTER QUIZ

1. Technician A says that a defective high-speed blower motor relay could prevent high-speed blower operation, yet allows normal operation at low speeds. Technician B says that a defective (open) blower motor resistor can prevent low-speed blower operation, yet permit normal high-speed operation. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. To determine if a windshield wiper problem is electrical or mechanical, the service technician should ________.
   - **a.** Disconnect the linkage arm from the windshield wiper motor and operate the windshield wiper
   - **b.** Check to see if the fuse is blown
   - **c.** Check the condition of the wiper blades
   - **d.** Check the washer fluid for contamination
3. A weak-sounding horn is being diagnosed. Technician A says that a poor ground connector at the horn itself can be the cause. Technician B says an open relay can be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. What controls the operation of a pulse wiper system?
   - **a.** Resistor that controls current flow to the wiper motor
   - **b.** Solid-state (electronic) module
   - **c.** Variable-speed gem set
   - **d.** Transistor
5. Which pitch horn is used for a single horn application?
   - **a.** High pitch
   - **b.** Low pitch
6. The horn switch on the steering wheel on a vehicle that uses a horn relay ________.
   - **a.** Sends electrical power to the horns
   - **b.** Provides the ground circuit for the horn
   - **c.** Grounds the horn relay coil
   - **d.** Provides power (12 V) to the horn relay
7. A rain sense wiper system uses a rain sensor that is usually mounted ________.
   - **a.** Behind the grille
   - **b.** Outside of the windshield at the top
   - **c.** Inside the windshield at the top
   - **d.** On the roof
8. Technician A says a blower motor can be tested using a fused jumper lead. Technician B says a blower motor can be tested using a clamp-on ammeter. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. A defective blower motor draws more current than a good motor because the ________.
   - **a.** Speed of the motor increases
   - **b.** CEMF decreases
   - **c.** Airflow slows down, which decreases the cooling of the motor
   - **d.** Both a and c
10. Windshield washer pumps can be damaged if ________.
    - **a.** Pure water is used in freezing weather
    - **b.** Contaminated windshield washer fluid is used
    - **c.** Ethylene glycol (antifreeze) is used
    - **d.** All of the above

chapter 24

ACCESSORY CIRCUITS

OBJECTIVES: After studying Chapter 24, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • Explain how the body control module or body computer controls the operation of electrical accessories. • Explain how cruise control operates and how to diagnose the circuit. • Describe how power door locks, windows, and seats operate. • Describe how a keyless remote can be reprogrammed. • Explain how the theft deterrent system works.

KEY TERMS: Adjustable pedals 350 • Backlight 341 • CHMSL 338 • Control wires 345 • Cruise control 336 • Direction wires 345 • Electric adjustable pedals (EAP) 350 • ETC 339 • HomeLink 343 • Independent switches 343 • Key fob 352 • Lockout switch 343 • Lumbar 346 • Master control switch 343 • Peltier effect 349 • Permanent magnet electric motors 343 • Rubber coupling 346 • Screw jack assembly 346 • Thermoelectric device (TED) 349 • Window regulator 344

CRUISE CONTROL

PARTS INVOLVED **Cruise control** (also called *speed control*) is a combination of electrical and mechanical components designed to maintain a constant, set vehicle speed without driver pressure on the accelerator pedal. Major components of a typical cruise control system include the following:

1. **Servo unit.** The servo unit attaches to the throttle linkage through a cable or chain.

   The servo unit controls the movement of the throttle by receiving a controlled amount of vacuum from a control module. ● **SEE FIGURE 24–1.**

   Some systems use a stepper motor and do not use engine vacuum.
2. **Computer or cruise control module.** This unit receives inputs from the brake switch, throttle position (TP) sensor, and vehicle speed sensor. It operates the solenoids or stepper motor to maintain the set speed.
3. **Speed set control.** A speed set control is a switch or control located on the steering column, steering wheel, dash, or console. Many cruise control units feature coast, accelerate, and resume functions. ● **SEE FIGURE 24–2.**
4. **Safety release switches.** When the brake pedal is depressed, the cruise control system is disengaged through use of an electrical or vacuum switch, usually located on the brake pedal bracket. Both electrical and vacuum releases are used to be certain that the cruise control system is released, even in the event of failure of one of the release switches.

WARNING

Most vehicle manufacturers warn in the owner manual that cruise control should not be used when it is raining or if the roads are slippery. Cruise control systems operate the throttle and, if the drive wheels start to hydroplane, the vehicle slows, causing the cruise control unit to accelerate the engine. When the engine is accelerated and the drive wheels are on a slippery road surface, vehicle stability will be lost and might possibly cause a crash.

CRUISE CONTROL OPERATION A typical cruise control system can be set only if the vehicle speed is 30 mph or more. In a noncomputer-operated system, the transducer contains a low-speed electrical switch that closes when the speed-sensing section of the transducer senses a speed exceeding the minimum engagement speed.

NOTE: Toyota-built vehicles do not retain the set speed in memory if the vehicle speed drops below 25 mph (40 km/h). The driver is required to set the desired speed again. This is normal operation and not a fault with the cruise control system.

When the set button is depressed on the cruise control, solenoid values on the servo unit allow engine vacuum to be applied to one side of the diaphragm, which is attached to the

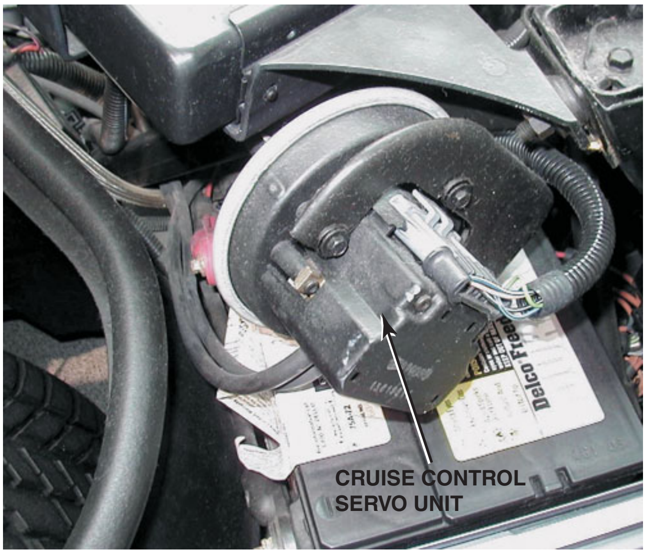


FIGURE 24–1 This cruise control servo unit has an electrical connection with wires that go to the cruise control module or the vehicle computer, depending on the vehicle. The vacuum hoses supply engine manifold vacuum to the rubber diaphragm that moves the throttle linkage to maintain the preset speed.

FIGURE 24–2 A cruise control used on a Toyota/Lexus.

> **TECH TIP**
>
> **Bump Problems**
>
> Cruise control problem diagnosis can involve a complex series of checks and tests. The troubleshooting procedures vary among manufacturers (and year), so a technician should always consult a service manual for the exact vehicle being serviced. However, every cruise control system uses a brake safety switch and, if the vehicle has manual transmission, a clutch safety switch. The purpose of these safety switches is to ensure that the cruise control system is disabled if the brakes or the clutch is applied. Some systems use redundant brake pedal safety switches, one electrical to cut off power to the system and the other a vacuum switch used to bleed vacuum from the actuating unit.
>
> If the cruise control "cuts out" or disengages itself while traveling over bumpy roads, the most common cause is a misadjusted brake (and/or clutch) safety switch(es). Often, a simple readjustment of these safety switches will cure the intermittent cruise control disengagement problems.
>
> **CAUTION: Always follow the manufacturer's recommended safety switch adjustment procedures. If the brake safety switch(es) is misadjusted, it could keep pressure applied to the master brake cylinder, resulting in severe damage to the braking system.**

throttle plate of the engine through a cable or linkage. The servo unit usually contains two solenoids to control the opening and closing of the throttle.

- One solenoid opens and closes to control the passage, which allows engine vacuum to be applied to the diaphragm of the servo unit, increasing the throttle opening.
- One solenoid bleeds air back into the sensor chamber to reduce the throttle opening.

The throttle position (TP) sensor or a position sensor, inside the servo unit, sends the throttle position information to the cruise control module.

Most computer-controlled cruise control systems use the vehicle's speed sensor input to the engine control computer for speed reference. Computer-controlled cruise control units also use servo units for throttle control, control switches for driver control of cruise control functions, and both electrical and vacuum brake pedal release switches. ● **SEE FIGURE 24–3.**

TROUBLESHOOTING CRUISE CONTROL

Cruise control system troubleshooting is usually performed using the step-by-step procedure as specified by the vehicle manufacturer.

The usual steps in the diagnosis of an inoperative or incorrectly operating mechanical-type cruise control include the following:

STEP 1 Use a factory or enhanced scan tool to retrieve any cruise control diagnostic trouble codes (DTCs). Perform bidirectional testing if possible using the scan tool.

STEP 2 Check that the cruise control fuse is not blown and that the cruise control dash light is on when the cruise control is turned on.

STEP 3 Check for proper operation of the brake and/or clutch switch.

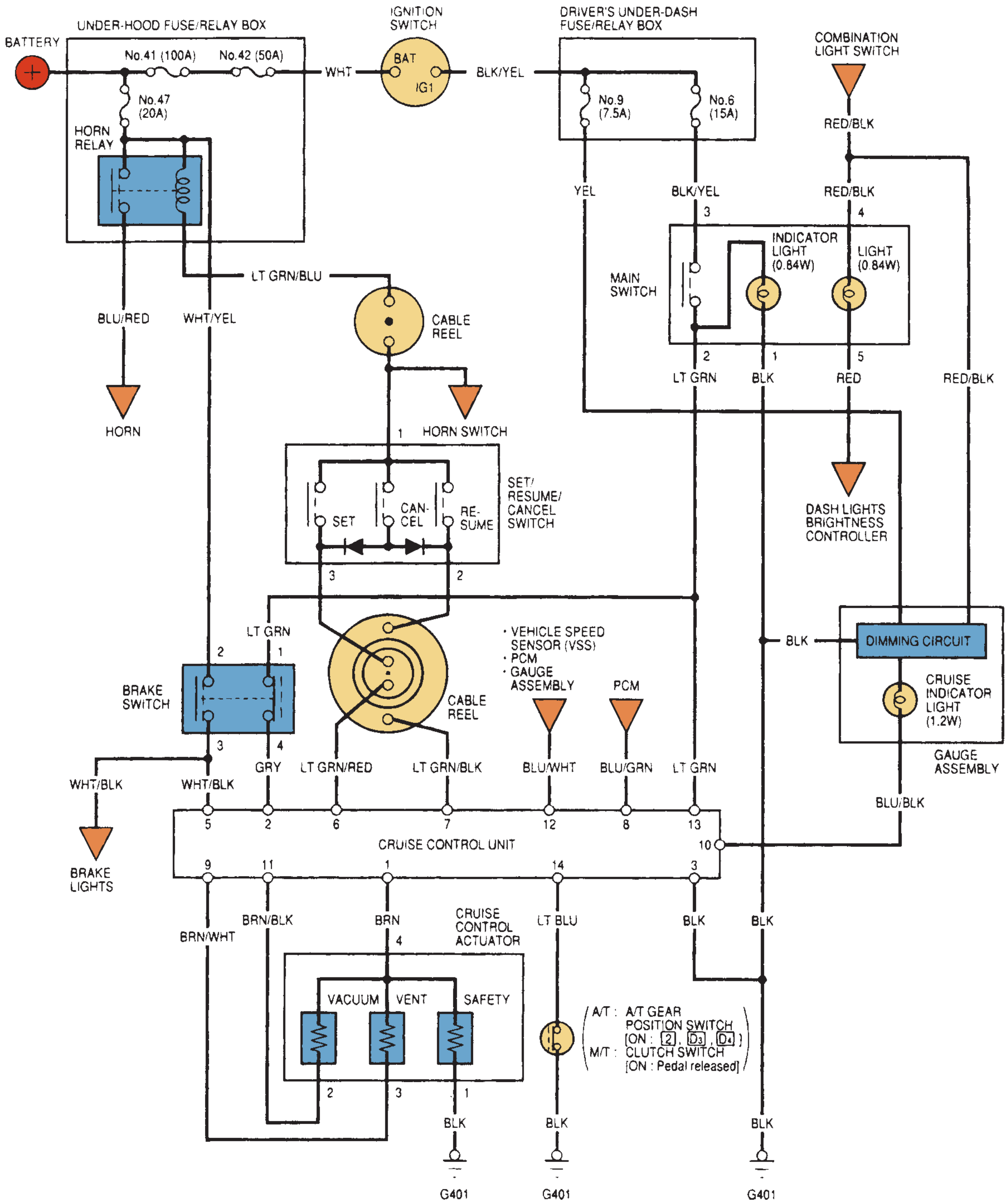


FIGURE 24–3 Circuit diagram of a typical electronic cruise control system.

STEP 4 Inspect the throttle cable and linkage between the sensor unit and the throttle plate for proper operation without binding or sticking.

STEP 5 Check the vacuum hoses for cracks or other faults.

STEP 6 Check that the vacuum servo unit (if equipped), using a hand-operated vacuum pump, can hold vacuum without leaking.

STEP 7 Check the servo solenoids for proper operation, including a resistance measurement check.

TECH TIP

Check the Third Brake Light

On many General Motors vehicles, the cruise control will not work if the third brake light is out. This third brake light is called the **center high-mounted stop light (CHMSL).** Always check the brake lights first if the cruise control does not work on a General Motors vehicle.

FIGURE 24–4 A typical electronic throttle with the protective covers removed.

FIGURE 24–5 A trailer icon lights on the dash of this Cadillac when the transmission trailer towing mode is selected.

ELECTRONIC THROTTLE CRUISE CONTROL

PARTS AND OPERATION Many vehicles are equipped with an **electronic throttle control (ETC)** system. Vehicles equipped with such a system do not use throttle actuators for the cruise control. The ETC system operates the throttle under all engine operating conditions. An ETC system uses a DC electric motor to move the throttle plate that is spring loaded to a partially open position. The motor actually closes the throttle at idle against spring pressure. The spring-loaded position is the default position and results in a high idle speed. The powertrain control module (PCM) uses the input signals from the *accelerator pedal position (APP)* sensor to determine the desired throttle position. The PCM then commands the throttle to the necessary position of the throttle plate. ● **SEE FIGURE 24–4.**

The cruise control on a vehicle equipped with an electronic throttle control system consists of a switch to set the desired speed. The PCM receives the vehicle speed information from the vehicle speed (VS) sensor and uses the ETC system to maintain the set speed.

DIAGNOSIS AND SERVICE Any fault in the APP sensor or ETC system will disable the cruise control function. Always follow the specified troubleshooting procedures, which will usually include the use of a scan tool to properly diagnose the ETC system.

TECH TIP

Use Trailer Tow Mode

Some customers complain that when using cruise control while driving in hilly or mountainous areas that the speed of the vehicle will sometimes go 5 to 8 mph below the set speed. The automatic transmission then downshifts, the engine speed increases, and the vehicle returns to the set speed. To help avoid the slowdown and rapid acceleration, ask the customer to select the trailer towing position. When this mode is selected, the automatic transmission downshifts almost as soon as the vehicle speed starts to decrease. This results in a smoother operation and is less noticeable to both the driver and passengers. ● **SEE FIGURE 24–5.**

RADAR CRUISE CONTROL

PURPOSE AND FUNCTION The purpose of a radar cruise control system is to give the driver more control over the vehicle by keeping an assured clear distance behind the vehicle in front. If the vehicle in front slows, the radar cruise control detects the slowing vehicle and automatically reduces the speed of the vehicle to keep a safe distance. Then if the vehicle speeds up, the radar cruise control also allows the vehicle to increase to the preset speed. This makes driving in congested areas easier and less tiring.

TERMINOLOGY Depending on the manufacturer, radar cruise control is also referred to as the following:

- **Adaptive cruise control** (Audi, Ford, General Motors, and Hyundai)
- **Dynamic cruise control** (BMW, Toyota/Lexus)
- **Active cruise control** (Mini Cooper, BMW)
- **Autonomous cruise control** (Mercedes)

It uses forward-looking radar to sense the distance to the vehicle in front and maintains an assured clear distance. This type of cruise control system works within the following conditions.

1. Speeds from 20 to 100 mph (30 to 161 km/h)
2. Designed to detect objects as far away as 500 ft (150 m)

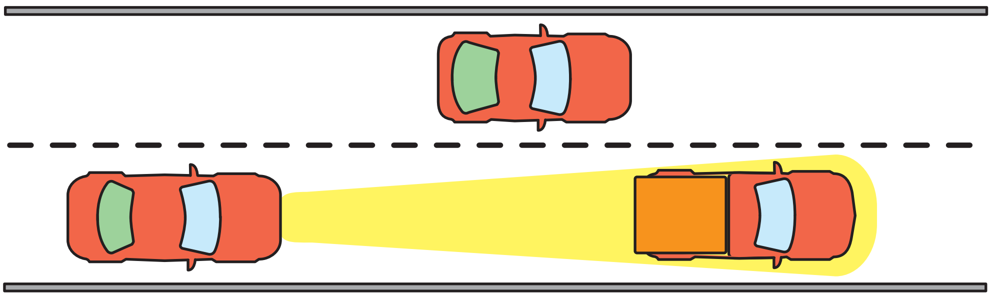


FIGURE 24–6 Radar cruise control uses sensors to keep the distance the same even when traffic slows ahead.

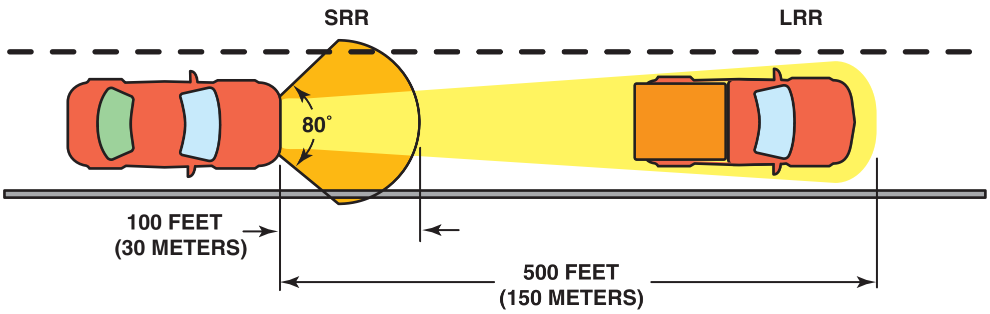


FIGURE 24–7 Most radar cruise control systems use radar, both long and short range. Some systems use optical or infrared cameras to detect objects.

? FREQUENTLY ASKED QUESTION

Will Radar Cruise Control Set Off My Radar Detector?

It is doubtful. The radar used for radar cruise control systems operates on frequencies that are not detectable by police radar detector units. Cruise control radar works on the following frequencies.

- 76 to 77 GHz (long range)
- 24 GHz (short range)

The frequencies used for the various types of police radar include:

- X-band: 8 to 12 GHz
- K-band: 24 GHz
- Ka-band: 33 to 36 GHz

The only time there may be interference is when the radar cruise control, as part of a precollision system, starts to use short-range radar (SRR) in the 24 GHz frequency. This would trigger the radar detector but would be an unlikely event and just before a possible collision with a vehicle coming toward you.

The cruise control system is able to sense both distance and relative speed. ● **SEE FIGURE 24–6.**

PARTS AND OPERATION Radar cruise control systems use long-range radar (LRR) to detect faraway objects in front of the moving vehicle. Some systems use a short-range radar (SRR) and/or infrared (IR) or optical cameras to detect distances for when the distance between the moving vehicle and another vehicle in front is reduced. ● **SEE FIGURE 24–7.**

The radar frequencies include:

- 76 to 77 GHz (long-range radar)
- 24 GHz (short-range radar)

PRECOLLISION SYSTEM

PURPOSE AND FUNCTION The purpose and function of a precollision system is to monitor the road ahead and prepare to avoid a collision, and to protect the driver and passengers. A precollision system uses components of the following systems.

1. The long-range and short-range radar or detection systems used by a radar cruise control system to detect objects in front of the vehicle
2. Antilock brake system (ABS)
3. Adaptive (radar) cruise control
4. Brake assist system

TERMINOLOGY Precollision systems can be called various names depending on the make of the vehicle. Some commonly used names for a precollision or precrash system include:

- **Ford/Lincoln:** Collision Warning with Brake Support
- **Honda/Acura:** Collision Mitigation Brake System (CMBS)
- **Mercedes-Benz:** Pre-Safe or Attention Assist
- **Toyota/Lexus:** Pre-Collision System (PCS) or Advanced Pre-Collision System (APCS)

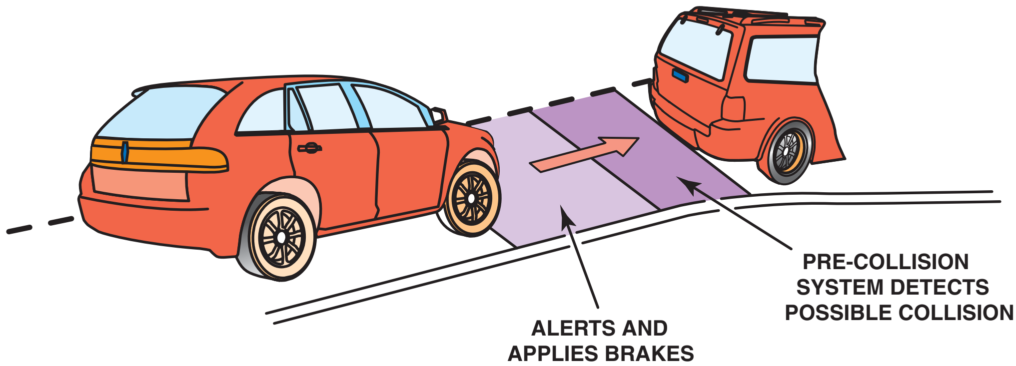


FIGURE 24–8 A precollision system is designed to prevent a collision first, and then interacts to prepare for a collision if needed.

- **General Motors:** Pre-Collision System (PCS)
- **Volvo:** Collision Warning with Brake Support or Collision Warning with Brake Assist

OPERATION The system functions by monitoring objects in front of the vehicle and can act to avoid a collision by the following actions.

- Sounds an alarm
- Flashes a warning lamp
- Applies the brakes and brings the vehicle to a full stop (if needed), if the driver does not react

● **SEE FIGURE 24–8.**

If the system is unable to prevent a collision, the system will perform the following actions.

1. Apply the brakes full force to reduce vehicle speed as much as possible
2. Close all windows and the sunroof to prevent the occupants from being ejected from the vehicle
3. Move the seats to an upright position
4. Raise the headrest (if electrically powered)
5. Pretension the seat belts
6. Airbags and seat belt tensioners function as designed during the collision

HEATED REAR WINDOW DEFOGGERS

PARTS AND OPERATION An electrically heated rear window defogger system uses an electrical grid baked on the glass that warms the glass to about 85°F (29°C) and clears it of fog or frost. The rear window is also called a **backlight**. The rear window defogger system is controlled by a driver-operated switch and a timer relay. ● **SEE FIGURE 24–9.**

The timer relay is necessary because the window grid can draw up to 30 A, and continued operation would put a strain on the battery and the charging system. Generally, the timer relay permits current to flow through the rear window grid for only 10 minutes. If the window is still not clear of fog after 10 minutes, the driver can turn the defogger on again, but after the first 10 minutes any additional defogger operation is limited to 5 minutes.

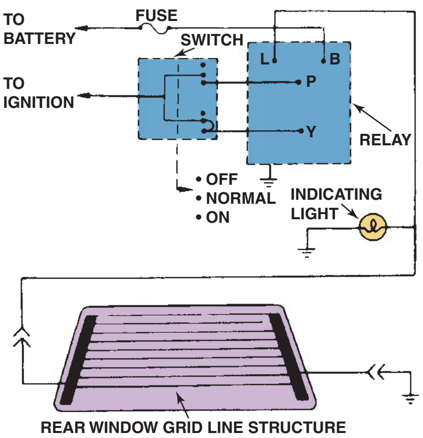


FIGURE 24–9 A switch and relay control current through the heating grid of a rear window defogger.

PRECAUTION Electric grid-type rear window defoggers can be damaged easily by careless cleaning or scraping of the inside of the rear window glass. Short, broken sections of the rear window grid can be repaired using a special epoxy-based electrically conductive material. If more than one section is damaged or if the damaged grid length is greater than approximately 1.5 in. (3.8 cm), a replacement rear window glass may be required to restore proper defogger operation.

The electrical current through the grids depends, in part, on the temperature of the conductor grids. As the temperature decreases, the resistance of the grids decreases and the current flow increases, helping to warm the rear glass. As the temperature of the glass increases, the resistance of the conductor grids increases and the current flow decreases. Therefore, the defogger system tends to self-regulate the electrical current requirements to match the need for defogging.

NOTE: Some vehicles use the wire grid of the rear window defogger as the radio antenna. Therefore, if the grid is damaged, radio reception can also be affected.

HEATED REAR WINDOW DEFOGGER DIAGNOSIS Troubleshooting a nonfunctioning rear window defogger unit involves using a test light or a voltmeter to check for voltage to

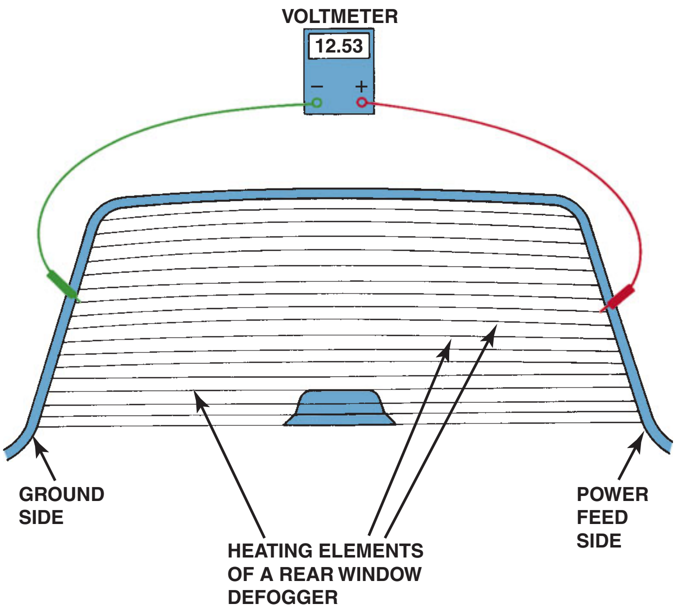


FIGURE 24–10 A rear window defogger electrical grid can be tested using a voltmeter to check for a decreasing voltage as the meter lead is moved from the power side toward the ground side. As the voltmeter positive lead is moved along the grid (on the inside of the vehicle), the voltmeter reading should steadily decrease as the meter approaches the ground side of the grid.

TECH TIP

The Breath Test

It is difficult to test for the proper operation of all grids of a rear window defogger unless the rear window happens to be covered with fog. A common trick that works is to turn on the rear defogger and exhale onto the outside of the rear window glass. In a manner similar to that of people cleaning eyeglasses with their breath, this procedure produces a temporary fog on the glass so that all sections of the rear grids can quickly be checked for proper operation.

the grid. If no voltage is present at the rear window, check for voltage at the switch and relay timer assembly. A poor ground connection on the opposite side of the grid from the power side can also cause the rear defogger not to operate. Because most defogger circuits use an indicator light switch and a relay timer, it is possible to have the indicator light on, even if the wires are disconnected at the rear window grid. A voltmeter can be used to test the operation of the rear window defogger grid. ● **SEE FIGURE 24–10.**

With the negative test terminal attached to a good body ground, carefully probe the grid conductors. There should be a decreasing voltage reading as the probe is moved from the power ("hot") side of the grid toward the ground side of the grid.

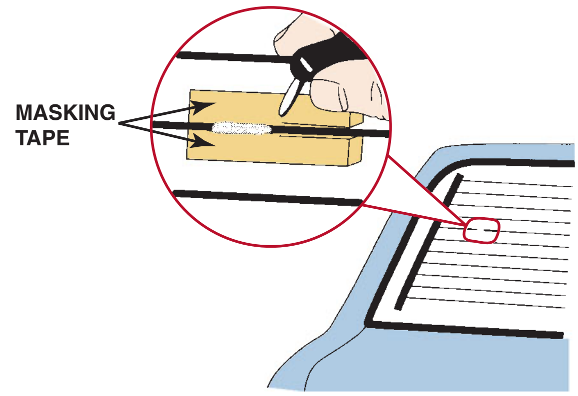


FIGURE 24–11 The typical repair material contains conductive silver-filled polymer, which dries in 10 minutes and is usable in 30 minutes.

REPAIR OR REPLACEMENT If there is a broken grid wire, it can be repaired using an electrically conductive substance available in a repair kit.

Most vehicle manufacturers recommend that grid wire less than 2 in. (5 cm) long be repaired. If a bad section is longer than 2 in., the entire rear window will need to be replaced. ● **SEE FIGURE 24–11.**

HEATED MIRRORS

PURPOSE AND FUNCTION The purpose and function of heated outside mirrors is to heat the surface of the mirror, which evaporates moisture on the surface. The heat helps keep ice and fog off the mirrors, to allow for better driver visibility.

PARTS AND OPERATION Heated outside mirrors are often tied into the same electrical circuit as the rear window defogger. Therefore, when the rear defogger is turned on, the heating grid on the backside of the mirror is also turned on. Some vehicles use a switch for each mirror.

DIAGNOSIS The first step in any diagnosis procedure is to verify the customer concern. Check the owner's manual or service information for the proper method to use to turn on the heated mirrors.

NOTE: Heated mirrors are not designed to melt snow or a thick layer of ice.

If a fault has been detected, follow service information instructions for the exact procedure to follow. If the mirror itself is found to be defective, it is usually replaced as an assembly instead of being repaired.

FIGURE 24–12 Typical HomeLink garage door opener buttons. Notice that three different units can be controlled from the vehicle using the HomeLink system.

HOMELINK GARAGE DOOR OPENER

OPERATION **HomeLink** is a device installed in many new vehicles that duplicates the radio-frequency code of the original garage door opener. The frequency range which HomeLink is able to operate is 288 to 418 MHz. The typical vehicle garage door opening system has three buttons that can be used to operate one or more of the following devices.

1. Garage doors equipped with a radio transmitter electric opener
2. Gates
3. Entry door locks
4. Lighting or small appliances

The devices include both fixed-frequency devices, usually older units, and rolling (encrypted) code devices. ● **SEE FIGURE 24–12.**

PROGRAMMING A VEHICLE GARAGE DOOR OPENER

When a vehicle is purchased, it must be programmed using the transmitter for the garage door opener or other device.

NOTE: The HomeLink garage door opening controller can only be programmed by using a transmitter. If an automatic garage door system does not have a remote transmitter, HomeLink cannot be programmed.

Normally, the customer is responsible for programming the HomeLink to the garage door opener. However, some customers may find that help is needed from the service department. The steps that are usually involved in programming HomeLink in the vehicle to the garage door opener are as follows:

STEP 1 Unplug the garage door opener during programming to prevent it from being cycled on and off, which could damage the motor.

STEP 2 Check that the frequency of the handheld transmitter is between 288 and 418 MHz.

STEP 3 Install new batteries in the transmitter to be assured of a strong signal being transmitted to the HomeLink module in the vehicle.

STEP 4 Turn the ignition on, engine off (KOEO).

STEP 5 While holding the transmitter 4 to 6 in. away from the HomeLink button, press and hold the HomeLink button while pressing and releasing the handheld transmitter every two seconds. Continue pressing and releasing the transmitter until the indicator light near the HomeLink button changes from slow blink to a rapid flash.

STEP 6 Verify that the vehicle garage door system (HomeLink) button has been programmed. Press and hold the garage door button. If the indicator light blinks rapidly for two seconds and then comes on steady, the system has been successfully programmed using a rolling code design. If the indicator light is on steady, then it has been successfully programmed to a fixed-frequency device.

DIAGNOSIS AND SERVICE If a fault occurs with the HomeLink system, first verify that the garage door opener is functioning correctly. Also, check if the garage door opener remote control is capable of operating the door. Repair the garage door opener system as needed.

If the problem still exists, attempt reprogramming the HomeLink vehicle system, being sure that the remote has a newly purchased battery.

POWER WINDOWS

SWITCHES AND CONTROLS Power windows use electric motors to raise and lower door glass. They can be operated by both a **master control switch** located beside the driver and additional **independent switches** for each electric window. Some power window systems use a **lockout switch** located on the driver's controls to prevent operation of the power windows from the independent switches. Power windows are designed to operate only with the ignition switch in the on (run) position, although some manufacturers use a time delay for accessory power after the ignition switch is turned off. This feature permits the driver and passengers an opportunity to close all windows or operate other accessories for about 10 minutes or until a vehicle door is opened after the ignition has been turned off. This feature is often called *retained accessory power*.

POWER WINDOW MOTORS Most power window systems use **permanent magnet (PM) electric motors**. It is possible to run a PM motor in the reverse direction simply by reversing the polarity of the two wires going to the motor. Most power window motors do not require that the motor be grounded to the body (door) of the vehicle. The ground for all the power windows is most often centralized near the driver's master control switch. The up-and-down motion of the individual window motors is controlled by double-pole, double-throw

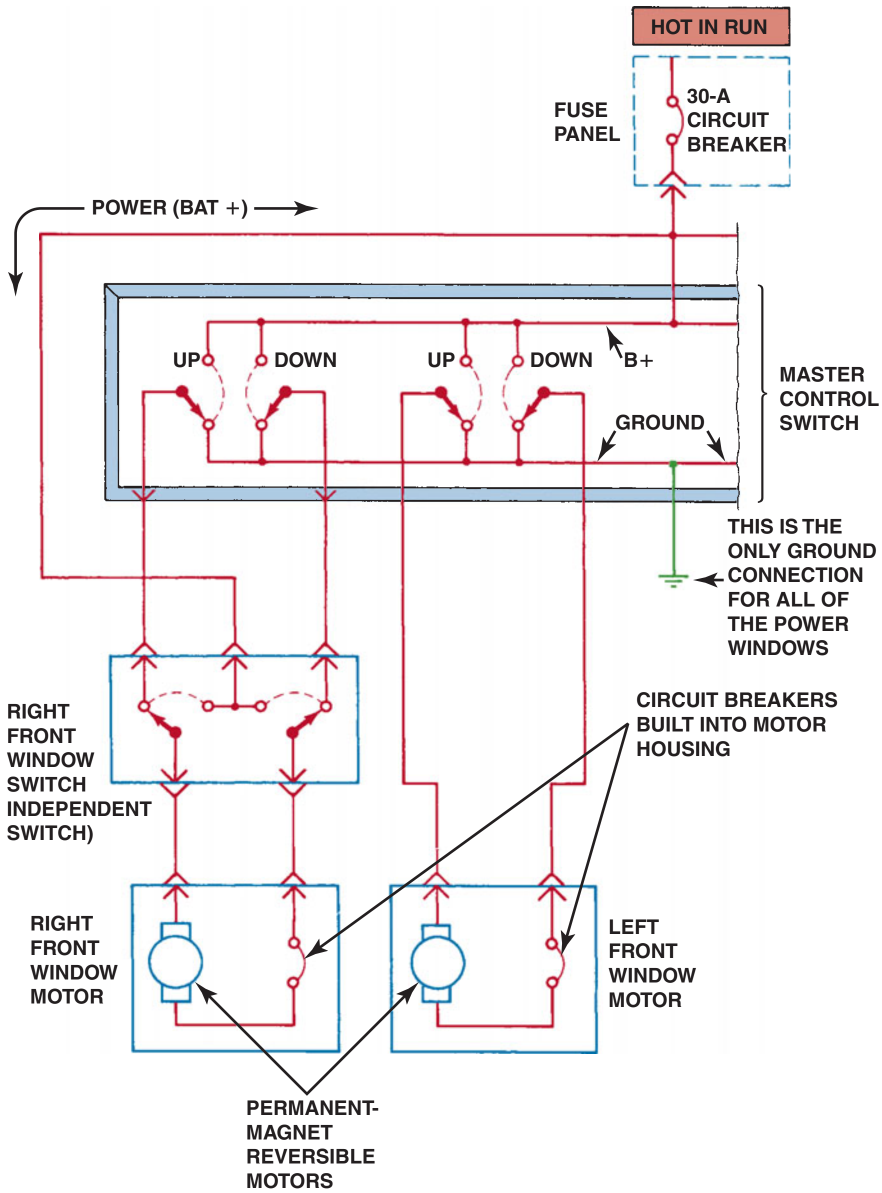


FIGURE 24–13 A typical power window circuit using PM motors. Control of the direction of window operation is achieved by directing the polarity of the current through the nongrounded motors. The only ground for the entire system is located at the master control (driver's side) switch assembly.

(DPDT) switches. These DPDT switches have five contacts and permit battery voltage to be applied to the power window motor, as well as reverse the polarity and direction of the motor. Each motor is protected by an electronic circuit breaker. These circuit breakers are built into the motor assembly and are not a separate replaceable part. ● **SEE FIGURE 24–13.**

The power window motors rotate a mechanism called a **window regulator.** The window regulator is attached to the door glass and controls opening and closing of the glass. Door glass adjustments such as glass tilt and upper and lower stops are usually the same for both power and manual windows. ● **SEE FIGURE 24–14.**

AUTO DOWN/UP FEATURES Many power windows are equipped with an auto down feature that allows windows to be lowered all of the way if the control switch is moved to a detent or held down for longer than 0.3 second. The window will then move down all the way to the bottom, and then the motor stops.

Many vehicles are equipped with the auto up feature that allows the driver to raise the driver's side or all windows in some cases, with just one push of the button. A sensor in the window motor circuit measures the current through the motor. The circuit is opened if the window touches an object, such as a hand or finger. When the window reaches the top or hits an object, the current through the window motor increases. When the upper limit amperage draw is reached, the motor circuit is opened and the window either stops or reverses. Most newer power windows use network communications modules to operate the power windows, and the switches are simply voltage signals to the module which supplies current to the individual window motors. ● **SEE FIGURE 24–15.**

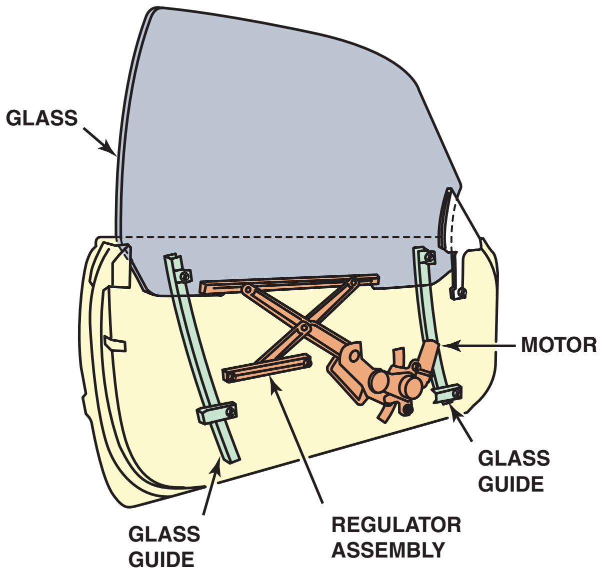


FIGURE 24–14 An electric motor and a regulator assembly raise and lower the glass on a power window.

> **TECH TIP**
>
> **Programming Auto Down Power Windows**
>
> Many vehicles are equipped with automatic operation that can cause the window to go all the way down (or up) if the switch is depressed beyond a certain point or held for a fraction of a second. Sometimes this feature is lost if the battery in the vehicle has been disconnected. Although this programming procedure can vary depending on the make and model, many times the window(s) can be reprogrammed without using a scan tool by simply depressing and holding the down button for 10 seconds. If the vehicle is equipped with an auto up feature, repeat the procedure by holding the button up for 10 seconds. Always check exact service information for the vehicle being serviced.

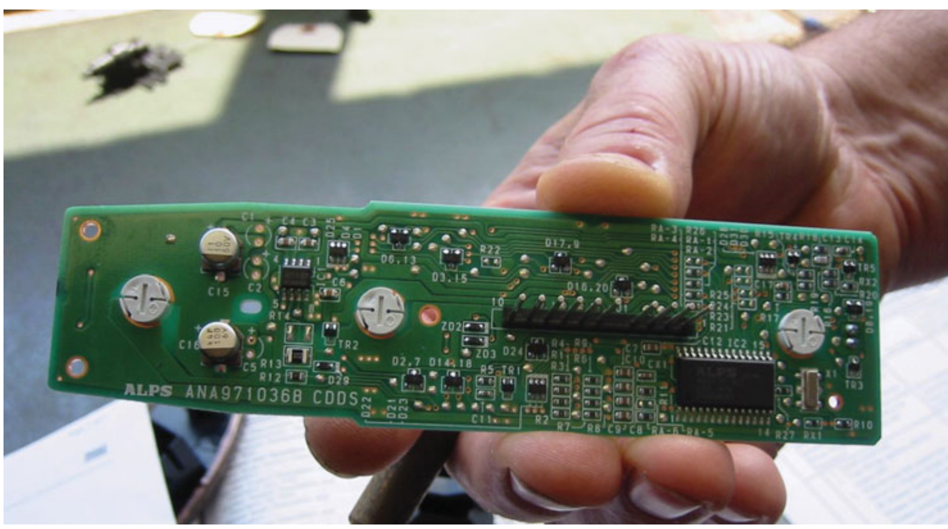


FIGURE 24–15 A master power window control panel with the buttons and the cover removed.

TROUBLESHOOTING POWER WINDOWS

Before troubleshooting a power window problem, check for proper operation of all power windows. Check service information for the exact procedure to follow. In a newer system, a scan tool can be used to perform the following:

- Check for B (body) or U (network) diagnostic trouble codes (DTCs)
- Operate the power windows using the bidirectional control feature
- Relearn or program the operation of the power windows after a battery disconnect

For older systems, if one of the **control wires** that run from the independent switch to the master switch is cut (open), the power window may operate in only one direction. The window may go down but not up, or vice versa. However, if one of the **direction wires** that run from the independent switch to the motor is cut (open), the window will not operate in either direction. The direction wires and the motor must be electrically connected to permit operation and change of direction of the electric lift motor in the door.

1. If *both* rear door windows fail to operate from the independent switches, check the operation of the window lockout (if the vehicle is so equipped) and the master control switch.
2. If one window can move in one direction only, check for continuity in the control wires (wires between the independent control switch and the master control switch).
3. If *all* windows fail to work or fail to work occasionally, check, clean, and tighten the ground wire(s) located either behind the driver's interior door panel or under the dash on the driver's side. A defective fuse or circuit breaker could also cause all the windows to fail to operate.
4. If one window fails to operate in both directions, the problem could be a defective window lift motor. The window could be

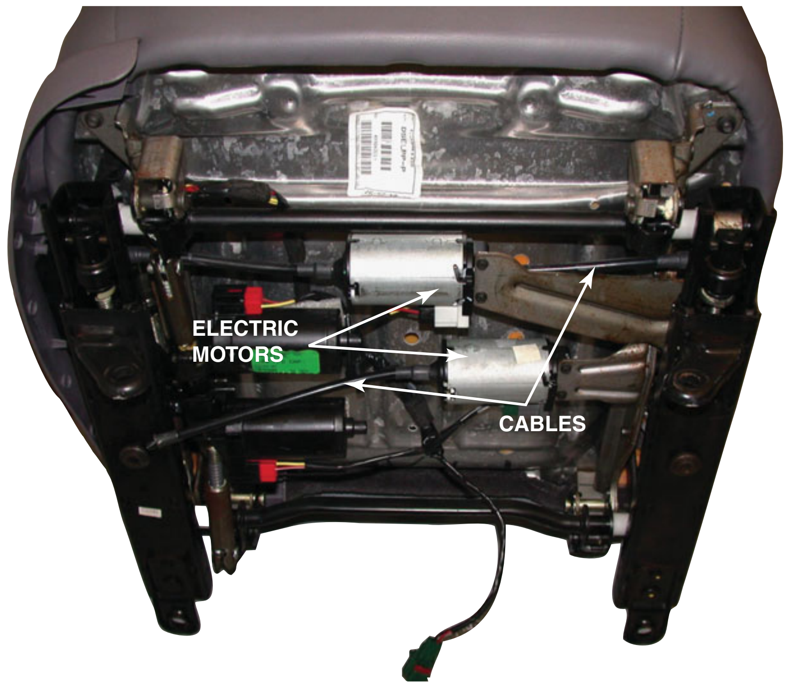


FIGURE 24–16 A power seat uses electric motors under the seat, which drive cables that extend to operate screw jacks (up and down) or gears to move the seat forward and back.

stuck in the track of the door, which could cause the circuit breaker built into the motor to open the circuit to protect the wiring, switches, and motor from damage. To check for a stuck door glass, attempt to move (even slightly) the door glass up and down, forward and back, and side to side. If the window glass can move slightly in all directions, the power window motor should be able to at least move the glass.

5. Always refer to and follow service information when diagnosing power window circuits.

POWER SEATS

PARTS AND OPERATION A typical power-operated seat includes a reversible electric motor and a transmission assembly that may have three solenoids and six *drive cables* that turn the six seat adjusters. A six-way power seat offers seat movement forward and backward, plus seat cushion movement up and down at the front and the rear. The drive cables are similar to speedometer cables because they rotate inside a cable housing and connect the power output of the seat transmission to a gear or screw jack assembly that moves the seat. ● **SEE FIGURE 24–16.**

A **screw jack assembly** is often called a *gear nut.* It is used to move the front or back of the seat cushion up and down.

A **rubber coupling**, usually located between the electric motor and the transmission, and prevents electric motor damage in the event of a jammed seat. This coupling is designed to prevent motor damage.

Most power seats use a permanent magnet motor that can be reversed by simply reversing the polarity of the current sent to the motor by the seat switch. ● **SEE FIGURE 24–17.**

POWER SEAT MOTOR(S) Most PM motors have a built-in circuit breaker or PTC circuit protector to protect the motor from overheating. Many Ford power seat motors use three separate armatures inside one large permanent magnet field housing. Some power seats use a series-wound electric motor with two separate field coils, one field coil for each direction of rotation. This type of power seat motor typically uses a relay to control the direction of current from the seat switch to the corresponding field coil of the seat motor. This type of power seat can be identified by the "click" heard when the seat switch is changed from up to down or front to back, or vice versa. The click is the sound of the relay switching the field coil current. Some power seats use as many as eight separate PM motors that operate all functions of the seat, including headrest height, seat length, and side bolsters, in addition to the usual six-way power seat functions.

NOTE: Some power seats use a small air pump to inflate a bag (or bags) in the lower part of the back of the seat, called the lumbar, because it supports the lumbar section of the spine. The lumbar section of the seat can also be changed, using a lever or knob that the driver can move to change the seat section for the lower back.

MEMORY SEAT Memory seats use a potentiometer to sense the position of the seat. The seat position can be programmed into the body control module (BCM) or memory seat module and stored by position number 1, 2, or 3. The driver pushes the desired button and the seat moves to the stored position. ● **SEE FIGURE 24–18** on page 348.

On some vehicles, the memory seat position is also programmed into the remote keyless entry key fob.

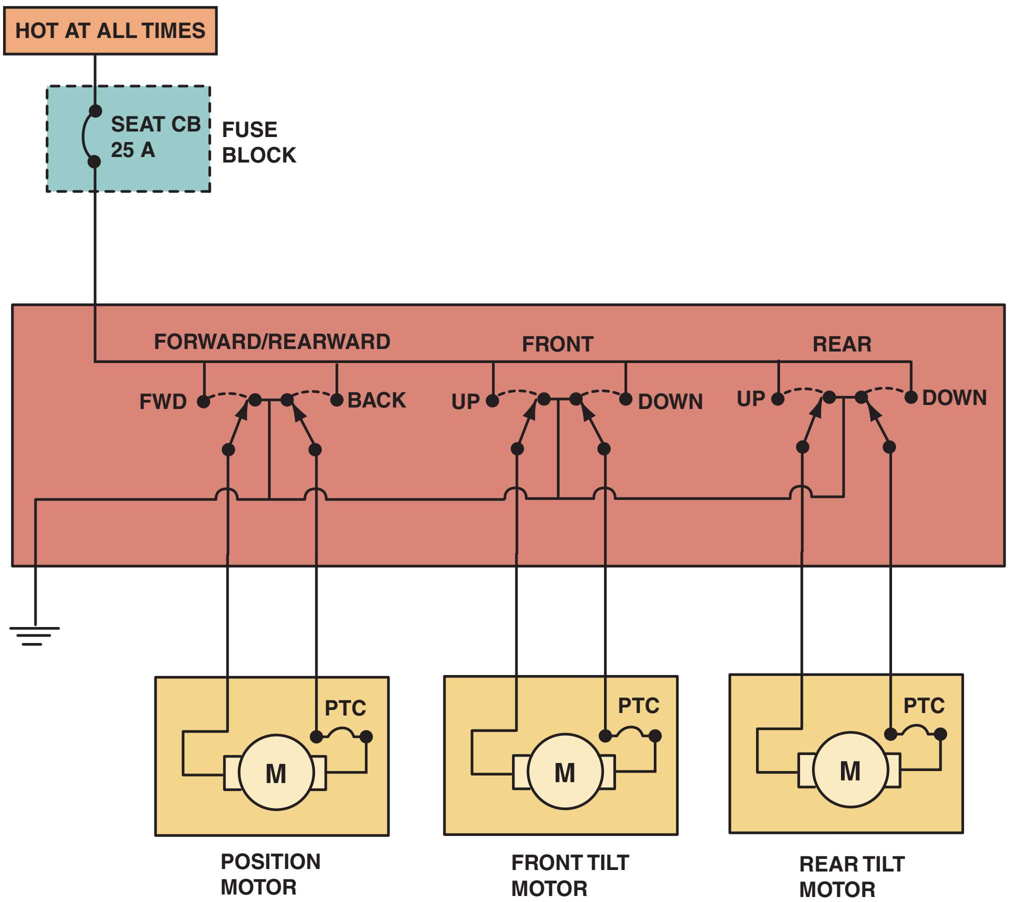


FIGURE 24–17 A typical power seat circuit diagram. Notice that each motor has a built-in electronic (solid-state) PTC circuit protector. The seat control switch can change the direction in which the motor(s) runs by reversing the direction in which the current flows through the motor.

TECH TIP

Easy Exit Seat Programming

Some vehicles are equipped with memory seats that allow the seat to move rearward when the ignition is turned off to allow easy exit from the vehicle. Vehicles equipped with this feature include an *exit/entry* button that is used to program the desired exit/entry position of the seat for each of two drivers.

If the vehicle is not equipped with this feature and only one driver primarily uses the vehicle, the second memory position can be programmed for easy exit and entry. Simply set position 1 to the desired seat position and position 2 to the entry/exit position. Then, when exiting the vehicle, press memory 2 to allow easy exit and easy entry the next time. Press memory 1 when in the vehicle to return the seat memory to the desired driving position.

TROUBLESHOOTING POWER SEATS Power seats are usually wired from the fuse panel so they can be operated without having to turn the ignition switch to on (run). If a power seat does not operate or make any noise, the circuit breaker (or fuse, if the vehicle is so equipped) should be checked first. The steps usually include:

STEP 1 Check service information for the exact procedure to follow when diagnosing power seats. If the seat relay clicks, the circuit breaker is functioning, but the relay or electric motor may be defective.

STEP 2 Remove the screws or clips that retain the controls to the inner door panel or seat and check for voltage at the seat control.

STEP 3 Check the ground connection(s) at the transmission and clutch control solenoids (if equipped). The solenoids must be properly grounded to the vehicle body for the power seat circuit to operate.

If the power seat motor runs but does not move the seat, the most likely fault is a worn or defective rubber clutch sleeve between the electric seat motor and the transmission.

If the seat relay clicks but the seat motor does not operate, the problem is usually a defective seat motor or defective wiring between the motor and the relay. If the power seat uses a motor relay, the motor has a double reverse-wound field for reversing the motor direction. This type of electric motor must be properly grounded. Permanent magnet motors do not require grounding for operation.

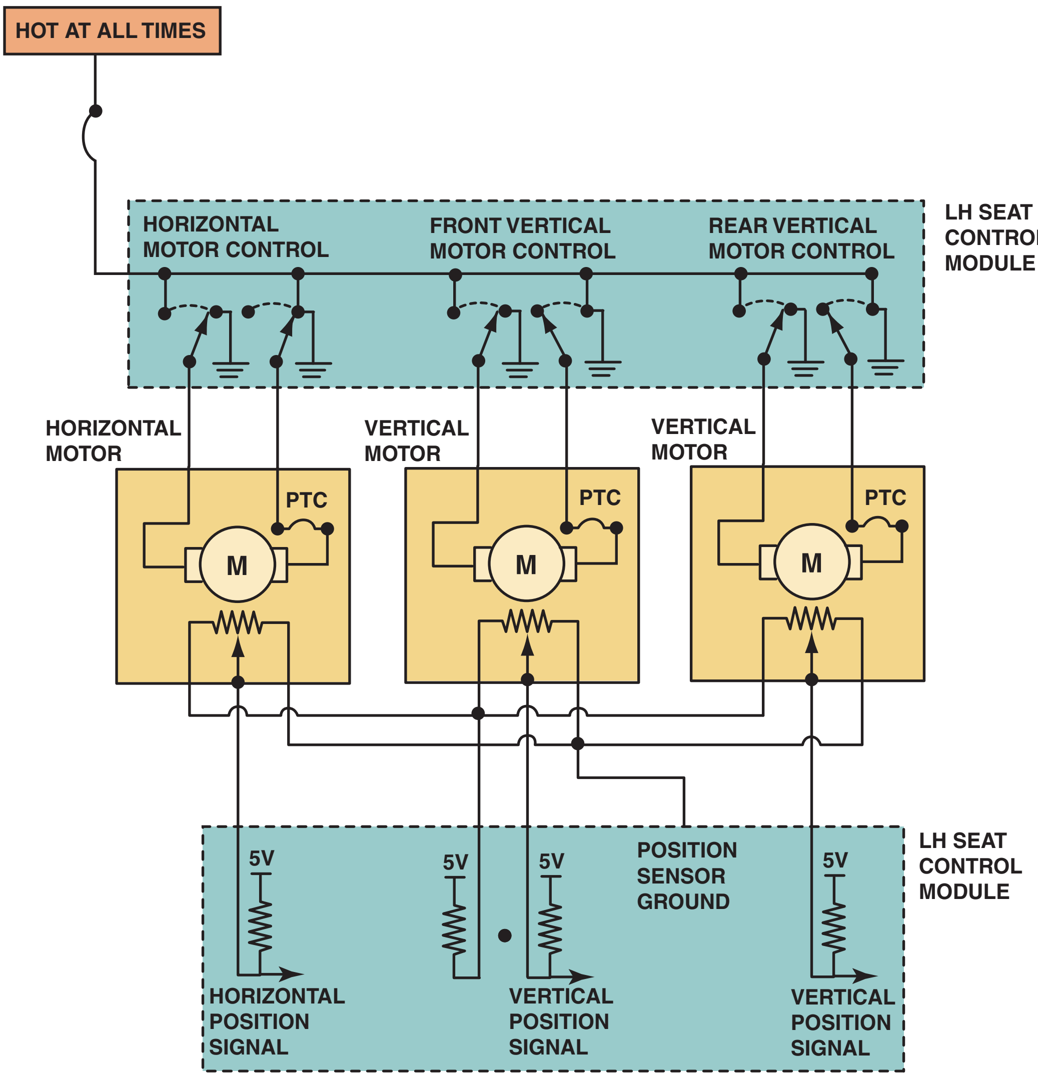


FIGURE 24–18 A typical memory seat module showing the three-wire potentiometer used to determine seat position.

TECH TIP

What Every Driver Should Know About Power Seats

Power seats use an electric motor or motors to move the position of the seat. These electric motors turn small cables that operate mechanisms that move the seat. *Never* place rags, newspapers, or any other object under a power seat. Even ice scrapers can get caught between moving parts of the seat and can often cause serious damage or jamming of the power seat.

NOTE: Power seats are often difficult to service because of restricted working room. If the entire seat cannot be removed from the vehicle because the track bolts are covered, attempt to remove the seat from the top of the power seat assembly. These bolts are almost always accessible regardless of seat position.

ELECTRICALLY HEATED SEATS

PARTS AND OPERATION Heated seats use electric heating elements in the seat bottom, as well as in the seat back in many vehicles. The heating element is designed to warm the seat and/or back of the seat to about 100°F (37°C) or close to normal body temperature (98.6°F). Many heated seats also include a high-position or a variable temperature setting, so the temperature of the seats can therefore be as high as 110°F (44°C).

A temperature sensor in the seat cushion is used to regulate the temperature. The sensor is a variable resistor which changes with temperature and is used as an input signal to a heated seat control module. The heated seat module uses the seat temperature input, as well as the input from the high-low (or variable) temperature control, to turn the current on or off to the heating element in the seat. Some vehicles are equipped with heated seats in both the rear and the front seats.

FIGURE 24–19 The heating element of a heated seat is a replaceable part, but service requires that the upholstery be removed. The yellow part is the seat foam material and the entire white cover is the replaceable heating element. This is then covered by the seat material.

DIAGNOSIS AND SERVICE When diagnosing a heated seat concern, start by verifying that the switch is in the on position and that the temperature of the seat is below normal body temperature. Using service information, check for power and ground at the control module and to the heating element in the seat. Most vehicle manufacturers recommend replacing the entire heating element if it is defective. ● **SEE FIGURE 24–19.**

HEATED AND COOLED SEATS

PARTS AND OPERATION Most electrically heated and cooled seats use a **thermoelectric device (TED)** located under the seat cushion and seat back. The thermoelectric device consists of positive and negative connections between two ceramic plates. Each ceramic plate has copper fins to allow the transfer of heat to air passing over the device and directed into the seat cushion. The thermoelectric device uses the **Peltier effect,** named after the inventor, Jean C. A. Peltier, a French clockmaker. When electrical current flows through the module, one side is heated and the other side is cooled. Reversing the polarity of the current changes which side is heated. ● **SEE FIGURE 24–20.**

Most vehicles equipped with heated and cooled seats use two modules per seat, one for the seat cushion and one for the seat back. When the heated and cooled seats are turned on, air is forced through a filter and then through the thermoelectric modules. The air is then directed through passages in the foam of the seat cushion and seat back. Each thermoelectric device has a temperature sensor, called a thermistor. The control module uses sensors to determine the temperature of the fins in the thermoelectric device so the controller can maintain the set temperature.

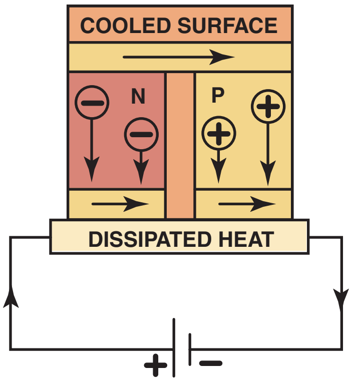


FIGURE 24–20 A Peltier effect device is capable of heating or cooling, depending on the polarity of the applied current.

TECH TIP

Check the Seat Filter

Heated and cooled seats often use a filter to trap dirt and debris to help keep the air passages clean. If a customer complains of a slow heating or cooling of the seat, check the air filter and replace or clean as necessary. Check service information for the exact location of the seat filter and for instructions on how to remove and/or replace it.

DIAGNOSIS AND SERVICE The first step in any diagnosis is to verify that the heated-cooled seat system is not functioning. Check the owner's manual or service information for the specified procedures. If the system works partially, check the air filter, usually located under the seat for each thermoelectric device. A partially clogged filter can restrict airflow and reduce the heating or cooling effect. If the system control indicator light is not on or the system does not work at all, check for power and ground at the thermoelectric devices. Always follow the vehicle manufacturer's recommended diagnosis and service procedures.

HEATED STEERING WHEEL

PARTS INVOLVED A heated steering wheel usually consists of the following components.

- Steering wheel with a built-in heater in the rim
- Heated steering wheel control switch
- Heated steering wheel control module

OPERATION When the steering wheel heater control switch is turned on, a signal is sent to the control module and electrical current flows through the heating element in the rim of the steering wheel. ● **SEE FIGURE 24–21.**

FIGURE 24–21 The heated steering wheel is controlled by a switch on the steering wheel in this vehicle.

The system remains on until the ignition switch is turned off or the driver turns off the control switch. The temperature of the steering wheel is usually calibrated to stay at about 90°F (32°C), and it requires three to four minutes to reach that temperature depending on the outside temperature.

DIAGNOSIS AND SERVICE Diagnosis of a heated steering wheel starts with verifying that the heated steering wheel is not working as designed.

NOTE: Most heated steering wheels do not work if the temperature inside the vehicle is about 90°F (32°C) or higher.

If the heated steering wheel is not working, follow the service information testing procedures which would include a check of the following:

1. Check the heated steering wheel control switch for proper operation. This is usually done by checking for voltage at both terminals of the switch. If voltage is available at only one of the two terminals of the switch and the switch has been turned on and off, an open (defective) switch is indicated.
2. Check for voltage and ground at the terminals leading to the heating element. If voltage is available at the heating element and the ground has less than 0.2 volt drop to a good chassis ground, the heating element is defective. The entire steering wheel has to be replaced if the element is defective.

Always follow the vehicle manufacturer's recommended diagnosis and testing procedures.

ADJUSTABLE PEDALS

PURPOSE AND FUNCTION **Adjustable pedals**, also called **electric adjustable pedals (EAP)**, place the brake pedal and the accelerator pedal on movable brackets that are motor operated. A typical adjustable pedal system includes the following components.

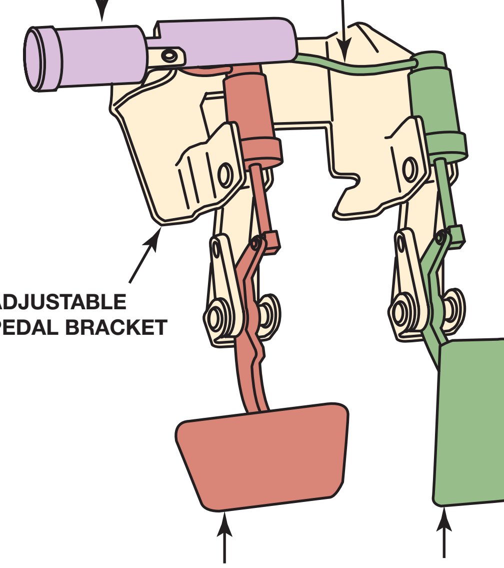


FIGURE 24–22 A typical adjustable pedal assembly. Both the accelerator and the brake pedal can be moved forward and rearward by using the adjustable pedal position switch.

TECH TIP

Check the Remote

The memory function may be programmed to a particular key fob remote, which would command the adjustable pedals to move to the position set in memory. Always check both remote settings before attempting to repair a problem that may not be a problem.

- **Adjustable pedal position switch.** Allows the driver to position the pedals
- **Adjustable pedal assembly.** Includes the motor, threaded adjustment rods, and a pedal position sensor

● SEE FIGURE 24–22.

The position of the pedals, as well as the position of the seat system, is usually included as part of the memory seat function and can be set for two or more drivers.

DIAGNOSIS AND SERVICE The first step when there is a customer concern about the functioning of the adjustable pedals is to verify that the unit is not working as designed. Check the owner manual or service information for the proper operation. Follow the vehicle manufacturer's recommended troubleshooting procedure. Many diagnostic procedures include the use of a factory scan tool with bidirectional control capabilities to test this system.

FIGURE 24–23 Electrically folded mirror in the folded position.

FIGURE 24–24 The electric mirror control is located on the driver's side door panel on this Cadillac Escalade.

REAL WORLD FIX

The Case of the Haunted Mirrors

The owner complained that while driving, either one or the other outside mirror would fold in without any button being depressed. Unable to verify the customer concern, the service technician looked at the owner's manual to find out exactly how the mirrors were supposed to work. In the manual, a caution statement said that if the mirror is electrically folded inward and then manually pushed out, the mirror will not lock into position. The power folding mirrors must be electrically cycled outward, using the mirror switches to lock them in position. After cycling both mirrors inward and outward electrically, the problem was solved. ● **SEE FIGURES 24–23 AND 24–24.**

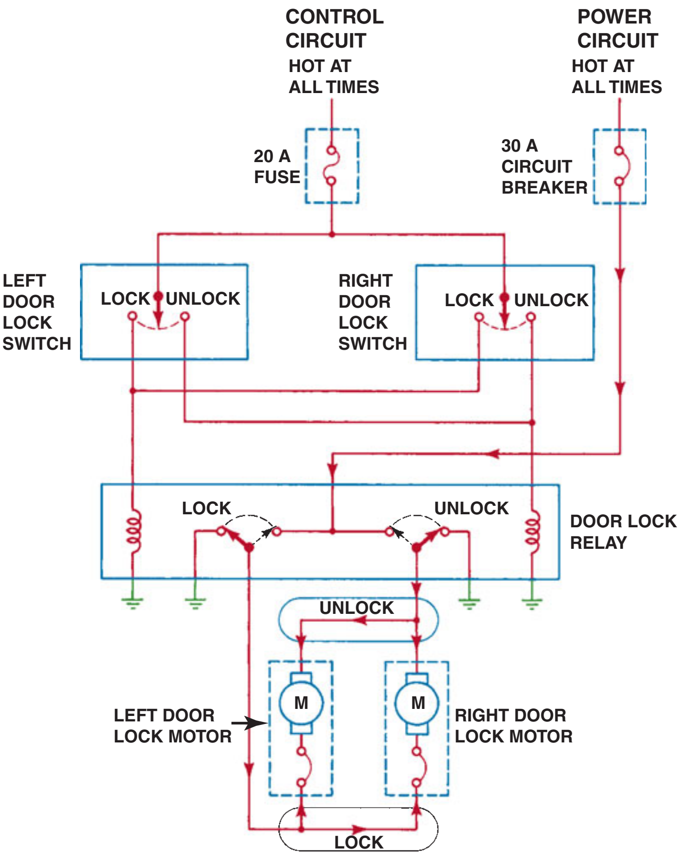


FIGURE 24–25 A typical electric power door lock circuit diagram. Note that the control circuit is protected by a fuse, whereas the power circuit is protected by a circuit breaker. As with the operation of power windows, power door locks typically use reversible permanent magnet (PM) nongrounded electric motors. These motors are geared mechanically to the lock-unlock mechanism.

OUTSIDE FOLDING MIRRORS

Mirrors that can be electrically folded inward are a popular feature, especially on larger sport utility vehicles. A control inside is used to fold both mirrors inward when needed, such as when entering a garage or close parking spot. For diagnosis and servicing of outside folding mirrors, check service information for details.

ELECTRIC POWER DOOR LOCKS

Electric power door locks use a permanent magnet (PM) reversible motor to lock or unlock all vehicle door locks from a control switch or switches.

The electric motor uses a built-in circuit breaker and operates the lock-activating rod. PM reversible motors do not require grounding because, as with power windows, the motor control is determined by the polarity of the current through the two motor wires. ● **SEE FIGURE 24–25.**

Some two-door vehicles do *not* use a power door lock relay because the current flow for only two PM motors can be handled through the door lock switches. However, most four-door vehicles and vans with power locks on rear and side doors use a relay to control the current flow necessary to operate four or more power door lock motors. The door lock relay is controlled by the door lock switch and is commonly the location of the one and only *ground* connection for the entire door lock circuit.

KEYLESS ENTRY

Even though some Ford vehicles use a keypad located on the outside of the door, most keyless entry systems use a wireless transmitter built into the key or key fob. A **key fob** is a decorative tab or item on a key chain. ● **SEE FIGURE 24–26.**

The transmitter broadcasts a signal that is received by the electronic control module, which is generally mounted in the trunk or under the instrument panel. ● **SEE FIGURE 24–27.**

The electronic control unit sends a voltage signal to the door lock actuator(s) located in the doors. Generally, if the transmitter unlock button is depressed once, only the driver's door is unlocked. If the unlock button is depressed twice, then all doors unlock.

ROLLING CODE RESET PROCEDURE Many keyless remote systems use a rolling code type of transmitter and receiver. In a conventional system, the transmitter emits a certain fixed frequency, which is received by the vehicle control module. This single frequency can be intercepted and rebroadcast to open the vehicle.

A rolling code type of transmitter emits a different frequency every time the transmitter button is depressed and then rolls over to another frequency so that it cannot be intercepted. Both the transmitter and the receiver must be kept in synchronized order so that the remote will function correctly.

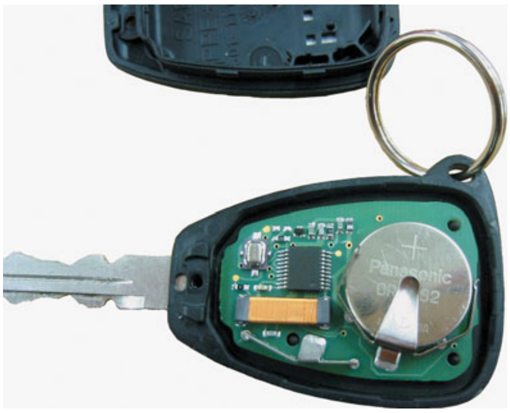


FIGURE 24–26 A key fob remote with the cover removed showing the replaceable battery.

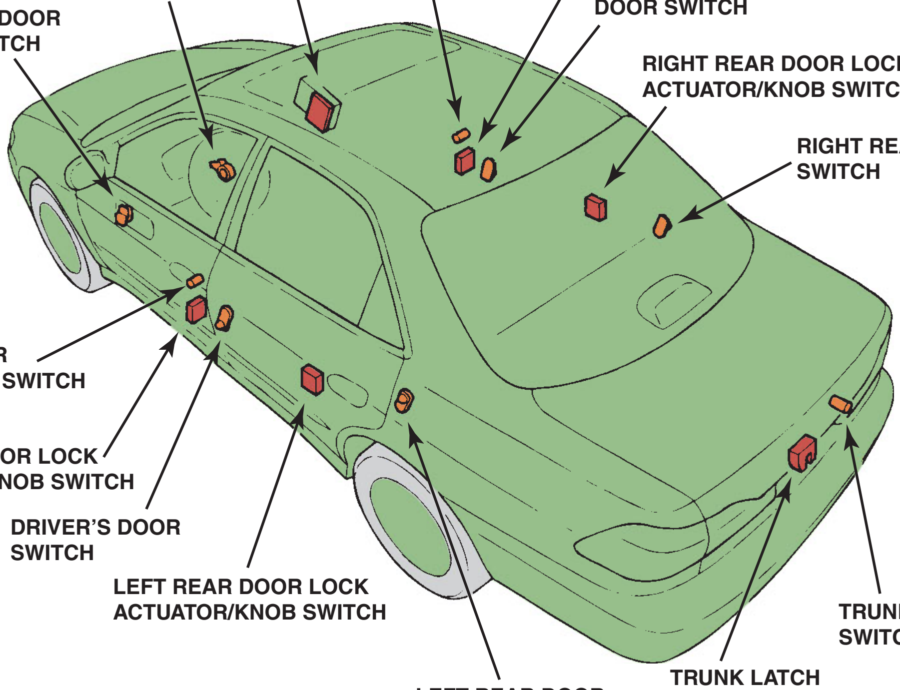


FIGURE 24–27 A typical vehicle showing the location of the various components of the remote keyless entry system.

If the transmitter is depressed when it is out of range from the vehicle, the proper frequency may not be recognized by the receiver, which did not roll over to the new frequency when the transmitter was depressed. If the transmitter does not work, try to resynchronize the transmitter to the receiver by depressing and holding both the lock and the unlock button for 10 seconds when within range of the receiver.

KEYLESS ENTRY DIAGNOSIS A small battery powers the transmitter, and a weak battery is a common cause of remote power locks failing to operate. If the keyless entry system fails to operate after the transmitter battery has been replaced, check the following items.

- Mechanical binding in the door lock
- Low vehicle battery voltage
- Blown fuse
- Open circuit to the control module
- Defective control module
- Defective transmitter

PROGRAMMING A NEW REMOTE If a new or additional remote transmitter is to be used, it must be programmed to the vehicle. The programming procedure varies and may require the use of a scan tool. Check service information for the exact procedure to follow. ● **SEE CHART 24–1.**

MAKE/MODEL	NOTES	PROCEDURE
Acura RSX MDX 3.2TL RSX **Honda** Accord Civic CR-V Odyssey	Be careful to maintain the time limits between steps. Ensure that the hood, tailgate, and doors are closed. Aim the transmitter at the receiver in the power window master switch. The keyless receiver can store up to three codes. If a fourth code is stored, the first code that was input will be erased.	1. Turn the ignition on. 2. Within 1 to 4 seconds, press the lock or unlock button. 3. Within 1 to 4 seconds, turn the ignition off. 4. Repeat steps 1 through 3 two more times. 5. Within 1 to 4 seconds, turn the ignition on (fourth time). 6. Within 1 to 4 seconds, press the lock or unlock button. 7. The door lock actuators should cycle. 8. Press the lock or unlock button a second time within 1 to 4 seconds to store the code. 9. For additional transmitters, repeat steps 6, 7, and 8. 10. Turn the ignition off and remove the key to exit programming mode.
BMW All models with transmitter in key head	Up to four transmitters can be programmed. All transmitters to be programmed must be programmed at the same time. This procedure erases all learned transmitters.	1. Use the vehicle key to unlock the central locking system. 2. Enter the vehicle and close all doors. 3. Put the key in the ignition and switch the ignition switch to position 1 and then back to off, within 5 seconds. 4. Press and hold key button 2 (arrow button). 5. While holding button 2, press button 1 (BMW logo) three times within 10 seconds. 6. Release button 2. 7. The locks will cycle to confirm programming. 8. Repeat steps 4 through 7 within 30 seconds for any additional transmitters. 9. After 30 seconds with no button pressed the programming mode will exit.
Buick Rendezvous Lucerne LaCrosse **Chevrolet** Blazer Impala Monte Carlo Uplander	A scan tool is required. A total of four transmitters can be learned. All transmitters to be programmed must be programmed at the same time. Activating program mode erases previously learned codes.	1. Install a scan tool and access the BCM Special Functions, Lift Gate Module (LGM), or Module Setup; Program Key Fobs menu. 2. Press the start key on the scan tool. 3. Press and hold both the lock and unlock buttons on the first transmitter. Within 5 to 10 seconds the scan tool will report that the transmitter is programmed. 4. Repeat step 3 to program up to four transmitters. 5. Turn off and remove the scan tool to exit programming mode.

CHART 24–1

(CONTINUED)

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

MAKE/MODEL	NOTES	PROCEDURE
Pontiac Grand Prix Montana **Saturn** Relay		
Buick Rainier **Cadillac** Escalade **Chevrolet** C/K Trucks Suburban Tahoe Trailblazer **Saab** 9-7 (some)	Fobs can also be programmed with a scan tool. All fobs to be used must be programmed at the same time. The first fob learned will be fob 1 and the second that is learned will be fob 2.	1. Enter the vehicle and close all the doors. 2. Insert the key into the ignition lock. 3. Press and hold the door unlock switch, then turn the ignition on, off, then release the unlock switch. 4. The door locks will cycle one time to confirm programming mode. 5. Press and hold the lock and unlock buttons on the key fob for about 15 seconds. 6. The locks will cycle once when the fob has been learned. 7. Repeat steps 5 and 6 to program any additional fobs. 8. Turn the ignition key to run, to exit the programming mode.
Cadillac CTS SRX	All programmed key fobs will be erased. All transmitters to be programmed must be relearned during this procedure. Up to four fobs can be programmed. The first to be learned will be fob 1 and the second to be learned will be fob 2.	1. Install the scan tool and turn the ignition on. 2. Navigate to the Body, RFA (or RCDLR), Special Functions; Program Key Fobs menu. 3. Follow the directions on the scan tool to program the transmitters.
Cadillac Deville Seville **Pontiac** Bonneville Grand Am	Up to four transmitters can be programmed. All fobs to be used must be programmed at the same time. The first fob learned will be fob 1 and the second that is learned will be fob 2.	1. Install a scan tool and turn on the ignition. 2. Navigate to the Remote Function Actuator (RFA) module: Special function, Program Key Fobs menu to activate program mode. 3. The doors will lock and unlock to indicate programming mode. 4. Press and hold the lock and unlock buttons on the fob. The door locks will cycle to indicate the fob has been learned. 5. Repeat step 4 for any additional fobs. 6. To exit programming mode, turn off and remove the scan tool.
Cadillac STS XLR **Chevrolet** Corvette	A scan tool can also be used to program key fobs. This procedure will take 30 minutes to complete. All programmed key fobs will be erased. All transmitters to be programmed must be relearned during this procedure. Up to four fobs can be programmed. The first to be learned will be fob 1 and the second to be learned will be fob 2.	1. Start with the vehicle off. 2. Place the fob to be learned in the console pocket with the buttons facing forward. 3. Insert the vehicle key into the driver's door lock cylinder and cycle the key five times within 5 seconds. The DIC will display "OFF/ACC TO LEARN." 4. Press the OFF/ACC part of the ignition button. 5. The DIC will display "WAIT 10 MINUTES," then count down to zero, 1 minute at a time. The display will change to "OFF/ACC TO LEARN." 6. Repeat steps 4 and 5 two more times for a total of 30 minutes. 7. When the DIC displays "OFF/ACC TO LEARN" for the fourth time, press the OFF/ACC button again; the DIC will display "READY FOR FOB 1." 8. When fob 1 has been learned, a beep will be heard and the DIC will display "READY FOR FOB 2." 9. Remove fob 1 from the pocket and insert fob 2. A beep will be heard when that fob has been learned. 10. Repeat steps 8 and 9 for additional fobs. 11. To exit programming, press the OFF/ACC portion of the ignition button.

CHART 24–1

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

MAKE/MODEL	NOTES	PROCEDURE
Chevrolet Cavalier Equinox Malibu SSR S/T Trucks **Saab** 9–7 (some models) **Saturn** Vue	A scan tool is required. Up to four transmitters can be programmed. On vehicles with personalization features, the transmitters are numbered 1 and 2. The first transmitter programmed will become driver 1 and the second will become driver 2.	1. Install the scan tool and navigate to the BCM or RFA menu, Special Functions; select Program Key Fobs. 2. Select Add/Replace Key Fob to program a new or additional fob. 3. Select Clear Memory and Program All Fobs option to replace all fobs or to recode driver 1 and driver 2 fobs. 4. Follow the scan tool instructions to complete the programming.
Chevrolet Venture van GM "U" vans	All fobs to be used must be programmed at the same time. Up to four transmitters can be programmed. If the BCM displays DTCs in step 5, they may have to be resolved before programming can continue.	1. With the ignition key out of the ignition, remove the BCM PRGRM fuse from the passenger side fuse block. 2. Enter the vehicle and close all doors. 3. Insert the key and turn the ignition to ACC. 4. The seat belt indicator and chime will activate two, three, or four times, depending on the type of BCM in the vehicle. 5. Turn the key off and then back to ACC within 1 second. If the BCM has any stored DTCs, they will be displayed by the chime and belt indicator at this time. 6. Open and close any door. The chime will sound to indicate programming mode. 7. Press and hold the fob lock and unlock buttons for about 14 seconds. The BCM will sound the chime when the fob has been learned. 8. Repeat step 7 for up to four total transmitters. 9. After programming, remove the ignition key and replace the BCM PRGRM fuse.
Chrysler PT Cruiser Concorde	A scan tool is required if there are no functioning transmitters. Maximum of four transmitters can be programmed. Programming mode will exit after 30 seconds.	1. Turn ignition to run and wait until the chimes stop or fasten seat belt to cancel chimes. 2. Using any original working transmitter, press and hold the unlock button for 4 to 10 seconds. 3. While holding the unlock button, press the panic button for 1 second. Chime will sound to indicate programming mode is ready. 4. Press and release any button on the transmitters to be programmed. All transmitters should be programmed at this time, including previously programmed transmitters. A chime will sound after each programming success. 5. Turn the ignition off to exit programming.
Chrysler Sebring Town and Country **Dodge** Pickup R1500 Stratus R/T Caravan Dakota Durango	Programming is by scan tool or by "customer learn" mode. If no functioning transmitter is available the scan tool must be used. Programming mode will cancel 60 seconds after the chimes stop in step 3. All programming must be completed within this time period.	CUSTOMER LEARN MODE 1. Turn ignition to run and wait until the chimes stop or fasten seat belt to cancel chimes. 2. Using any original working transmitter, press and hold the unlock button for 4 to 10 seconds. 3. While holding the unlock button, press the panic button for 1 second. Chime will sound for 3 seconds to indicate programming mode is ready. 4. Press lock and unlock buttons together for 1 second and release.

CHART 24–1 *(CONTINUED)*

Continued

MAKE/MODEL	NOTES	PROCEDURE
Jeep Liberty	Up to four transmitters can be stored.	5. Press and release any button on the same transmitter. If the code is successfully learned, the chime will sound. 6. To program additional transmitters, repeat steps 4 and 5. 7. Turn ignition off.
Ford Focus	Maximum of four transmitters can be programmed. All transmitters must be programmed at the same time. Programming mode will exit if: • The engine is started. • The 10 second time expires. • Four transmitters are programmed.	1. Enter vehicle. Close all doors. 2. Turn ignition switch from ACC to run, four times within 6 seconds. 3. Turn ignition switch to off. 4. Chime will sound to indicate ready to program. 5. Within 10 seconds press any button on the transmitter. A chime will indicate code accepted. 6. To program additional transmitters repeat step 5.
Ford F150 Pickup Explorer Taurus Escape Expedition Excursion Ranger **Lincoln** Navigator **Mazda** B2300 **Mercury** Mountaineer Mariner	All transmitters must be programmed at the same time. RKE transmitters can also be programmed using a scan tool. Programming mode will exit if: • The key is turned off. • The 20 second time expires. • The maximum number of transmitters are programmed (depends on vehicle).	1. Electrically unlock the doors using the RKE transmitter of door lock switch. 2. Turn the key from off to run, eight times within 10 seconds, ending with the key on. The module will lock and unlock the doors, indicating program mode. 3. Within 20 seconds press any button on the transmitter. The locks will cycle to indicate the transmitter has been learned. 4. Repeat step 3 for any additional RKE transmitters. 5. Turn the key off to exit the programming mode.
Infiniti G20 G35 FX35 Q45	Key fob codes can be checked and changed using a scan tool. If step 2 is done too fast, the system will not enter programming mode. Up to five key fobs can be registered. If more than five are input, the oldest ID code will be overwritten. It is possible to enter the same key code into all five memories. This can be used to erase the ID code of a fob that has been lost, if needed.	1. Enter the vehicle and close all doors. 2. Insert and then completely remove key from the ignition cylinder more than six times within 10 seconds. Hazard warning lamps will flash twice to indicate programming mode is active. 3. Insert the key and turn the ignition to ACC. 4. Press any key on the fob once. The hazard warning lamps will flash twice to indicate that the code is stored. 5. To end programming mode open the driver's door. If programming additional fobs proceed to step 6 (don't open the driver's door). 6. To enter an additional code unlock and then lock the driver's door using the window main switch. 7. Press any button on the additional fob. The hazard warning lamps will flash twice to indicate the code is learned. 8. To enter another key fob code repeat steps 6 and 7. 9. Open the driver's door to end programming mode.

CHART 24–1

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

MAKE/MODEL	NOTES	PROCEDURE
Lincoln Town Car Continental Navigator **Mercury** Grand Marquis	All RKE transmitters must be programmed at the same time. RKE transmitters can also be programmed using a scan tool. Additional transmitters must be programmed within 7 seconds or the process will have to be repeated from step 1. Wait at least 20 seconds after exiting programming mode to test the RKE transmitters.	1. Turn the key from off to run, eight times (four times for early systems) within 10 seconds, ending with the key on. The module will lock and unlock the doors, indicating program mode. 2. Press any button on the transmitter. Doors will lock and unlock to confirm programming success. 3. To program additional repeat step 2 within 7 seconds. 4. Wait 7 seconds or turn the key off to exit programming mode.
Mazda 5 6	Start with the key out and all doors, trunk lid, and lift gate closed. A total of three transmitters can be programmed. Previously programmed transmitters may be erased during this procedure. If possible, program all desired transmitters at the same time.	1. Open the driver's side door. 2. Put the key in the ignition lock and turn the ignition to on and back to lock, three times (ending in the lock position with the key in the ignition). 3. Close and then open the driver's door three times, ending with the door open. The door locks will lock and unlock. 4. Push the unlock button on the transmitter twice. Door locks will lock and unlock to verify programming is okay. 5. Repeat step 4 for any additional transmitter to be programmed. 6. When the last transmitter to be programmed has been learned, push the unlock button twice on that transmitter to exit programming mode.
Mazda 626 Millenia Protégé	Start with the key out and all doors, trunk lid, and lift gate closed. A total of three transmitters can be programmed. Previously programmed transmitters may be erased during this procedure. If possible, program all desired transmitters at the same time. Protégé will cycle locks instead of sounding a buzzer.	1. Open the driver's side door. 2. Put the key in the ignition lock and turn the ignition to on and back to lock, three times, then remove the key. 3. Close and then open the driver's door three times, ending with the door open. A buzzer will sound from the CPU. 4. Push any button on the transmitter twice. Buzzer will sound once to verify programming is okay. 5. Repeat step 4 for any additional transmitter to be programmed. 6. When the last transmitter to be programmed has been learned, push any button twice on that transmitter. The buzzer will sound twice to exit programming mode.
Nissan Altima Armada Frontier Maxima Murano Titan	Key fob codes can also be checked and changed using a scan tool. If step 2 is done too fast, the system will not enter programming mode. Up to five key fobs can be registered. If more than five are input, the oldest ID code will be overwritten. It is possible to enter the same key code into all five memories. This can be used to erase the ID code of a fob that has been lost, if needed.	1. Enter the vehicle and close all doors. 2. Insert and then completely remove key from the ignition cylinder more than six times within 10 seconds. Hazard warning lamps will flash twice to indicate programming mode is active. 3. Insert the key and turn the ignition to ACC. 4. Press any key on the fob once. The hazard warning lamps will flash twice to indicate that the code is stored. 5. To end programming mode, open the driver's door. If programming additional fobs proceed to step 6 (don't open the driver's door). 6. To enter an additional code unlock and then lock the driver's door using the window main switch. 7. Press any button on the additional fob. The hazard warning lamps will flash twice to indicate the code is learned. 8. To enter another key fob code repeat steps 6 and 7. 9. Open the driver's door to end programming mode.

CHART 24–1

Continued

(CONTINUED)

MAKE/MODEL	NOTES	PROCEDURE
Pontiac Vibe **Scion** xB **Toyota** Camry Corolla	Up to four transmitters can be programmed. If more than four transmitters are programmed, the oldest transmitter code will be overwritten. There are four programming modes: • Add mode: Used to program additional transmitters • Rewrite mode: Erases all previously programmed transmitters • Confirmation mode: Indicates how many transmitters are already programmed • Prohibition mode: Erases all learned codes and disables the wireless entry system In confirmation mode, if no codes are stored the door locks will cycle five times. Open any door to exit the programming mode.	1. Enter the vehicle, key out of ignition, close all doors except the driver's door. 2. Insert and remove the key from the ignition twice within 5 seconds. 3. Close and open the driver's door twice within 40 seconds and then insert the key and remove it. 4. Close and open the driver's door twice again, then insert the ignition key and close the door. 5. Turn the key from lock to on and back to lock to select the programming mode: • One time for add mode (go to step 6) • Two times for rewrite mode (go to step 6) • Three times for confirmation mode (go to step 10) • Five times for prohibition mode (see step 11) 6. Remove the key from the ignition. 7. The doors will lock-unlock once for add mode or twice for rewrite mode. 8. To program a transmitter, press lock and unlock buttons for 1.5 seconds and release; then within 3 seconds press either button for more than 1 second to confirm programming: • One lock-unlock cycle indicates okay. • Two lock-unlock cycles indicates not okay; repeat this step. 9. Repeat step 8 to program additional transmitters. 10. In confirmation mode the number of lock-unlock cycles will indicate the number of codes already stored and programming mode will exit. Example: Two cycles indicates two codes are stored. 11. If prohibition mode is selected the locks will cycle five times and programming mode will exit.
Pontiac G6 **Saturn** Ion L300	A scan tool is used to program key fobs. Up to four transmitters can be programmed. If any key fob is programmed, all fobs must be programmed at the same time. On vehicles with personalization features, the transmitters are numbered 1 and 2. The first transmitter programmed will become driver 1 and the second will become driver 2.	1. Install the scan tool and navigate to the Program Key Fobs menu. 2. Select the number of fobs to be programmed. 3. Press and hold the lock and unlock buttons on the first fob to be programmed. The locks should cycle to indicate okay. NOTE: This fob becomes driver 1 key fob. 4. Repeat step 3 for the second fob. This fob becomes driver 2 key fob. 5. Repeat step 3 for any other key fobs to be programmed. 6. Turn off and remove the scan tool to exit programming.
Saab 9-2	Up to four transmitters can be programmed.	1. Sit in the driver's seat and close all doors. 2. Open and close the driver's door. 3. Turn the ignition switch from on to lock, 10 times within 15 seconds. The horn will chirp to indicate programming mode. 4. Open and close the driver's door. 5. Press any button on the fob to be programmed. 6. The horn will chirp two times to indicate that the transmitter has been learned. 7. Repeat steps 4, 5, and 6 for any additional transmitters. 8. To exit from programming mode remove the key from the ignition. The horn should chirp three times to confirm.

CHART 24–1

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

MAKE/MODEL	NOTES	PROCEDURE
Subaru Forester Impreza Legacy Outback Tribeca	A scan tool is used to program RKE codes. Up to four RKE transmitters can be registered. The eight-digit code is on the plastic bag of a new transmitter on the circuit board inside the transmitter.	1. Install the scan tool and navigate to the keyless transmitter ID registration menu. 2. Input the transmitter eight-digit ID number into the scan tool. 3. When the number is correct, press yes. 4. The scan tool will display “ID registration done” when the ID is programmed. 5. Follow the scan tool menus to program additional transmitters.
Toyota Tundra Sequoia **Lexus** GS 430 RX 300	Up to four transmitters can be programmed. If more than four transmitters are programmed, the oldest transmitter code will be overwritten. There are four programming modes: • Add mode: Used to program additional transmitters • Rewrite mode: Erases all previously programmed transmitters • Confirmation mode: Indicates how many transmitters are already programmed • Prohibition mode: Erases all learned codes and disables the wireless entry system In confirmation mode, if no codes are stored the door locks will cycle five times. Open any door to exit the programming mode.	1. Enter the vehicle, key out of ignition, close all doors except the driver’s door. 2. Insert and remove the key from the ignition key cylinder. 3. Use the driver’s door lock control switch to lock and unlock the doors five times, at about 1 second intervals. 4. Close and open the driver’s door. 5. Use the driver’s door lock control switch to lock and unlock the doors fivetimes, at about 1 second intervals. 6. Insert the ignition key. 7. Turn the key from lock to on and back to lock to select the programming mode: • One time for add mode (go to step 10) • Two times for rewrite mode (go to step 10) • Three times for confirmation mode (go to step 12) • Five times for prohibition mode (see step 13) 8. Remove the key from the ignition. 9. The doors will lock-unlock once, twice, three times of five times to confirm the mode. 10. To program a transmitter press lock and unlock buttons for 1.5 seconds and release; then within 3 seconds press either button for more than 1 second to confirm programming: One lock-unlock cycle indicates okay. Two lock-unlock cycles indicates not okay; repeat this step. 11. Repeat step 10 to program additional transmitters. 12. In confirmation mode the number of lock-unlock cycles will indicate the number of codes already stored and programming mode will exit. Example: Two cycles indicates two codes are stored. 13. If prohibition mode is selected the locks will cycle five times and programming mode will exit.

CHART 24–1

Continued

ANTITHEFT SYSTEMS

PARTS AND OPERATION Antitheft devices flash lights or sound an alarm if the vehicle is broken into or vandalized. In addition to the alarm, some systems prevent the engine from starting by disabling the starter, ignition, or fuel system once the antitheft device is activated. Others permit the engine to start, but then disable it after several seconds. Switches in the doorjambs, trunk, and hood provide an input signal to the control module should an undesirable entry occur on a typical system. Some antitheft systems are more complex and also have electronic sensors that trigger the alarm if there is a change in battery current draw, a violent vehicle motion, or if glass is broken. These sensors also provide an input signal to the control module, which may be a separate antitheft unit or incorporated into the PCM or BCM. ● **SEE FIGURE 24–28** on page 360 for an example of a shock sensor used in an antitheft alarm system.

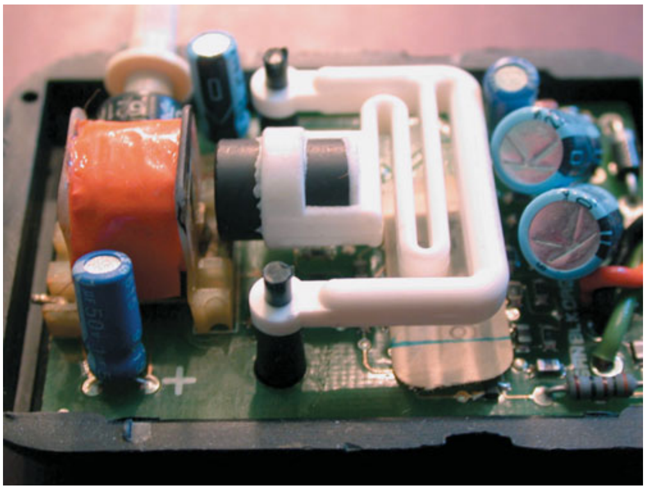


FIGURE 24–28 A shock sensor used in alarm and antitheft systems. If the vehicle is moved, the magnet will move relative to the coil, inducing a small voltage that will trigger the alarm.

ANTITHEFT SYSTEM DIAGNOSIS Most factory-installed antitheft systems are integrated with several other circuits to form a complex, multiple-circuit system. The major steps are as follows:

1. It is essential to have accurate diagrams, specifications, and test procedures for the specific model being serviced.
2. The easiest way to reduce circuit complexity is to use the wiring diagram to break the entire system into its subcircuits, then check only those related to the problem.
3. If any step indicates that a subcircuit is not complete, check the power source, ground, components, and wiring in that subcircuit.

Many systems use a computer chip in the plastic part of the key. Most systems are electronically regulated and have a self-diagnostic program. This self-diagnostic program is generally accessed and activated using a scan tool. Diagnostic and test procedures are similar as for any of the other electronic control systems used on the vehicle.

ANTITHEFT SYSTEM TESTING AND SERVICE Before performing any diagnostic checks, make sure that all of the following electrical devices function correctly.

- Parking and low-beam headlights
- Dome and courtesy lights
- Horn
- Electric door locks

Circuit information from these devices often provides basic inputs to the control module. If a problem is detected in any of these circuits, such as a missing signal or a signal that is out of range, the control module disables the antitheft system and may record a diagnostic trouble code (DTC).

If all of the previously mentioned devices are operational, check all the circuits leading to the antitheft control module. Make sure all switches are in their normal or off positions. Doorjamb switches complete the ground circuit when a door is opened. ● **SEE FIGURE 24–29.**

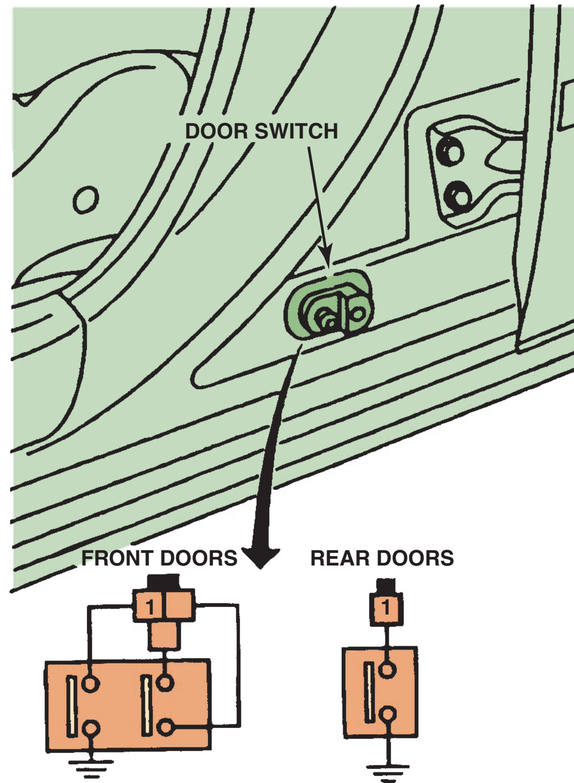


FIGURE 24–29 Door switches, which complete the ground circuit with the door open, are a common source of high resistance.

FIGURE 24–30 A special tool is needed to diagnose a General Motors VATS security system and special keys that contain a resistor pellet.

Frequently, corrosion that builds up on the switch contacts prevents the switch from operating properly. Conduct voltage drop tests to isolate faulty components and circuit problems. Repair as needed and retest to confirm that the system is operational. Follow procedures from the manufacturer to clear DTC records, and then run the self-diagnostic program to verify repairs. Some system diagnostic procedures specify the use of special testers. ● **SEE FIGURE 24–30.**

● **SEE CHART 24–2** for programming procedures for selected vehicles.

MAKE/MODEL	NOTES	PROCEDURES
Chrysler Pacifica Town and Country PT Cruiser Sebring 300 Some other models **Dodge** Caravan Durango Magnum Neon Pickup Stratus **Jeep** Liberty Grand Cherokee Some other models	Programming is by scan tool or by "customer learn" mode. Customer learn mode requires at least two functioning Sentry keys. If no functioning Sentry keys are available, the scan tool and the vehicle PIN number are required for programming. Both the immobilizer and RKE are programmed with this procedure. Only a blank key transponder can be programmed. Once programmed, the key cannot be used in another vehicle. The customer learn mode will exit after each key is programmed. The complete procedure must be completed for each key to be programmed. A total of eight keys can be programmed by the Sentry Key Remote Entry Module (four on some models).	CUSTOMER LEARN MODE 1. Using a blank Sentry key, cut the key to match the lock cylinder code. 2. Insert one of the two valid keys into the ignition and turn the ignition on. 3. After 3 seconds, but before 15 seconds expire, turn off the ignition and remove the key. 4. Within 15 seconds insert the second valid key and turn the ignition on. 5. Within 10 seconds a chime will sound and/or the indicator lamp will flash, indicating customer learn mode is active. 6. Within 60 seconds turn the ignition off, insert the blank Sentry key, and turn the ignition on. 7. After about 10 seconds a single chime will sound and the indicator lamp will stay on solid for about 3 seconds; this indicates the key has been programmed.
Ford Taurus Some other models **Lincoln** Some models **Mercury** Grand Marquis Milan Montego	This procedure requires two or more programmed keys. If two programmed keys are not available a scan tool must be used. Maximum of eight keys can be programmed. Repeat the complete procedure for each key to be learned. If the programming is not successful the antitheft indicator will flash and the vehicle will not start. Leave the key on for 30 seconds and then retry the procedure.	1. Using the first programmed key, turn the ignition from off to run. Leave the switch in run for at least 3 seconds but not more than 10 seconds. 2. Turn the switch to off. Within 10 seconds repeat step 1 with the second programmed key. 3. Turn the ignition switch off. 4. Within 20 seconds, insert the un-programmed key and turn the ignition switch from off to run. 5. After 3 seconds, attempt to start the vehicle. If the programming is successful the vehicle will start and the antitheft indicator will light for 3 seconds and go out.
Ford Crown Victoria Some other models	This procedure requires two or more programmed keys. If two programmed keys are not available a scan tool must be used. Maximum of eight keys can be programmed.	1. Using the first programmed key, turn the ignition from off to run. Leave the switch in run for 1 second. 2. Turn the switch to off. Within 5 seconds repeat step 1 with the second programmed key. 3. Turn the ignition switch off.

CHART 24–2

(CONTINUED)

Immobilizer or vehicle theft deterrent key learn procedures for some popular vehicles.

<table>
<tr><th>MAKE/MODEL</th><th>NOTES</th><th>PROCEDURES</th></tr>
<tr><td></td><td>Repeat the complete procedure for each key to be learned.

If the programming is not successful the antitheft indicator will flash and the vehicle will not start. Leave the key on for 30 seconds and then retry the procedure.</td><td>4. Within 10 seconds, insert the un-programmed key and turn the ignition switch from off to run.
5. After 1 second, attempt to start the vehicle. If the programming is successful the vehicle will start and the antitheft indicator will light for 3 seconds and go out.</td></tr>
<tr><td>General Motors
Passkey
Passkey II
(except vehicles with BCM)</td><td>The Passkey decoder will learn the first pellet read when the decoder module is first installed. This learned value cannot be changed.

A Passkey Interrogator special tool is needed to read key pellet resistance when replacing keys. The tool will read out a code number related to the pellet resistance.

PELLET CODE — RESISTANCE
1 — 402
2 — 523
3 — 681
4 — 887
5 — 1,130
6 — 1,470
7 — 1,870
8 — 2,370
9 — 3,010
10 — 3,740
11 — 4,750
12 — 6,040
13 — 7,500
14 — 9,530
15 — 11,800</td><td>NEW DECODER MODULE
1. Install the new decoder module.
2. Insert the key and start the vehicle to program the pellet code into the new module.

DUPLICATE KEY
1. Use the Interrogator tool to read the existing key code.
2. Obtain a key with the matching pellet code and cut the key to match the original key.

LOST KEY
1. The Interrogator tool must be used to determine the stored code.
2. Cut a blank key so that the ignition can be turned.
3. Access the lock cylinder 2 wire connector and connect it to the Interrogator.
4. Alternately select each of the 15 code positions on the Interrogator until the vehicle starts. This is then the correct pellet code.
5. Obtain the correct coded key and cut it to fit.</td></tr>
<tr><td>General Motors
Passkey II (vehicles with BCM)</td><td>On vehicles with a body control module (BCM) the Passkey II pellet code is stored in the BCM. The BCM can learn the pellet code of a replacement key using a scan tool or this procedure.

Make sure that the battery is fully charged.

If the learning procedure is not successful check the system for codes and repair.</td><td>1. Insert the key to be learned and turn the ignition on. Leave the switch on for 11 minutes. The security lamp will be on or flashing during this time.
2. When the security lamp goes off turn the ignition off for 30 seconds.
3. Repeat step 1 two more times.
4. Turn the ignition off for 30 seconds.
5. Attempt to start the vehicle. The vehicle should start and run if the learn is successful.</td></tr>
</table>

CHART 24–2

Immobilizer or vehicle theft deterrent key learn procedures for some popular vehicles.

MAKE/MODEL	NOTES	PROCEDURES
General Motors Passkey III Passkey III+	Quick-Learn requires at least one programmed master (black) key. Keys can be learned with a scan tool. If no programmed master key is available the 30 minute Auto Learn procedure must be used. Auto Learn procedure will erase all learned keys. Make sure that the battery is fully charged. On vehicles with a driver information center (DIC) a "STARTING DISABLED DUE TO THEFT" message will display during the 10 minute timer.	QUICK LEARN 1. Insert a programmed master key and turn on the ignition. 2. Turn the ignition off and remove the key. 3. Within 10 seconds insert the key to be learned and turn the ignition on. 4. The key is now programmed. 30 MINUTE AUTO LEARN 1. Insert the new master key and turn on the ignition. The security lamp should be on and then turn it off after 10 minutes. 2. Turn the ignition off for 5 seconds. 3. Repeat steps 1 and 2 two more times (30 minutes total). 4. From the off position turn on and start the vehicle. 5. The vehicle should start and run, indicating the key has been learned.
General Motors Passlock (early systems)	Passlock systems do not have coded keys. Replacement or new keys do not have to be learned. Early Passlock systems pass an "R" code to the instrument cluster and then the IPC sends a password on to the PCM. Perform this procedure if replacing the instrument cluster, lock cylinder, or PCM.	1. After parts are installed, attempt to start the vehicle. 2. The vehicle should start and stall. 3. Leave the key on and wait until the flashing theft lamp stays on steady. 4. Attempt to start the vehicle again. It should start and continue to run. 5. The theft lamp should flash for 10 seconds and then go out to indicate the password has been learned.
General Motors Passlock (later models)	Replacement or additional keys do not have to be learned. Programming is necessary if the Passlock sensor, BCM, or PCM has been replaced. A scan tool can also be used to program the Passlock system. ● **SEE FIGURE 24–31** on page 364.	1. Turn the ignition on and attempt to start the vehicle. 2. The vehicle will not start. Release the key to on. Wait about 10 minutes for the security lamp to go off. 3. Turn off the ignition for 5 seconds. 4. Repeat steps 1 through 3 two more times. 5. For a fourth time turn the key on and start the vehicle. The vehicle should start and run, indicating that the lock code has been learned.
Honda	A programmed key, scan tool, and password are required to program keys.	1. Connect the scan tool and navigate to the ADD and DELETE KEYS menu. 2. Follow the instructions on the scan tool to add or delete keys as needed.
Hyundai	A scan tool can be used to program keys. A special ID key is needed to program new or additional keys.	1. Using the ID key, turn the ignition on then off. 2. Using the key to be programmed, turn the ignition on then off. This will program the key. 3. Repeat step 2 for any additional keys.

CHART 24–2

Continued

(CONTINUED)

MAKE/MODEL	NOTES	PROCEDURES
Toyota Camry Land Cruiser Some other earlier models	Up to seven master (black) keys can be learned. An already learned master key must be used to initiate the procedure. Keys can also be programmed with a scan tool.	1. Insert a programmed master key into the ignition switch. 2. Within 15 seconds, press and release the accelerator pedal five times. 3. Within 20 seconds, press and release the brake pedal six times. 4. Remove the master key. 5. Within 10 seconds, insert the key to be programmed into the lock cylinder and press and release the accelerator pedal one time. 6. The security indicator should flash for about 1 minute and then go out to indicate that the key has been learned. 7. To program additional keys repeat steps 5 and 6 within 10 seconds.
Toyota Corolla Matrix Tacoma Sienna RAV4 Some other late models **Lexus** LS430 Some other models	Up to five keys can be learned. A scan tool should be used to register keys.	1. Insert a programmed master key into the ignition and turn the ignition on. 2. Install the scan tool and navigate to the IMMOBILIZER, TRANSP CODE REG. screen. Follow the instructions on the scan tool. 3. The security indicator will turn on. Within 20 seconds, remove the master key. 4. Within 10 seconds, insert the new key to be programmed. 5. The security indicator will blink for 60 seconds and then go off when the key is learned.

CHART 24–2

Immobilizer or vehicle theft deterrent key learn procedures for some popular vehicles.

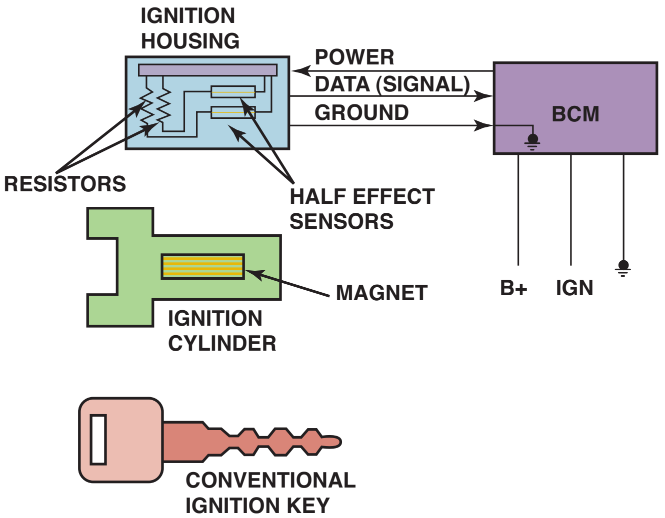


FIGURE 24–31 The Passlock series of General Motors security systems uses a conventional key. The magnet is located in the ignition lock cylinder and triggers the Hall-effect sensors.

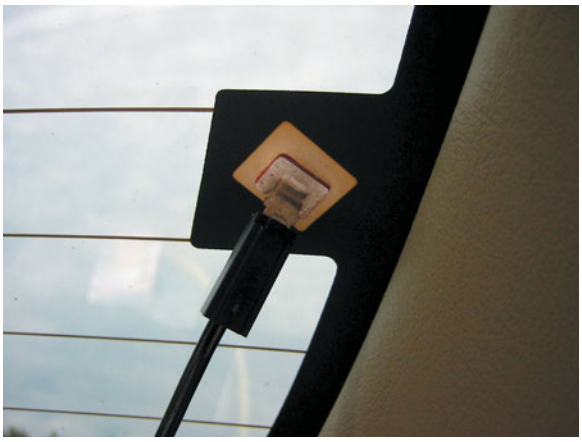


FIGURE 24–32 Corrosion or faults at the junction between the wiring and the rear window electrical grid are the source of many rear window defogger problems.

ELECTRICAL ACCESSORY SYMPTOM GUIDE

Cruise Control Problem	Possible Causes and/or Solutions
Cruise (speed) control is inoperative.	1. Blown fuse 2. Defective or misadjusted electrical or vacuum safety switch near the brake pedal arm 3. Lack of engine vacuum to servo or transducer 4. Defective transducer; defective speed control switch
Cruise (speed) control speed is incorrect or variable.	1. Misadjusted activation cable 2. Defective or pinched vacuum hose 3. Misadjustment of transducer

Power Windows Problem	Possible Causes and/or Solutions
Power windows are inoperative.	1. Defective (blown) fuse (circuit breaker) 2. Defective relay (if used) 3. Poor ground for master control switch 4. Poor connections at switch(es) or motor(s) 5. Open circuit (usually near the master control switch) 6. Defective lockout switch
One power window is inoperative.	1. Defective motor; defective or open control switch 2. Open or loose wiring to the switch or the motor
Only one power window can be operated from the master switch.	1. Poor connection or open circuit in the control wire(s)

Power Seats Problem	Possible Causes and/or Solutions
Power seats are inoperative, no click or noise.	1. Defective circuit breaker 2. Poor ground at the switch or relay (if used) 3. Open in the wiring between the switch and relay (if used); defective switch 4. Defective solenoid(s) or wiring 5. Defective door switch
Power seats are inoperative, click is heard.	1. "Flex" in the cables from the motor(s) to check for motor operation (If flex is felt, the motor is trying to operate the gear nut or the screw jack.) 2. Binding or obstruction 3. Defective motor (The click is generally the relay sound.) 4. Defective solenoid(s) or wiring to the solenoid(s)
All power seat functions are operative except one.	1. Defective motor 2. Defective solenoid or wiring to the solenoid

Electric Power Door Lock Problem	Possible Causes and/or Solutions
Power door locks are inoperative.	1. Defective circuit breaker, fuse, or wiring to the switch or relay (if used) 2. Defective relay (if used); defective switch 3. Defective door lock solenoid or ground for solenoid (if solenoid operated) 4. Open in the wiring to the door lock solenoid or the motor 5. Mechanical obstruction of the door lock mechanism
Only one door lock is inoperative.	1. Defective switch; poor ground on the solenoid (if solenoid operated) 2. Defective door lock solenoid or motor; poor electrical connection at the motor or solenoid

Rear Window Defogger Problem	Possible Causes and/or Solutions
Rear window defogger is inoperative.	1. Proper operation by performing breath test and/or voltmeter (Check at the power side of the rear window grid.); defective relay or timer assembly 2. Defective switch 3. Open ground connection at the rear window grid (● **SEE FIGURE 24–32.**) **NOTE: If there is an open circuit (power side or ground side), the dash indicator light will still operate in most cases.**
Rear window defogger cleans only a portion of the rear window.	1. Broken grid wire(s) or poor electrical connections at either the power side or the ground side of the wire grid

DOOR PANEL REMOVAL

1 Looking at the door panel there appears to be no visible fasteners.

2 Gently prying at the edge of the light shows that it snaps in place and can be easily removed.

3 Under the red "door open" warning light is a fastener.

4 Another screw is found under the armrest.

5 A screw is removed from the bezel around the interior door handle.

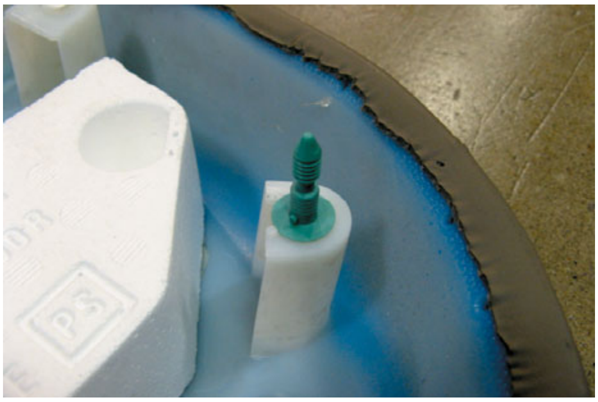
6 The electric control panel is held in by clips.

7 Another screw is found after the control panel is removed.

8 The panel beside the outside mirror is removed by gently prying.

9 A gentle tug and the door panel is removed.

10 The sound-deadening material also acts as a moisture barrier and would need to be removed to gain access to the components inside the door.



11 Carefully inspect the door panel clips before reinstalling the door panel.

12 Align and press the door panel clips into the openings and reinstall all of the fasteners and components.

SUMMARY

1. Most power windows and power door locks use a permanent magnet motor that has a built-in circuit breaker and is reversible. The control switches and relays direct the current through the motors.
2. The current flow through a rear window defogger is often self-regulating. As the temperature of the grid increases, its resistance increases, reducing current flow. Some rear window defoggers are also used as radio antennas.
3. Radar cruise control systems use many of the same components as the precollision system.
4. Remote keyless entry systems use a wireless transmitter built into the key fob to operate the power door lock.
5. Factory antitheft systems must function properly to allow the engine to crank and/or start.

REVIEW QUESTIONS

1. How do power door locks on a four-door vehicle function with only one ground wire connection?
2. How does a rear window defogger regulate how much current flows through the grids based on temperature?
3. What is the usual procedure to follow to resynchronize a remote keyless entry transmitter?
4. How do heated and cooled seats operate?

CHAPTER QUIZ

1. The owner of a vehicle equipped with cruise control complains that the cruise control often stops working when driving over rough or bumpy pavement. Technician A says the brake switch may be out of adjustment. Technician B says a defective servo unit is the most likely cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. Technician A says that the cruise control on a vehicle that uses an electronic throttle control (ETC) system uses a servo to move the throttle. Technician B says that the cruise control on a vehicle with ETC uses the APP sensor to set the speed. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. All power windows fail to operate from the independent switches but all power windows operate from the master switch. Technician A says the window lockout switch may be on. Technician B says the power window relay could be defective. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Technician A says that a defective ground connection at the master control switch (driver's side) could cause the failure of all power windows. Technician B says that if *one* control wire is disconnected, all windows will fail to operate. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. A typical radar cruise control system uses ________.
   - **a.** Long-range radar (LRR)
   - **b.** Short-range radar (SRR)
   - **c.** Electronic throttle control system to control vehicle speed
   - **d.** All of the above
6. When checking the operation of a rear window defogger with a voltmeter, ________.
   - **a.** The voltmeter should be set to read AC volts
   - **b.** The voltmeter should read close to battery voltage anywhere along the grid
   - **c.** Voltage should be available anytime at the power side of the grid because the control circuit just completes the ground side of the heater grid circuit
   - **d.** The voltmeter should indicate decreasing voltage when the grid is tested across the width of the glass

7. PM motors used in power windows, mirrors, and seats can be reversed by ________.
   a. Sending current to a reversed field coil
   b. Reversing the polarity of the current to the motor
   c. Using a reverse relay circuit
   d. Using a relay and a two-way clutch

8. If only one power door lock is inoperative, a possible cause is a ________.
   a. Poor ground connection at the power door lock relay
   b. Defective door lock motor (or solenoid)
   c. Defective (open) circuit breaker for the power circuit
   d. Defective (open) fuse for the control circuit

9. A keyless remote control stops working. Technician A says the battery in the remote could be dead. Technician B says that the key fob may have to be resynchronized. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Two technicians are discussing antitheft systems. Technician A says that some systems require a special key. Technician B says that some systems use a computer chip in the key. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

chapter 25

AIRBAG AND PRETENSIONER CIRCUITS

OBJECTIVES: After studying Chapter 25, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • List the appropriate safety precautions to be followed when working with airbag systems. • Describe the procedures to diagnose and repair common faults in airbag systems. • Explain how the passenger presence system works.

KEY TERMS: Airbag 370 • Arming sensor 372 • Clockspring 375 • Deceleration sensor 374 • Dual-stage airbags 375 • EDR 382 • Integral sensor 374 • Knee airbags 378 • Occupant detection systems (ODS) 380 • Passenger presence system (PPS) 380 • Pretensioners 370 • SAR 372 • Side airbags 381 • SIR 372 • Squib 372 • SRS 372

SAFETY BELTS AND RETRACTORS

SAFETY BELTS Safety belts are used to keep the driver and passengers secured to the vehicle in the event of a collision. Most safety belts include three-point support and are constructed of nylon webbing about 2 in. (5 cm) wide. The three support points include two points on either side of the seat for the belt over the lap and one crossing over the upper torso, which is attached to the "B" pillar or seat back. Every crash consists of three types of collisions.

Collision 1: The vehicle strikes another vehicle or object.

Collision 2: The driver and/or passengers hit objects inside the vehicle if unbelted.

Collision 3: The internal organs of the body hit other organs or bones, which causes internal injuries.

If a safety belt is being worn, the belt stretches, absorbing a lot of the impact, thereby preventing collision with other objects in the vehicle and reducing internal injuries. ● **SEE FIGURE 25–1.**

BELT RETRACTORS Safety belts are also equipped with one of the following types of retractors.

- Nonlocking retractors, which are used primarily on recoiling
- Emergency locking retractors, which lock the position of the safety belt in the event of a collision or rollover
- Emergency and web speed-sensitive retractors, which allow freedom of movement for the driver and passenger but lock if the vehicle is accelerating too fast or if the vehicle is decelerating too fast.

● **SEE FIGURE 25–2** for an example of an inertia-type seat belt locking mechanism.

SAFETY BELT LIGHTS AND CHIMES All late-model vehicles are equipped with a safety belt warning light on the dash and a chime that sounds if the belt is not fastened. ● **SEE FIGURE 25–3.**

Some vehicles will intermittently flash the reminder light and sound a chime until the driver and sometimes the front passenger fasten their safety belts.

PRETENSIONERS A **pretensioner** is an explosive (pyrotechnic) device that is part of the seat belt retractor assembly and tightens the seat belt as the airbag is being deployed. The purpose of the pretensioning device is to force the occupant back into position against the seat back and to remove any slack in the seat belt. ● **SEE FIGURE 25–4.**

CAUTION: The seat belt pretensioner assemblies must be replaced in the event of an airbag deployment. Always follow the vehicle manufacturer's recommended service procedure. Pretensioners are explosive devices that could be ignited if voltage is applied to the terminals. Do not use a jumper wire or powered test light around the wiring near the seat belt latch wiring. Always follow the vehicle manufacturer's recommended test procedures.

FRONT AIRBAGS

PURPOSE AND FUNCTION **Airbag** passive restraints are designed to cushion the driver (or passenger, if the passenger side is so equipped) during a frontal collision. The system

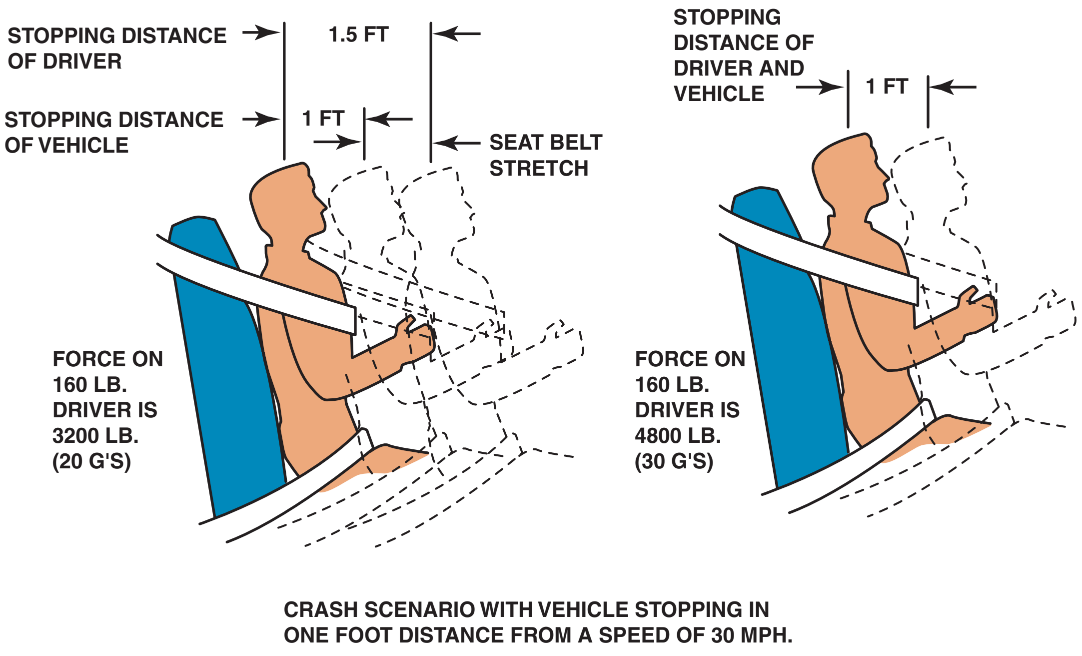


FIGURE 25–1 (a) Safety belts are the primary restraint system. (b) During a collision the stretching of the safety belt slows the impact to help reduce bodily injury.

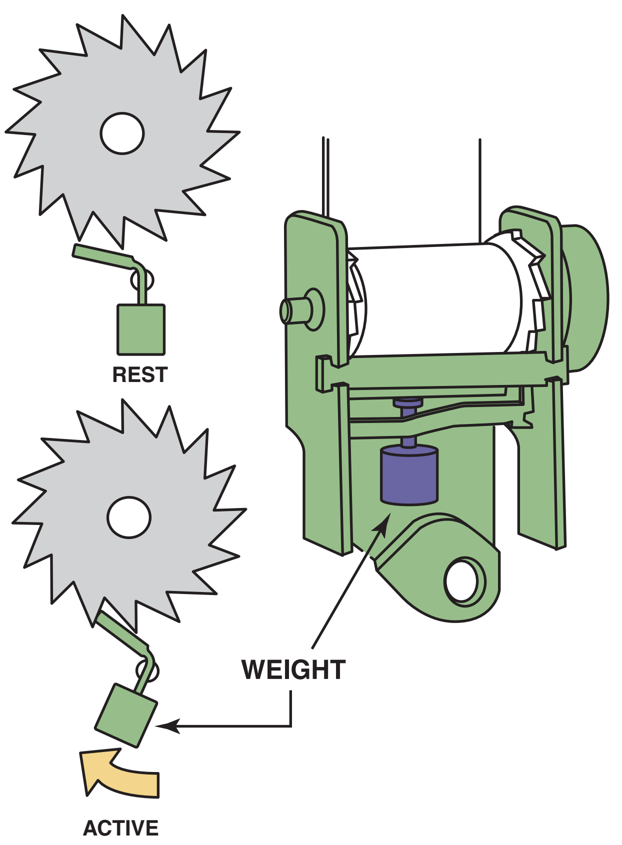


FIGURE 25–2 Most safety belts have an inertia-type mechanism that locks the belt in the event of rapid movement.

FIGURE 25–3 A typical safety belt warning light.

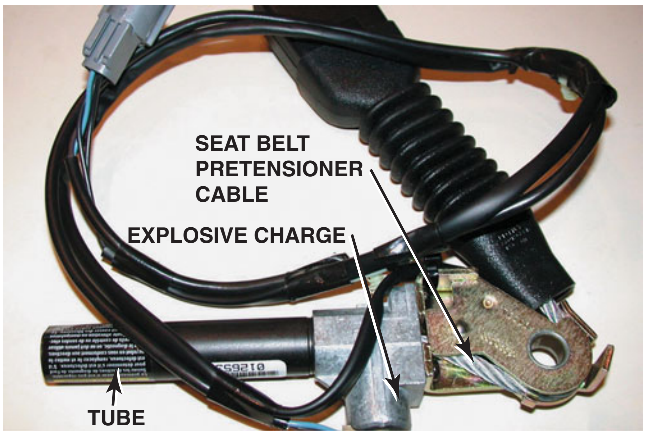


FIGURE 25–4 A small explosive charge in the pretensioner forces the end of the seat belt down the tube, which removes any slack in the seat belt.

consists of one or more nylon bags folded up in compartments located in the steering wheel, dashboard, interior panels, or side pillars of the vehicle. During a crash of sufficient force, pressurized gas instantly fills the airbag and then deploys out of the storage compartment to protect the occupant from serious injury. These airbag systems may be known by many different names, including the following:

1. **Supplemental restraint system (SRS)**
2. **Supplemental inflatable restraints (SIR)**
3. **Supplemental air restraints (SAR)**

Most airbags are designed to supplement the safety belts in the event of a collision, and front airbags are meant to be deployed only in the event of a frontal impact within 30 degrees of center. Front (driver and passenger side) airbag systems are *not* designed to inflate during side or rear impact. The force required to deploy a typical airbag is approximately equal to the force of a vehicle hitting a wall at over 10 mph (16 km/hr).

The force required to trigger the sensors within the system prevents accidental deployment if curbs are hit or the brakes are rapidly applied. The system requires a substantial force to deploy the airbag to help prevent accidental inflation.

PARTS INVOLVED

● **SEE FIGURE 25–5** for an overall view of the parts included in a typical airbag system.

The parts include:

1. Sensors
2. Airbag (inflator) module
3. Clockspring wire coil in the steering column
4. Control module
5. Wiring and connectors

OPERATION

To cause inflation, the following events must occur.

- To cause a deployment of the airbag, two sensors must be triggered at the same time. The **arming sensor** is used to provide electrical power, and a *forward* or *discriminating sensor* is used to provide the ground connection.
- The arming sensor provides the electrical power to the airbag heating unit, called a **squib**, inside the inflator module.
- The squib uses electrical power and converts it into heat for ignition of the propellant used to inflate the airbag.
- Before the airbag can inflate, however, the squib circuit also must have a ground provided by the forward or the discriminating sensor. In other words, two sensors (arming and forward sensors) *must* be triggered *at the same time* before the airbag will be deployed. ● **SEE FIGURE 25–6.**

TYPES OF AIRBAG INFLATORS

There are two different types of inflators used in airbags.

1. **Solid fuel.** This type uses sodium azide pellets and, when ignited, generates a large quantity of nitrogen gas that quickly inflates the airbag. This was the first type used and is still commonly used in driver and passenger side airbag inflator modules. ● **SEE FIGURE 25–7.** The squib is the electrical heating element used to ignite the gas-generating material, usually sodium azide. It requires about 2 A of current to heat the heating element and ignite the inflator.
2. **Compressed gas.** Commonly used in passenger side airbags and roof-mounted systems, the compressed gas system uses a canister filled with argon gas, plus a small percentage of helium at 3,000 psi (435 kPa). A small igniter ruptures a burst disc to release the gas when energized. The compressed gas inflators are long cylinders that can be installed inside the instrument panel, seat back, door panel, or along any side rail or pillar of the vehicle. ● **SEE FIGURE 25–8.**

Once the inflator is ignited, the nylon bag quickly inflates (in about 30 ms or 0.030 second) with nitrogen gas generated by the inflator. During an actual frontal collision accident, the driver is being thrown forward by the driver's own momentum toward the steering wheel. The strong nylon bag inflates at the

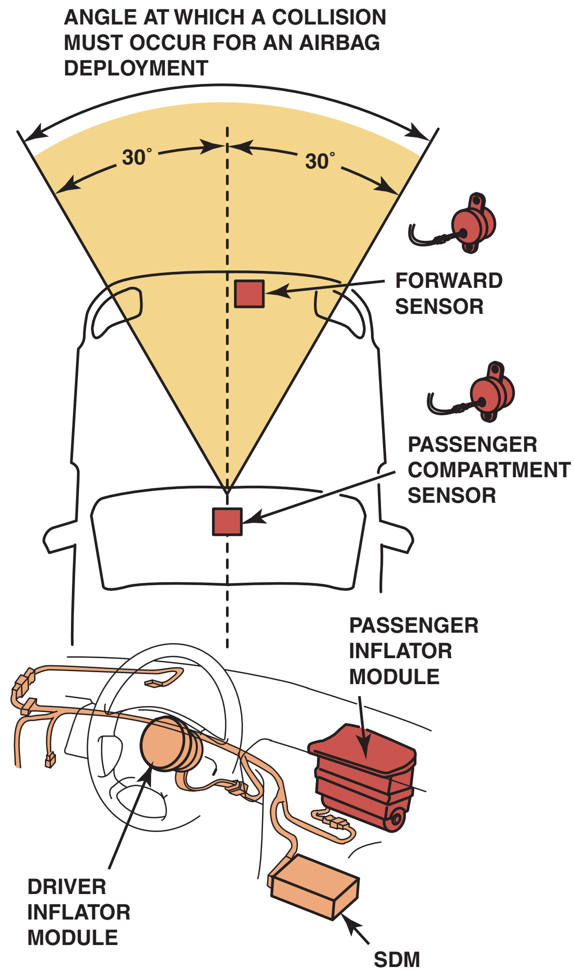


FIGURE 25–5 A typical airbag system showing many of the components. The SDM is the "sensing and diagnostic module" and includes the arming sensor as well as the electronics that keep checking the circuits for continuity and the capacitors that are discharged to deploy the air bags.

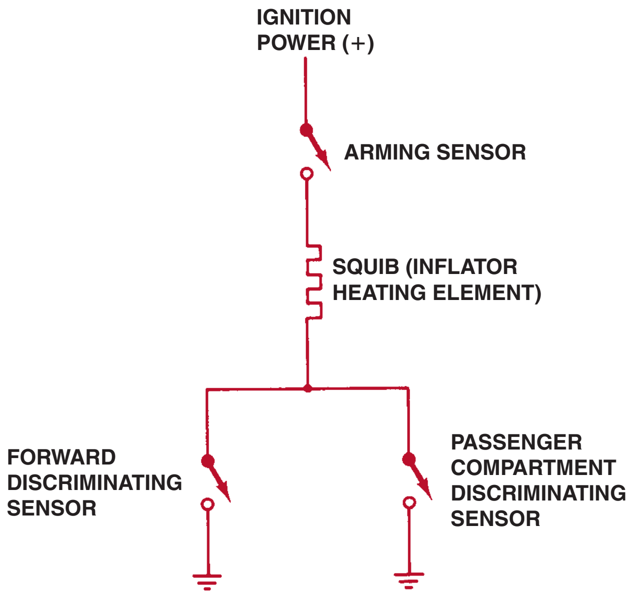


FIGURE 25–6 A simplified airbag deployment circuit. Note that both the arming sensor and at least one of the discriminating sensors must be activated at the same time. The arming sensor provides the power, and either one of the discriminating sensors can provide the ground for the circuit.

FIGURE 25–7 The inflator module is being removed from the airbag housing. The squib, inside the inflator module, is the heating element that ignites the pyrotechnic gas generator that rapidly produces nitrogen gas to fill the airbag.

same time. Personal injury is reduced by the spreading of the stopping force over the entire upper-body region. The normal collapsible steering column remains in operation and collapses in a collision when equipped with an airbag system. The bag is equipped with two large side vents that allow the bag to deflate immediately after inflation, once the bag has cushioned the occupant in a collision.

TIMELINE FOR AIRBAG DEPLOYMENT

Following are the times necessary for an airbag deployment in milliseconds (each millisecond is equal to 0.001 second or 1/1,000 of a second).

1. Collision occurs: 0.0 ms
2. Sensors detect collision: 16 ms (0.016 second)

FIGURE 25–8 This shows a deployed side curtain airbag on a training vehicle.

3. Airbag is deployed and seam cover rips: 40 ms (0.040 second)
4. Airbag is fully inflated: 100 ms (0.100 second)
5. Airbag deflated: 250 ms (0.250 second)

In other words, an airbag deployment occurs and is over in about a quarter of a second.

SENSOR OPERATION

All three sensors are basically switches that complete an electrical circuit when activated. The sensors are similar in construction and operation, and the *location* of the sensor determines its name. All airbag sensors are rigidly mounted to the vehicle and *must* be mounted with the arrow pointing toward the front of the vehicle to ensure that the sensor can detect rapid forward deceleration.

There are three basic styles (designs) of airbag sensors.

1. **Magnetically retained gold-plated ball sensor.** This sensor uses a permanent magnet to hold a gold-plated steel ball away from two gold-plated electrical contacts. ● **SEE FIGURE 25–9.**

   If the vehicle (and the sensor) stops rapidly enough, the steel ball is released from the magnet because the inertia force of the crash was sufficient to overcome the magnetic pull on the ball and then makes contact with the two gold-plated electrodes. The steel ball only remains in contact with the electrodes for a relatively short time because the steel ball is drawn back into contact with the magnet.
2. **Rolled up stainless-steel ribbon-type sensor.** This sensor is housed in an airtight package with nitrogen gas inside to prevent harmful corrosion of the sensor parts. If the vehicle (and the sensor) stops rapidly, the stainless-steel roll "unrolls" and contacts the two gold-plated contacts. Once the force is stopped, the stainless-steel roll will roll back into its original shape. ● **SEE FIGURE 25–10.**

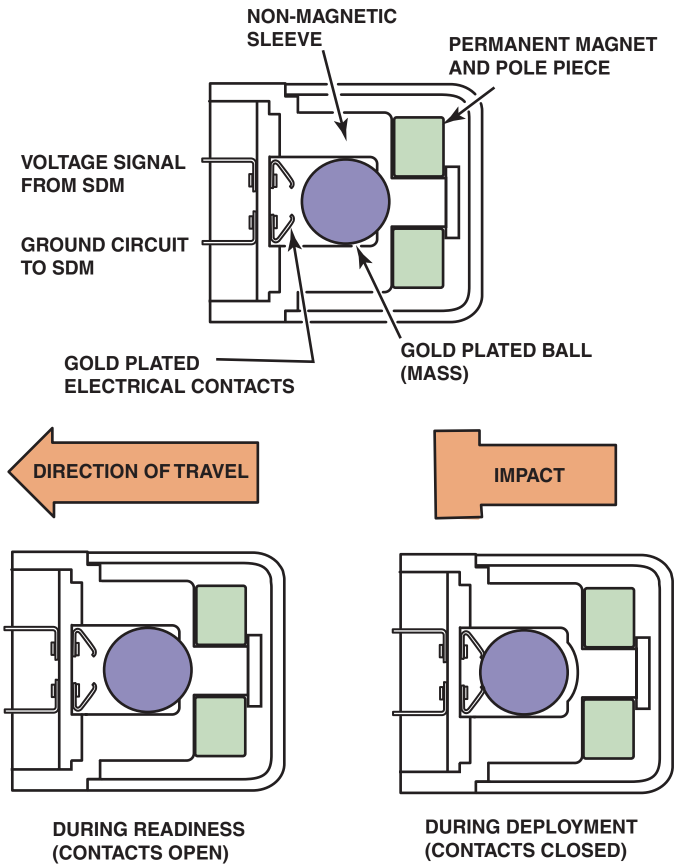


FIGURE 25–9 An airbag magnetic sensor.

3. **Integral sensor.** Some vehicles use electronic **deceleration sensors** built into the inflator module, called **integral sensors**. For example, General Motors uses the term *sensing and diagnostic module* (*SDM*) to describe their integrated sensor/module assembly. These units contain an accelerometer-type sensor which measures the rate of deceleration and, through computer logic, determines if the airbags should be deployed. ● **SEE FIGURE 25–11.**

TWO-STAGE AIRBAGS Two-stage airbags, often called advanced airbags or smart airbags, use an accelerometer-type of sensor to detect force of the impact. This type of sensor measures the actual amount of deceleration rate of the vehicle and is used to determine whether one or both elements of a two-stage airbag should be deployed.

- **Low-stage deployment.** This lower force deployment is used if the accelerometer detects a low-speed crash.
- **High-stage deployment.** This stage is used if the accelerometer detects a higher speed crash or a more rapid deceleration rate.
- **Both low- and high-stage deployment.** Under severe high-speed crashes, both stages can be deployed. ● **SEE FIGURE 25–12.**

WIRING Wiring and connectors are very important for proper identification and long life. Airbag-related circuits have the following features.

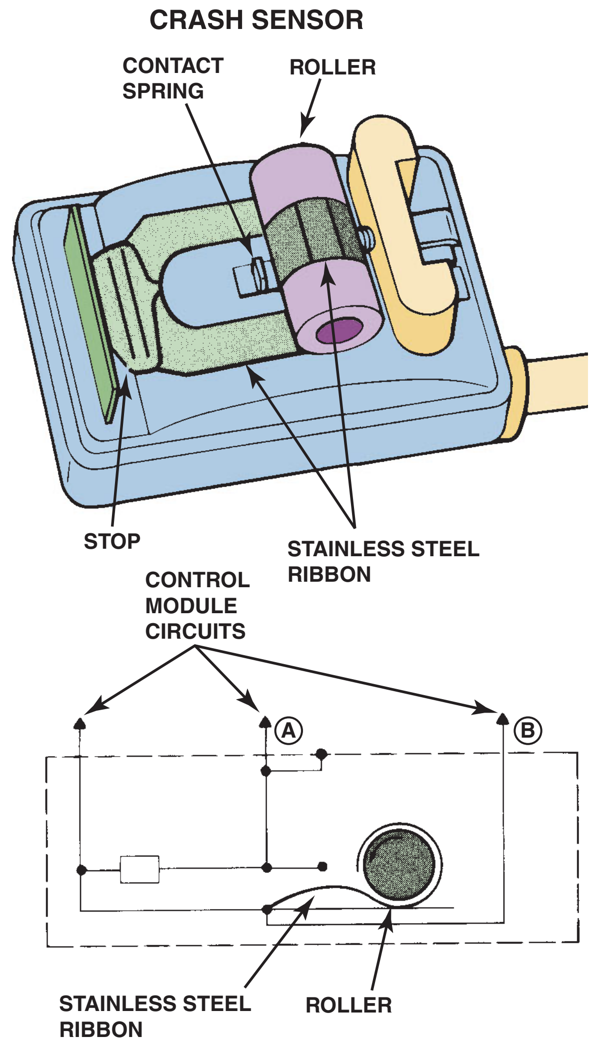


FIGURE 25–10 Some vehicles use a ribbon-type crash sensor.

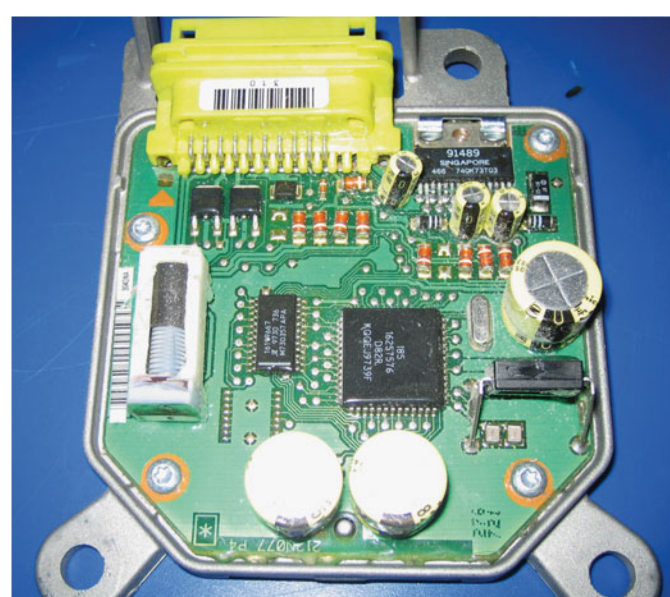


FIGURE 25–11 A sensing and diagnostic module that includes an accelerometer.

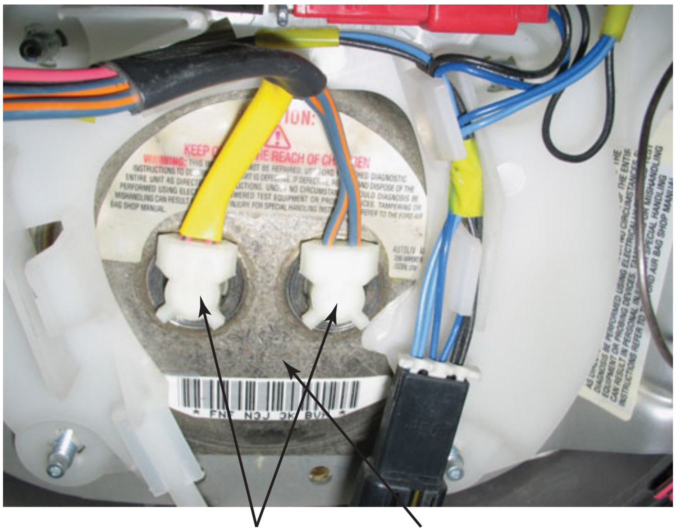


FIGURE 25–12 A driver's side airbag showing two inflator connectors. One is for the lower force inflator and the other is for the higher force inflator. Either can be ignited or both at the same time if the deceleration sensor detects a severe impact.

SAFETY TIP

Dual-Stage Airbag Caution

Many vehicles are equipped with **dual-stage airbags** (two-stage airbags) that actually contain two separate inflators, one for less severe crashes and one for higher speed collisions. These systems are sometimes called *smart airbag systems* because the accelerometer-type sensor used can detect how severe the impact is and deploy one or both stages. If one stage is deployed, the other stage is still active and could be accidentally deployed. A service technician cannot tell by looking at the airbag whether both stages have deployed. Always handle a deployed airbag as if it has not been deployed and take all precautions necessary to keep any voltage source from getting close to the inflator module terminals.

- All electrical wiring and conduit for airbags are colored yellow.
- To ensure proper electrical connection to the inflator module in the steering wheel, a coil assembly is used in the steering column. This coil is a ribbon of copper wires that operates much like a window shade when the steering wheel is rotated. As the steering wheel is rotated, this coil, usually called a **clockspring,** prevents the lack of continuity between the sensors and the inflator assembly that might result from a horn-ring type of sliding conductor.

TECH TIP

Pocket the Ignition Key to Be Safe

When replacing any steering gear such as a rack-and-pinion steering unit, be sure that no one accidentally turns the steering wheel. If the steering wheel is turned without being connected to the steering gear, the airbag wire coil (clockspring) can become off center. This can cause the wiring to break when the steering wheel is rotated after the steering gear has been replaced. To help prevent this from occurring, simply remove the ignition key from the ignition and keep it in your pocket while servicing the steering gear.

- Inside the yellow plastic airbag connectors are gold-plated terminals which are used to prevent corrosion.

● **SEE FIGURE 25–13.**

Most airbag systems also contain a diagnostic unit that often includes an auxiliary power supply, which is used to provide the current to inflate the airbag if the battery is disconnected from the vehicle during a collision. This auxiliary power supply normally uses capacitors that are discharged through the squib of the inflation module. When the ignition is turned off these capacitors are discharged. Therefore, after a few minutes an airbag system will not deploy if the vehicle is hit while parked.

AIRBAG DIAGNOSIS TOOLS AND EQUIPMENT

SELF-TEST PROCEDURE The electrical portion of airbag systems is constantly checked by the circuits within the airbag-energizing power unit or through the airbag controller. The electrical airbag components are monitored by applying a small-signal voltage from the airbag controller through the various sensors and components. Each component and sensor uses a resistor in parallel with the load or open sensor switch for use by the diagnostic signals. If continuity exists, the testing circuits will measure a small voltage drop. If an open or short circuit occurs, a dash warning light is lighted and a possible diagnostic trouble code (DTC) is stored. Follow exact manufacturer's recommended procedures for accessing and erasing airbag diagnostic trouble codes.

Diagnosis and service of airbag systems usually require some or all of the following items.

- Digital multimeter (DMM)
- Airbag simulator, often called a load tool
- Scan tool
- Shorting bar or shorting connector(s)

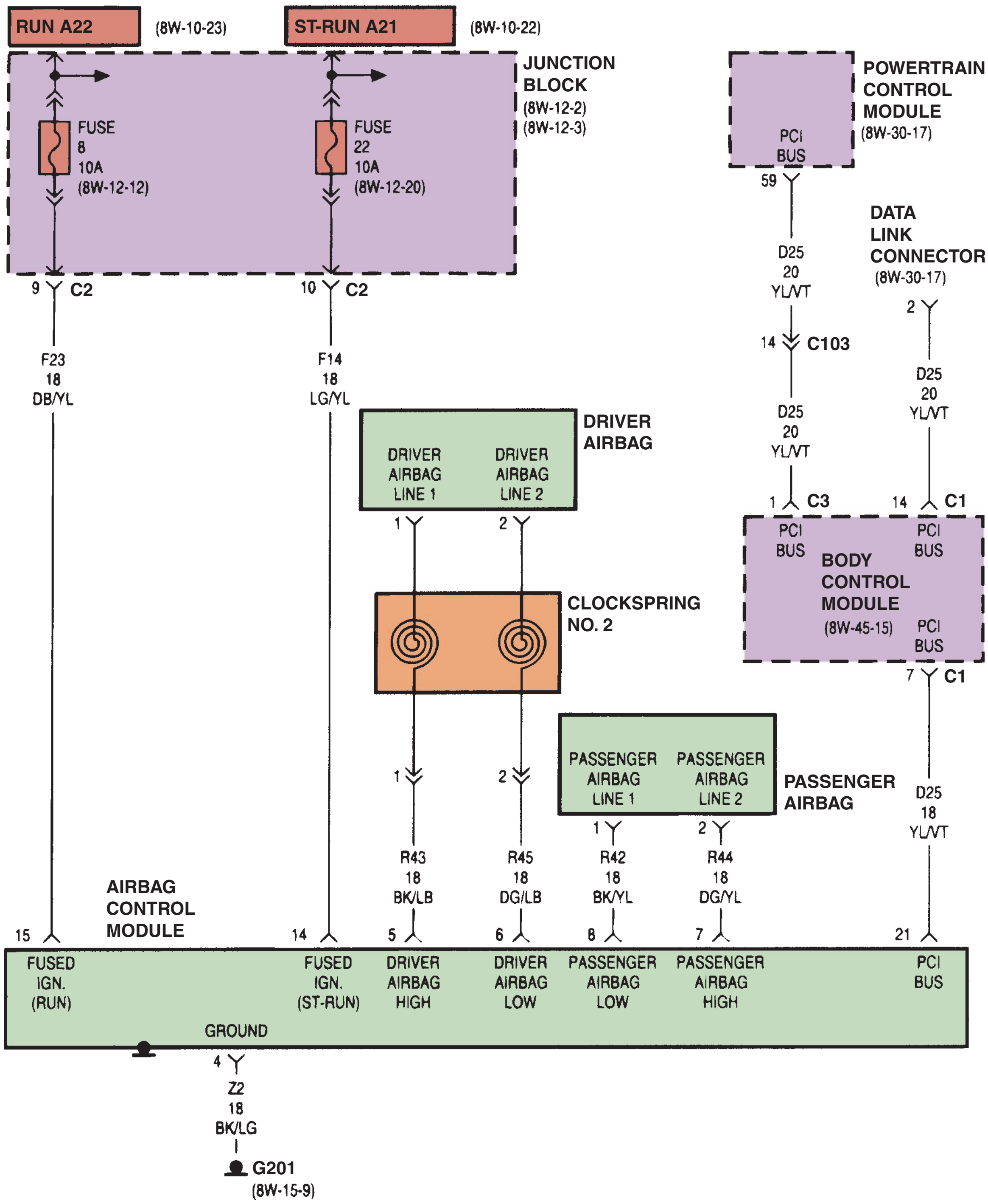


FIGURE 25–13 The airbag control module is linked to the powertrain control module (PCM) and the body control module (BCM) on this Chrysler system. Notice the airbag wire connecting the module to the airbag through the clockspring. Both power, labeled "driver airbag high" and ground, labeled "driver airbag low" are conducted through the clockspring.

- Airbag system tester
- Vehicle-specific test harness
- Special wire repair tools or connectors, such as crimp-and-seal weatherproof connectors

● **SEE FIGURE 25–14.**

CAUTION: Most vehicle manufacturers specify that the negative battery terminal be removed when testing or working around airbags. Be aware that a memory saver device used to keep the computer and radio memory alive can supply enough electrical power to deploy an airbag.

FIGURE 25–14 An airbag diagnostic tester. Included in the plastic box are electrical connectors and a load tool that substitutes for the inflator module during troubleshooting.

PRECAUTIONS Take the following precautions when working with or around airbags.

1. Always follow all precautions and warning stickers on vehicles equipped with airbags.
2. Maintain a safe working distance from all airbags to help prevent the possibility of personal injury in the unlikely event of an unintentional airbag deployment.
   - Side impact airbag: 5 in. (13 cm) distance
   - Driver front airbag: 10 in. (25 cm) distance
   - Passenger front airbag: 20 in. (50 cm) distance
3. In the event of a collision in which the bag(s) is deployed, the inflator module *and* all sensors usually must be replaced to ensure proper future operation of the system.
4. Avoid using a self-powered test light around the yellow airbag wiring. Even though it is highly unlikely, a self-powered test light could provide the necessary current to accidentally set off the inflator module and cause an airbag deployment.
5. Use care when handling the inflator module section when it is removed from the steering wheel. Always hold the inflator away from your body.
6. If handling a deployed inflator module, always wear gloves and safety glasses to avoid the possibility of skin irritation from the sodium hydroxide dust, which is used as a lubricant on the bag(s), that remains after deployment.
7. Never jar or strike a sensor. The contacts inside the sensor may be damaged, preventing the proper operation of the airbag system in the event of a collision.
8. When mounting a sensor in a vehicle, make certain that the arrow on the sensor is pointing toward the front of the vehicle. Also be certain that the sensor is securely mounted.

? FREQUENTLY ASKED QUESTION

What Are Smart Airbags?

Smart airbags use the information from sensors to determine the level of deployment. Sensors used include:

- **Vehicle speed (VS) sensors.** This type of sensor has a major effect on the intensity of a collision. The higher the speed is, the greater the amount of impact force.
- **Seat belt fastened switch.** If the seat belt is fastened, as determined by the seat belt buckle switch, the airbag system will deploy accordingly. If the driver or passenger is not wearing a seat belt, the airbag system will deploy with greater force compared to when the seat belt is being worn.
- **Passenger seat sensor.** The sensor in the seat on the passenger's side determines the force of deployment. If there is not a passenger detected, the passenger side airbag will not deploy on the vehicle equipped with a passenger seat sensor system.

AIRBAG SYSTEM SERVICE

DIS-ARMING The airbags should be dis-armed, (temporarily disconnected), whenever performing service work on any of the follow locations.

- Steering wheel
- Dash or instrument panel
- Glove box (instrument panel storage compartment)

Check service information for the exact procedure, which usually includes the following steps.

STEP 1 Disconnect the negative battery cable.

STEP 2 Remove the airbag fuse (has a yellow cover).

STEP 3 Disconnect the yellow electrical connector located at the base of the steering column to disable the driver's side airbag.

STEP 4 Disconnect the yellow electrical connector for the passenger side airbag.

This procedure is called "disabling air bags" in most service information. Always follow the vehicle manufacturer's specified procedures.

DIAGNOSTIC AND SERVICE PROCEDURE Airbag system components and their location in the vehicle vary according to system design, but the basic principles of testing are the same as for other electrical circuits. Use service information to determine how the circuit is designed and the correct sequence of tests to be followed.

- Some airbag systems require the use of special testers. The built-in safety circuits of such testers prevent accidental deployment of the airbag.

FREQUENTLY ASKED QUESTION

Why Change Knee Bolsters If Switching to Larger Wheels?

Larger wheels and tires can be installed on vehicles, but the powertrain control module (PCM) needs to be reprogrammed so the speedometer and other systems that are affected by a change in wheel/tire size can work effectively. When 20 in. wheels are installed on General Motors trucks or sport utility vehicles (SUVs), GM specifies that replacement knee bolsters be installed. Knee bolsters are the padded area located on the lower part of the dash where a driver or passenger's knees would hit in the event of a front collision. The reason for the need to replace the knee bolsters is to maintain the crash testing results. The larger 20 in. wheels would tend to be forced further into the passenger compartment in the event of a front-end collision. Therefore to maintain the frontal crash rating standard, the larger knee bolsters are required.

WARNING: Failure to perform the specified changes when changing wheels and tires could result in the vehicle not being able to provide occupant protection as designed by the crash test star rating that the vehicle originally achieved.

- If such a tester is not available, follow the recommended alternative test procedures specified by the manufacturer.
- Access the self-diagnostic system and check for diagnostic trouble code (DTC) records.
- The scan tool is needed to access the data stream on most systems.

SELF-DIAGNOSIS All airbag systems can detect system electrical faults, and if found will disable the system and notify the driver through an airbag warning lamp in the instrument cluster. Depending on circuit design, a system fault may cause the warning lamp to fail to illuminate, remain lit continuously, or flash. Some systems use a tone generator that produces an audible warning when a system fault occurs or if the warning lamp is inoperative.

The warning lamp should illuminate with the ignition key on and engine off as a bulb check. If not, the diagnostic module is likely disabling the system. If the airbag warning light remains on, the airbags may or may not be disabled, depending on the specific vehicle and the fault detected. Some warning lamp circuits have a timer that extinguishes the lamp after a few seconds. The airbag system generally does not require service unless there is a failed component. However, a steering wheel–mounted airbag module is routinely removed and replaced in order to service switches and other column-mounted devices.

KNEE AIRBAGS Some vehicles are equipped with **knee airbags** usually on the driver's side. Use caution if working under the dash and always follow the vehicle manufacturer's specified service procedures.

DRIVER SIDE AIRBAG MODULE REPLACEMENT

For the specific model being serviced, carefully follow the procedures provided by the vehicle manufacturer to disable and remove the airbag module. Failure to do so may result in serious injury and extensive damage to the vehicle. Replacing a discharged airbag is costly. The following procedure reviews the basic steps for removing an airbag module. Do not substitute these general instructions for the specific procedure recommended by the manufacturer.

1. Turn the steering wheel until the front wheels are positioned straight ahead. Some components on the steering column are removed only when the front wheels are straight.
2. Switch the ignition off and disconnect the negative battery cable, which cuts power to the airbag module.
3. Once the battery is disconnected, wait as long as recommended by the manufacturer before continuing. When in doubt, wait at least 10 minutes to make sure the capacitor is completely discharged.
4. Loosen and remove the nuts or screws that hold the airbag module in place. On some vehicles, these fasteners are located on the back of the steering wheel. On other vehicles, they are located on each side of the steering wheel. The fasteners may be concealed with plastic finishing covers that must be pried off with a small screwdriver to access them.
5. Carefully lift the airbag module from the steering wheel and disconnect the electrical connector. Connector location varies: Some are below the steering wheel behind a plastic trim cover; others are at the top of the column under the module. ● **SEE FIGURES 25–15 AND 25–16.**
6. Store the module pad side up in a safe place where it will not be disturbed or damaged while the vehicle is being serviced. Do not attempt to disassemble the airbag module. If the airbag is defective, replace the entire assembly.

When installing the airbag module, make sure the clockspring is correctly positioned to ensure module-to-steering-column continuity. ● **SEE FIGURE 25–17.**

Always route the wiring exactly as it was before removal. Also, make sure the module seats completely into the steering wheel. Secure the assembly using new fasteners, if specified.

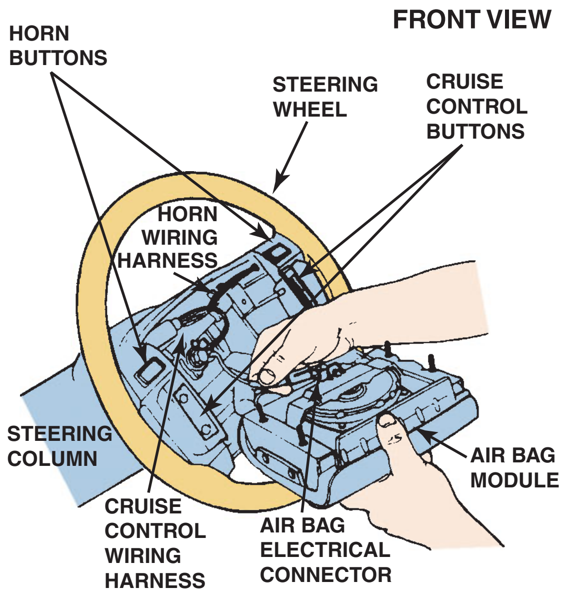


FIGURE 25–15 After disconnecting the battery and the yellow connector at the base of the steering column, the airbag inflator module can be removed from the steering wheel and the yellow airbag electrical connector at the inflator module disconnected.

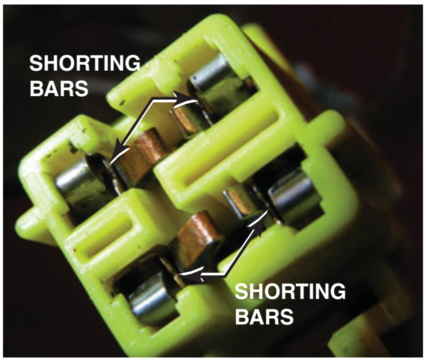


FIGURE 25–16 Shorting bars are used in most airbag connectors. These spring-loaded clips short across both terminals of an airbag connector when it is disconnected to help prevent accidental deployment of the airbag. If electrical power was applied to the terminals, the shorting bars would simply provide a low-resistance path to the other terminal and not allow current to flow past the connector. The mating part of the connector has a tapered piece that spreads apart the shorting bars when the connector is reconnected.

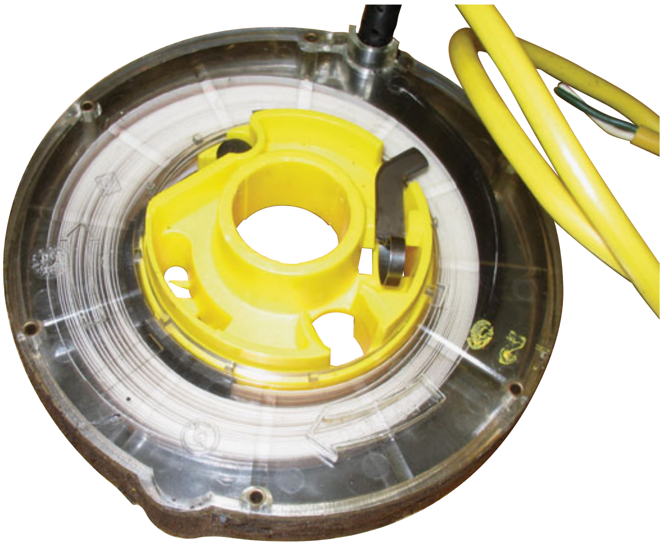


FIGURE 25–17 An airbag clockspring showing the flat conductor wire. It must be properly positioned to ensure proper operation.

FIGURE 25–18 An airbag being deployed as part of a demonstration in an automotive laboratory.

SAFETY WHEN MANUALLY DEPLOYING AIRBAGS

Airbag modules cannot be disposed of unless they are deployed. Do the following to prevent injury when manually deploying an airbag.

- When possible, deploy the airbag outside of the vehicle. Follow the vehicle manufacturer's recommendations.
- Follow the vehicle manufacturer's procedures and equipment recommendations.
- Wear the proper hearing and eye protection.
- Deploy the airbag with the trim cover facing up.
- Stay at least 20 ft (6 m) from the airbag. (Use long jumper wires attached to the wiring and routed outside the vehicle to a battery.)
- Allow the airbag module to cool.

● **SEE FIGURE 25–18.**

FIGURE 25–19 A dash warning lamp will light if the passenger side airbag is off because no passenger was detected by the seat sensor.

FIGURE 25–20 The passenger side airbag "on" lamp will light if a passenger is detected on the passenger seat.

OCCUPANT DETECTION SYSTEMS

PURPOSE AND FUNCTION The U.S. Federal Motor Vehicle Safety Standard 208 (FMVSS) specifies that the passenger side airbag be disabled or deployed with reduced force under the following conditions. This system is referred to as an **occupant detection system (ODS)** or the **passenger presence system (PPS)**.

- When there is no weight on the seat and no seat belt is fastened, the passenger side airbag will not deploy and the passenger airbag light should be off. ● **SEE FIGURE 25–19.**
- The passenger side airbag will be disabled and the disabled airbag light will be on if only 10 to 37 lb (4.5 to 17 kg) is on the passenger seat, which would generally represent a seated child.
- If 38 to 99 lb (17 to 45 kg) is detected on the passenger seat, which represents a child or small adult, the airbag will deploy at a decreased force.
- If 99 lb (45 kg) or more is detected on the passenger seat, the airbag will deploy at full force, depending on the severity of the crash, speed of the vehicle, and other factors which may result in the airbag deploying at a reduced force.

  ● **SEE FIGURE 25–20.**

TYPE OF SEAT SENSOR The passenger presence system (PPS) uses one of three types of sensors.

- **Gel-filled bladder sensor.** This type of occupant sensor uses a silicone-filled bag that has a pressure sensor attached. The weight of the passenger is measured by the pressure sensor, which sends a voltage signal to the module controlling the airbag deployment. A safety belt tension sensor is also used with a gel-filled bladder system to monitor the tension on the belt. The module then uses the information from both the bladder and the seat belt sensor to determine if a tightened belt may be used to restrain a child seat. ● **SEE FIGURE 25–21.**

FIGURE 25–21 A gel-filled (bladder-type) occupant detection sensor showing the pressure sensor and wiring.

- **Capacitive strip sensors.** This type of occupant sensor uses several flexible conductive metal strips under the seat cushion. These sensor strips transmit and receive a low-level electric field, which changes due to the weight of the front passenger seat occupant. The module determines the weight of the occupant based on the sensor values.
- **Force-sensing resistor sensors.** This type of occupant sensor uses resistors, which change their resistance based on the stress that is applied. These resistors are part of the seat structure, and the module can determine the weight of the occupant based on the change in the resistance of the sensors. ● **SEE FIGURE 25–22.**

FIGURE 25–22 A resistor-type occupant detection sensor. The weight of the passenger strains these resistors, which are attached to the seat, thereby signaling to the module the weight of the occupant.

CAUTION: Because the resistors are part of the seat structure, it is very important that all seat fasteners be torqued to factory specifications to ensure proper operation of the occupant detection system. A *seat track position (STP) sensor* is used by the airbag controller to determine the position of the seat. If the seat is too close to the airbag, the controller may disable the airbag.

DIAGNOSING OCCUPANT DETECTION SYSTEMS

A fault in the system may cause the passenger side airbag light to turn on when there is no weight on the seat. A scan tool is often used to check or calibrate the seat, which must be empty, by commanding the module to rezero the seat sensor. Some systems, such as those on Chrysler vehicles, use a unit that has various weights along with a scan tool to calibrate and diagnose the occupant detection system. ● **SEE FIGURE 25–23.**

FIGURE 25–23 A test weight is used to calibrate the occupant detection system on a Chrysler vehicle.

SEAT AND SIDE CURTAIN AIRBAGS

SEAT AIRBAGS Side and/or *curtain airbags* use a variety of sensors to determine if they need to be deployed. **Side airbags** are mounted in one of two general locations.

- In the side bolster of the seat (● **SEE FIGURE 25–24.**)
- In the door panel

Most side airbag sensors use an electronic accelerometer to detect when to deploy the airbags, which are usually mounted to the bottom of the left and right "B" pillars (where the front doors latch) behind a trim panel on the inside of the vehicle.

CAUTION: Avoid using a lockout tool (e.g., a "slim jim") in vehicles equipped with side airbags to help prevent damage to the components and wiring in the system.

FIGURE 25–24 A typical seat (side) airbag that deploys from the side of the seat.

TECH TIP

Aggressive Driving and OnStar

If a vehicle equipped with the OnStar system is being driven aggressively and the electronic stability control system has to intercede to keep the vehicle under control, OnStar may call the vehicle to see if there has been an accident. The need for a call from OnStar usually will be determined if the accelerometer registers slightly over 1 g-force, which could be achieved while driving on a race track.

SIDE CURTAIN AIRBAGS Side curtain airbags are usually deployed by a module based on input from many different sensors, including a lateral acceleration sensor and wheel speed sensors. For example, in one system used by Ford, the ABS controller commands that the brakes on one side of the vehicle be applied, using down pressure while monitoring the wheel speed sensors. If the wheels slow down with little brake pressure, the controller assumes that the vehicle could roll over, thereby deploying the side curtain airbags.

EVENT DATA RECORDERS

PARTS AND OPERATION As part of the airbag controller on many vehicles, the **event data recorder (EDR)** is used to record parameters just before and slightly after an airbag deployment. The following parameters are recorded.

- Vehicle speed
- Brake on/off
- Seat belt fastened
- G-forces as measured by the accelerometer

Unlike an airplane event data recorder, a vehicle unit is not a separate unit and does not record voice conversations and does not include all crash parameters. This means that additional crash data, such as skid marks and physical evidence at the crash site, will be needed to fully reconstruct the incident.

The EDR is embedded into the airbag controller and receives data from many sources and at varying sample rates. The data is constantly being stored in a memory buffer and not recorded into the EPROM unless an airbag deployment has been commanded. The combined data is known as an *event file.* The airbag is commanded on, based on input mainly from the accelerometer sensor. This sensor, usually built into the airbag controller, is located inside the vehicle. The accelerometer calculates the rate of change of the speed of the vehicle. This determines the acceleration rate and is used to predict if that rate is high enough to deploy the frontal airbags. The airbags will be deployed if the threshold g-value is exceeded. The passenger side airbag will also be deployed unless it is suppressed by either of the following:

- No passenger is detected.
- The passenger side airbag switch is off.

DATA EXTRACTION Data extraction from the event data recorder in the airbag controller can only be achieved using a piece of equipment known as the Crash Data Retrieval System, manufactured by Vetronics Corporation. This is the only authorized method for retrieving event files and only certain organizations are allowed access to the data. These groups or organizations include:

- Original equipment manufacturer's representatives
- National Highway Traffic Safety Administration
- Law enforcement agencies
- Accident reconstruction companies

Crash data retrieval must only be done by a trained crash data retrieval (CDR) technician or analyst. A technician undergoes specialized training and must pass an examination. An analyst must attend additional training beyond that of a technician to achieve CDR analyst certification.

SUMMARY

1. Airbags use a sensor(s) to determine if the rate of deceleration is enough to cause bodily harm.
2. All airbag electrical connectors and conduit are yellow and all electrical terminals are gold plated to protect against corrosion.
3. Always follow the manufacturer's procedure for disabling the airbag system prior to any work performed on the system.
4. Frontal airbags only operate within 30 degrees from center and do not deploy in the event of a rollover, side, or rear collision.
5. Two sensors must be triggered at the same time for an airbag deployment to occur. Many newer systems use an accelerometer-type crash sensor that actually measures the amount of deceleration.
6. Pretensioners are explosive (pyrotechnic) devices which remove the slack from the seat belt and help position the occupant.
7. Occupant detection systems use sensors in the seat to determine whether the airbag will be deployed and with full or reduced force.

REVIEW QUESTIONS

1. What are the safety precautions to follow when working around an airbag?
2. What sensor(s) must be triggered for an airbag deployment?
3. How should deployed inflation modules be handled?
4. What is the purpose of pretensioners?

CHAPTER QUIZ

1. A vehicle is being repaired after an airbag deployment. Technician A says that the inflator module should be handled as if it is still live. Technician B says rubber gloves should be worn to prevent skin irritation. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A seat belt pretensioner is ________.
   - **a.** A device that contains an explosive charge
   - **b.** Used to remove slack from the seat belt in the event of a collision
   - **c.** Used to force the occupant back into position against the seat back in the event of a collision
   - **d.** All of the above
3. What conducts power and ground to the driver's side airbag?
   - **a.** Twisted-pair wires
   - **b.** Clockspring
   - **c.** Carbon contact and brass surface plate on the steering column
   - **d.** Magnetic reed switch
4. Two technicians are discussing dual-stage airbags. Technician A says that a deployed airbag is safe to handle regardless of which stage caused the deployment of the airbag. Technician B says that both stages ignite, but at different speeds depending on the speed of the vehicle. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Where are shorting bars used?
   - **a.** In pretensioners
   - **b.** At the connectors for airbags
   - **c.** In the crash sensors
   - **d.** In the airbag controller
6. Technician A says that a deployed airbag can be repacked, reused, and reinstalled in the vehicle. Technician B says that a deployed airbag should be discarded and replaced with an entire new assembly. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. What color are the airbag electrical connectors and conduit?
   - **a.** Blue
   - **b.** Red
   - **c.** Yellow
   - **d.** Orange
8. Driver and/or passenger front airbags will only deploy if a collision occurs how many degrees from straight ahead?
   - **a.** 10 degrees
   - **b.** 30 degrees
   - **c.** 60 degrees
   - **d.** 90 degrees
9. How many sensors must be triggered at the same time to cause an airbag deployment?
   - **a.** One
   - **b.** Two
   - **c.** Three
   - **d.** Four
10. The electrical terminals used for airbag systems are unique because they are ________.
    - **a.** Solid copper
    - **b.** Tin-plated heavy-gauge steel
    - **c.** Silver plated
    - **d.** Gold plated

chapter 26

AUDIO SYSTEM OPERATION AND DIAGNOSIS

OBJECTIVES: After studying Chapter 26, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • Describe how AM and FM radio works. • Explain how to test speaker polarity. • Explain how to match speaker impedance. • Explain how crossovers work. • Describe how satellite radio works • Explain how Bluetooth systems work • Discuss voice recognition systems • List causes and corrections of radio noise and interference.

KEY TERMS: Active crossover 391 • Alternator whine 395 • AM 385 • Bluetooth 394 • Crossover 391 • Decibels (dB) 391 • Floating ground system 390 • FM 385 • Frequency 384 • Ground plane 387 • Hertz 384 • High-pass filter 391 • Impedance 389 • Low-pass filter 391 • Modulation 385 • Powerline capacitor 392 • Radio choke 396 • Radio frequency (RF) 384 • RMS 393 • SDARS 394 • Skin effect 390 • Speakers 388 • Stiffening capacitor 392 • Subwoofer 390 • THD 393 • Tweeter 390 • Voice recognition 392 • Wavelength 384

AUDIO FUNDAMENTALS

INTRODUCTION The audio system of today's vehicles is a complex combination of antenna system, receiver, amplifier, and speakers all designed to provide living room–type music reproduction while the vehicle is traveling in city traffic or at highway speed.

Audio systems produce audible sounds and include:

- Radio (AM, FM, and satellite)
- Antenna systems that are used to capture electronic energy broadcast to radios
- Speaker systems
- Aftermarket enhancement devices that increase the sound energy output of an audio system
- Diagnosis of audio-related problems

Many audio-related problems can be addressed and repaired by a service technician.

TYPES OF ENERGY There are two types of energy that affect audio systems.

- **Electromagnetic energy or radio waves.** Antennas capture the radio waves which are then sent to the radio or receiver to be amplified.
- **Acoustical energy, usually called sound.** Radios and receivers amplify the radio wave signals and drive speakers which reproduce the original sound as transmitted by radio waves.

● **SEE FIGURE 26–1.**

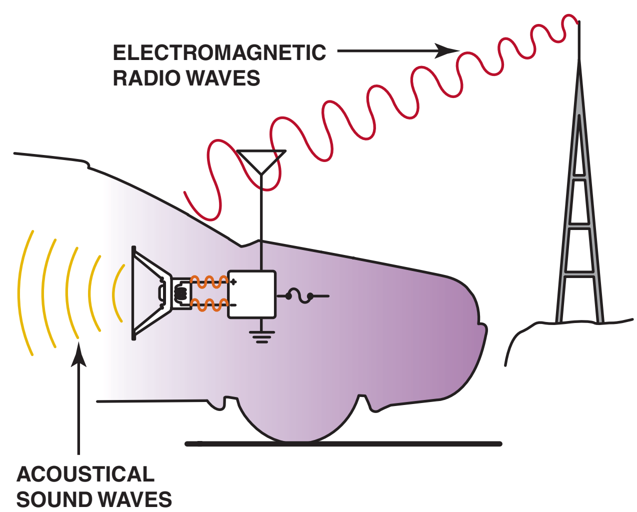


FIGURE 26–1 Audio systems use both electromagnetic radio waves and sound waves to reproduce sound inside the vehicle.

TERMINOLOGY Radio waves travel at approximately the speed of light (186,282,000 miles per second) and are electromagnetic. Radio waves are measured in two ways, wavelength and frequency. A radio wave has a series of high points and low points. A **wavelength** is the time and distance between two consecutive points, either high or low. A wavelength is measured in meters. **Frequency,** also known as **radio frequency (RF),** is the number of times a particular waveform repeats itself in a given amount of time, and is measured in **hertz (Hz).** A signal with a frequency of 1 Hz is one radio wavelength per second. Radio frequencies are measured in kilohertz (kHz), thousands

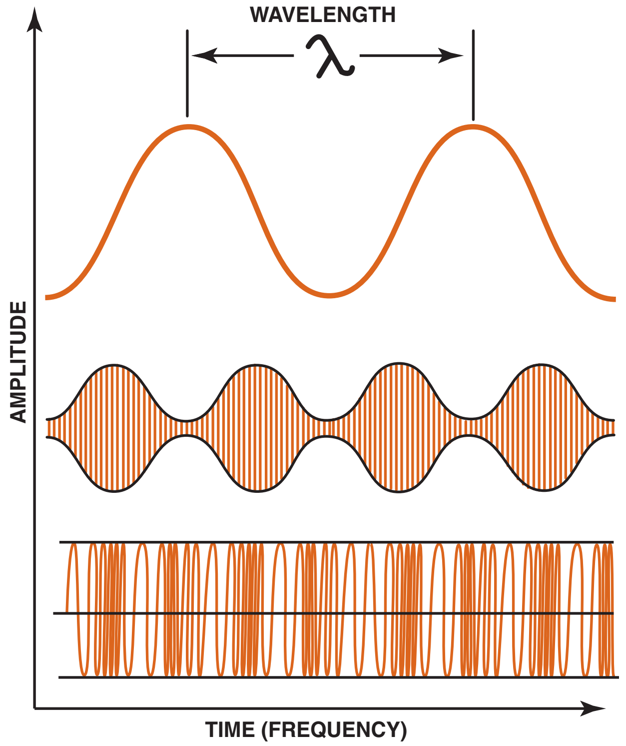


FIGURE 26–2 The relationship among wavelength, frequency, and amplitude.

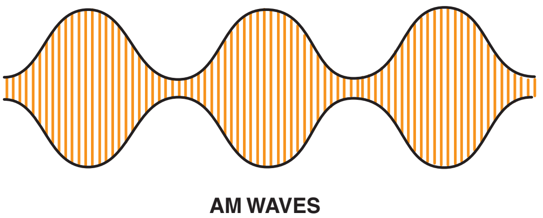


FIGURE 26–3 The amplitude changes in AM broadcasting.

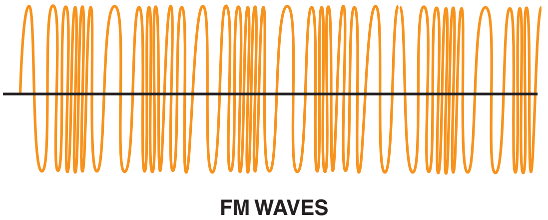


FIGURE 26–4 The frequency changes in FM broadcasting and the amplitude remains constant.

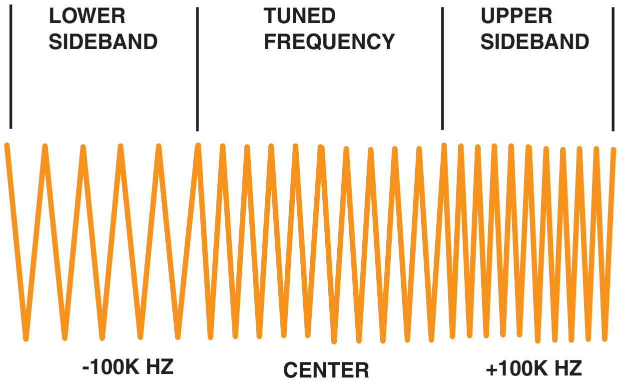


FIGURE 26–5 Using upper and lower sidebands allows stereo to be broadcast. The receiver separates the signals to provide left and right channels.

of wavelengths per second, and megahertz (MHz), millions of wavelengths per second. ● **SEE FIGURE 26–2.**

- The higher the frequency, the shorter the wavelength.
- The lower the frequency, the longer the wavelength.

A longer wavelength can travel a farther distance than a shorter wavelength. Therefore, lower frequencies provide better reception at further distances.

- AM radio frequencies range from 530 to 1,710 kHz.
- FM radio frequencies range from 87.9 to 107.9 MHz.

MODULATION **Modulation** is the term used to describe when information is added to a constant frequency. The base radio frequency used for RF is called the *carrier wave.* A carrier is a radio wave that is changed to carry information. The two types of modulation are:

- **Amplitude modulation (AM)**
- **Frequency modulation (FM)**

AM waves are radio waves that have amplitude that can be varied, transmitted, and detected by a receiver. Amplitude is the height of the wave as graphed on an oscilloscope. ● **SEE FIGURE 26–3.**

FM waves are also radio waves that have a frequency that can be varied, transmitted, and detected by a receiver. This type of modulation changes the number of cycles per second, or frequency, to carry the information. ● **SEE FIGURE 26–4.**

RADIO WAVE TRANSMISSION More than one signal can be carried by a radio wave. This process is called *sideband operation.* Sideband frequencies are measured in kilohertz. The amount of the signal above the assigned frequency is referred to as the upper sideband. The amount of the signal below the assigned frequency is called the lower sideband. This capability allows radio signals to carry stereo broadcasts. Stereo broadcasts use the upper sideband to carry one channel of the stereo signal, and the lower sideband to carry the other channel. When the signal is decoded by the radio, these two signals become the right and left channels. ● **SEE FIGURE 26–5.**

NOISE Because radio waves are a form of electromagnetic energy, other forms of energy can impact them. For example, a bolt of lightning generates broad radio-frequency bandwidths known as radio-frequency interference (RFI). RFI is one type

FREQUENTLY ASKED QUESTION

What Does a "Capture" Problem Mean?

A capture problem affects only FM reception and means that the receiver is playing more than one station if two stations are broadcasting at the same frequency. Most radios capture the stronger signal and block the weaker signal. However, if the stronger signal is weakened due to being blocked by buildings or mountains, the weaker signal will then be used. When this occurs, it will sound as if the radio is changing stations by itself. This is not a fault with the radio, but simply a rare occurrence with FM radio.

of electromagnetic interference (EMI) and is the frequency that interferes with radio transmission.

AM CHARACTERISTICS AM radio reception can be achieved over long distances from the transmitter because the waves can bounce off the ionosphere, usually at night. Even during the day, the AM signals can be picked up some distance from the transmitter. AM radio reception depends on a good antenna. If there is a fault in the antenna circuit, AM reception is affected the most.

FM CHARACTERISTICS Because FM waves have a high RF and a short wavelength, they travel only a short distance. The waves cannot follow the shape of the earth but instead travel in a straight line from the transmitter to the receiver. FM waves will travel through the ionosphere and into space and do not reflect back to earth like AM waves.

MULTIPATH Multipath is caused by reflected, refracted, or line of sight signals reaching an antenna at different times. Multipath results from the radio receiving two signals to process on the same frequency. This causes an echo effect in the speakers. *Flutter,* or *picket fencing* as it is sometimes called, is caused by the blocking of part of the FM signal. This blocking causes a weakening of the signal resulting in only part of the signal getting to the antenna, causing an on-again off-again radio sound. Flutter also occurs when the transmitter and the receiving antenna are far apart.

RADIOS AND RECEIVERS

The antenna receives the radio wave where it is converted into very weak fluctuating electrical current. This current travels along the antenna lead-in to the radio that amplifies the signal and sends the new signal to the speakers where it is converted into acoustical energy.

Most late-model radios and receivers use five input/output circuits.

1. **Power.** Usually a constant 12 volt feed to keep the internal clock alive
2. **Ground.** This is the lowest voltage in the circuit and connects indirectly to the negative terminal of the battery.
3. **Serial data.** Used to turn the unit on and off and provide other functions such as steering wheel control operation
4. **Antenna input.** From one or more antennas
5. **Speaker outputs.** These wires connect the receiver to the speakers or as an input to an amplifier.

ANTENNAS

TYPES OF ANTENNAS The typical radio electromagnetic energy from the broadcast antenna induces a signal in the antenna that is very small, only about 25 microvolts AC (0.000025 VAC) in strength. The radio contains amplifier circuits that increase the received signal strength into usable information.

For example, the five types of antennas used on vehicles include:

- **Slot antenna.** The slot antenna is concealed in the roof of some plastic body vehicles such as older General Motors plastic body vans. This antenna is surrounded by metal on a Mylar sheet.
- **Rear window defogger grid.** This type of system uses the heating wires to receive the signals and special circuitry to separate the RF from the DC heater circuit.
- **Powered mast.** These antennas are controlled by the radio. When the radio is turned on, the antenna is raised; when the radio is shut off, the antenna is retracted. The antenna system consists of an antenna mast and a drive motor controlled by the radio "on" signal through a relay.
- **Fixed mast antenna.** This antenna offers the best overall performance currently available. The mast is simply a vertical rod. Mast antennas are typically located on the fender or rear quarter panel of the vehicle.
- **Integrated antenna.** This type of antenna is sandwiched in the windshield and an appliqué on the rear window glass. The antenna in the rear window is the primary antenna and receives both AM and FM signals. The secondary antenna is located in the front windshield typically on the passenger side of the vehicle. This antenna receives only FM signals.

SEE FIGURE 26–6.

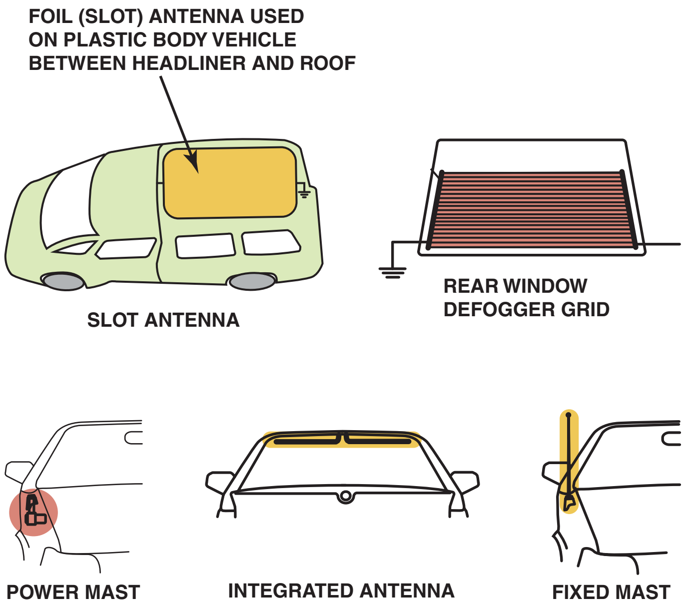


FIGURE 26–6 The five types of antennas used on General Motors vehicles include the slot antenna, fixed mast antenna, rear window defogger grid antenna, a powered mast antenna, and an integrated antenna.

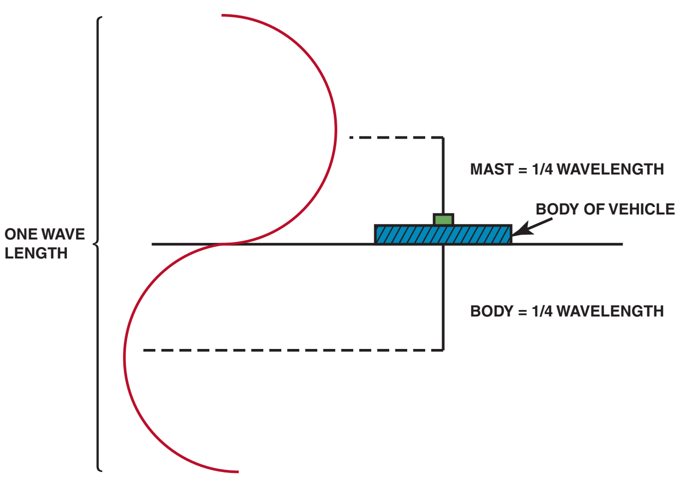


FIGURE 26–7 The ground plane is actually one-half of the antenna.

ANTENNA DIAGNOSIS

ANTENNA HEIGHT The antenna collects all radio-frequency signals. An AM radio operates best with as long an antenna as possible, but FM reception is best when the antenna height is exactly 31 in. (79 cm). Most fixed-length antennas are, therefore, exactly this height. Even the horizontal section of a windshield antenna is 31 in. (79 cm) long.

? FREQUENTLY ASKED QUESTION

What Is a Ground Plane?

Antennas designed to pick up the electromagnetic energy that is broadcast through the air to the transmitting antenna are usually one-half wavelength high, and the other half of the wavelength is the **ground plane**. This one-half wavelength in the ground plane is literally underground.

For ideal reception, the receiving antenna should also be the same as the wavelength of the signal. Because this length is not practical, a design compromise uses the length of the antenna as one-fourth of the wavelength; in addition, the body of the vehicle itself is one-fourth of the wavelength. The body of the vehicle, therefore, becomes the ground plane. ● **SEE FIGURE 26–7.**

Any faulty condition in the ground plane circuit will cause the ground plane to lose effectiveness, such as:

- Loose or corroded battery cable terminals
- Acid buildup on battery cables
- Engine grounds with high resistance
- Loss of antenna or audio system grounds
- Defective alternator, causing an AC ripple exceeding 50 mV (0.050 V)

A defective antenna will:

- Greatly affect AM radio reception
- May affect FM radio reception

ANTENNA TESTING If the antenna or lead-in cable is broken (open), FM reception will be heard but may be weak, and there will be *no* AM reception. An ohmmeter should read infinity between the center antenna lead and the antenna case. For proper reception and lack of noise, the case of the antenna must be properly grounded to the vehicle body. ● **SEE FIGURE 26–8.**

POWER ANTENNA TESTING AND SERVICE Most power antennas use a circuit breaker and a relay to power a reversible, permanent magnet (PM) electric motor that moves a nylon cord attached to the antenna mast. Some vehicles have a dash-mounted control that can regulate antenna mast height and/or operation, whereas many operate automatically when the radio is turned on and off. The power antenna assembly is usually mounted between the outer and inner front fender or in the rear quarter panel. The unit contains the motor, a spool for the cord, and upper- and lower-limit switches. The power antenna mast is tested in the same way as a fixed-mast antenna. (An infinity reading should be noted on an ohmmeter when the antenna is tested between the center antenna terminal and the housing or ground.) Except in the case of cleaning

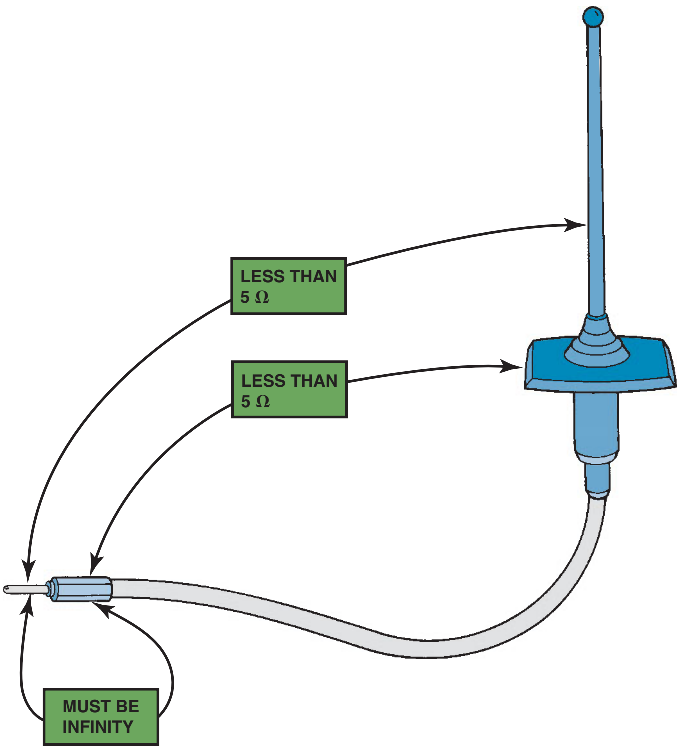


FIGURE 26–8 If all ohmmeter readings are satisfactory, the antenna is good.

FIGURE 26–9 Cutting a small hole in a fender cover helps to protect the vehicle when replacing or servicing an antenna.

TECH TIP

The Hole in the Fender Cover Trick

A common repair is to replace the mast of a power antenna. To help prevent the possibility of causing damage to the body or paint of the vehicle, cut a hole in a fender cover and place it over the antenna. ● **SEE FIGURE 26–9.**

If a wrench or tool slips during the removal or installation process, the body of the vehicle will be protected.

or mast replacement, most power antennas are either replaced as a unit or repaired by specialty shops. ● **SEE FIGURE 26–10.**

Making certain that the drain holes in the motor housing are not plugged with undercoating, leaves, or dirt can prevent many power antenna problems. All power antennas should be kept clean by wiping the mast with a soft cloth and lightly oiling with light oil such as WD-40 or similar.

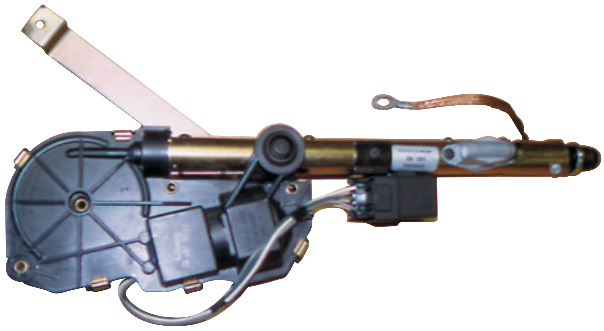


FIGURE 26–10 A typical power antenna assembly. Note the braided ground wire used to ensure that the antenna has a good ground plane.

SPEAKERS

PURPOSE AND FUNCTION The purpose of any **speaker** is to reproduce the original sound as accurately as possible. Speakers are also called *loudspeakers.* The human ear is capable of hearing sounds from a very low frequency of 20 Hz (cycles per seconds) to as high as 20,000 Hz. No one speaker is capable of reproducing sound over such a wide frequency range. ● **SEE FIGURE 26–11.**

Good-quality speakers are the key to a proper sounding radio or sound system. Replacement speakers should be securely mounted and wired according to the correct *polarity.* ● **SEE FIGURE 26–12.**

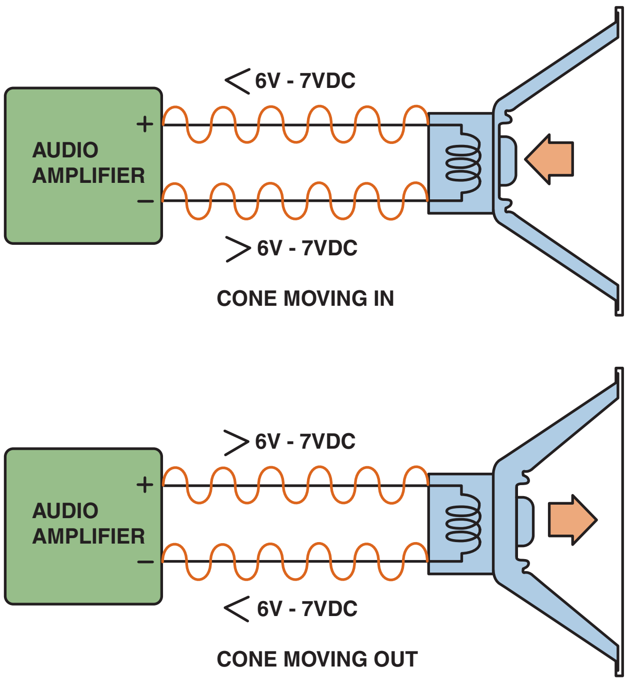


FIGURE 26–11 Between 6 and 7 volts is applied to each speaker terminal, and the audio amplifier then increases the voltage on one terminal and at the same time decreases the voltage on the other terminal causing the speaker cone to move. The moving cone then moves the air, causing sound.

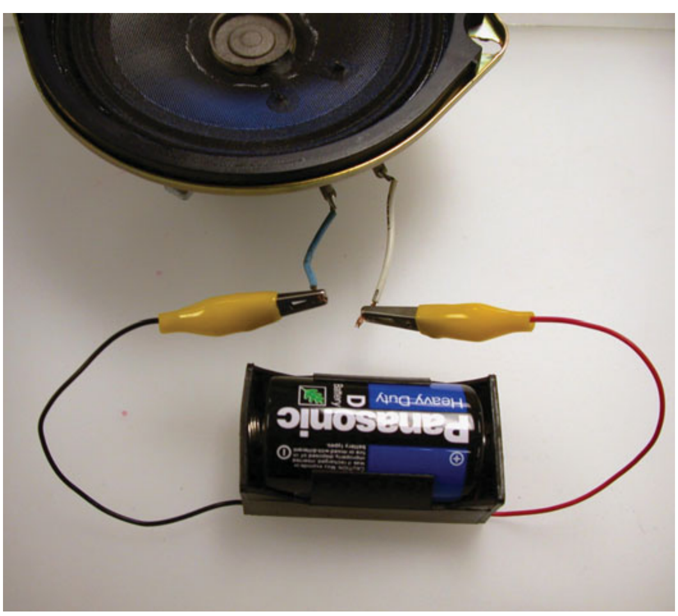


FIGURE 26–12 A typical automotive speaker with two terminals. The polarity of the speakers can be identified by looking at the wiring diagram in the service manual or by using a 1.5 volt battery to check. When the battery positive is applied to the positive terminal of the speaker, the cone will move outward. When the battery leads are reversed, the speaker cone will move inward.

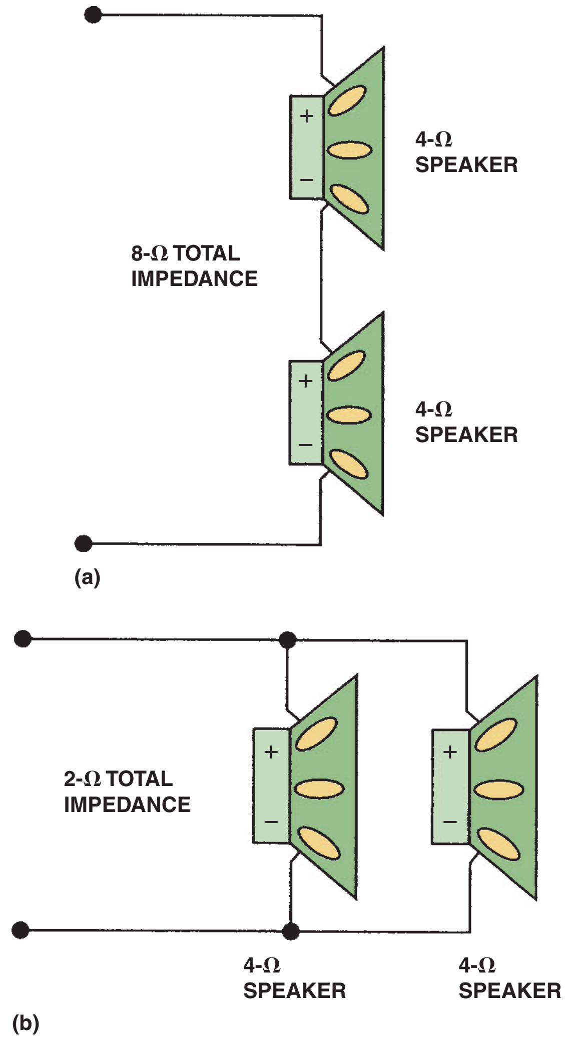


FIGURE 26–13 (a) Two 4 ohm speakers connected in series result in total impedance of 8 ohms. (b) Two 4 ohm speakers connected in parallel result in total impedance of 2 ohms.

IMPEDANCE MATCHING All speakers used on the same radio or amplifier should have the same internal coil resistance, called **impedance**. If unequal-impedance speakers are used, sound quality may be reduced and serious damage to the radio may result. ● **SEE FIGURE 26–13.**

All speakers should have the same impedance. For example, if two 4 ohm speakers are being used for the rear and they are connected in parallel, the total impedance is 2 ohms.

$$R_T = \frac{4\Omega(\text{impedance of each speaker})}{2\ (\text{number of speakers in parallel})} = 2 \text{ ohms}$$

The front speakers should also represent a 2 ohm load from the radio or amplifier. See the following example.

Two front speakers: each 2 ohms

Two rear speakers: each 8 ohms

Solution: Connect the front speakers in series (connect the positive [+] of one speaker to the negative [−] of the other) for a total impedance of 4 ohms (2 Ω + 2 Ω = 4 Ω).

TECH TIP

Skin Effect

When a high-frequency signal (AC voltage) is transmitted through a wire, the majority of it travels on the outside surface of the wire. This characteristic is called **skin effect**. The higher the frequency is, the closer to the outer surface the signal moves. To increase audio system output, most experts recommend the use of wire that has many strands of very fine wire to increase the surface area or the skin area of the conductor. Therefore, most aftermarket speaker wire is stranded with many small-diameter copper strands.

WARNING

Hearing loss is possible if exposed to loud sounds. According to noise experts (audiologists), hearing protection should be used whenever the following occurs.

1. You must raise your voice to be heard by others next to you.
2. You cannot hear someone else speaking who is less than 3 ft (1 m) away.
3. You are operating power equipment, such as a lawnmower.

Connect the two rear speakers in parallel (connect the positive [+] of each speaker together and the negative [−] of each speaker together) for a total impedance of 4 ohms (8 Ω ÷ 2 = 4 Ω).

SPEAKER WIRING The wire used for speakers should be as large a wire (as low an AWG gauge number) as is practical in order to be assured that full power is reaching the speakers. Typical "speaker wire" is about 22 gauge (0.35 mm^2), yet tests conducted by audio engineers have concluded that increasing the wire gauge—up to 4 gauge (19 mm^2) or larger—greatly increases sound quality. All wiring connections should be soldered after making certain that all speaker connections have the correct polarity.

CAUTION: Be careful when installing additional audio equipment on a General Motors vehicle system that uses a two-wire speaker connection called a floating ground system. Other systems run only one power (hot) lead to each speaker and ground the other speaker lead to the body of the vehicle.

This arrangement helps prevent interference and static that could occur if these components were connected to a chassis (vehicle) ground. If the components are chassis grounded, there may be a difference in the voltage potential (voltage); this condition is called a *ground loop.*

CAUTION: Regardless of radio speaker connections used, *never* operate any radio without the speakers connected, or the speaker driver section of the radio may be damaged as a result of the open speaker circuit.

SPEAKER TYPES

INTRODUCTION No one speaker is capable of reproducing sound over such a wide frequency range. Therefore, speakers are available in three basic types.

1. Tweeters are for high-frequency ranges.
2. Midrange are for mid-frequency ranges.
3. Woofers and subwoofers are for low-frequency ranges.

TWEETER A **tweeter** is a speaker designed to reproduce high-frequency sounds, usually between 4,000 and 20,000 Hz (4 and 20 kHz). Tweeters are very directional. This means that the human ear is most likely to be able to detect the location of the speaker while listening to music. This also means that a tweeter should be mounted in the vehicle where the sound can be directed in line of sight to the listener. Tweeters are usually mounted on the inside door near the top, windshield "A" pillar, or similar locations.

MIDRANGE A midrange speaker is designed and manufactured to be able to best reproduce sounds in the middle of the human hearing range, from 400 to 5,000 Hz. Most people are sensitive to the sound produced by these midrange speakers. These speakers are also directional in that the listener can usually locate the source of the sound.

SUBWOOFER A **subwoofer**, sometimes called a *woofer,* produces the lowest frequency of sounds, usually 125 Hz and lower. A *midbass* speaker may also be used to reproduce those frequencies between 100 and 500 Hz. Low-frequency sounds from these speakers are *not* directional. This means that the listener usually cannot detect the source of the sound from these speakers. The low-frequency sounds seem to be everywhere in the vehicle, so the location of the speakers is not as critical as with the higher frequency speakers.

The subwoofer can be placed almost anywhere in the vehicle. Most subwoofers are mounted in the rear of the vehicle where there is more room for the larger subwoofer speakers.

SPEAKER FREQUENCY RESPONSE Frequency response is how a speaker responds to a range of frequencies. A typical frequency response for a midrange speaker may be 500 to 4,000 Hz.

? FREQUENTLY ASKED QUESTION

What Is a Bass Blocker?

A bass blocker is a capacitor and coil assembly that effectively blocks low frequencies. A bass blocker is normally used to block low frequencies being sent to the smaller front speakers. Using a bass blocker allows the smaller front speakers to more efficiently reproduce the midrange and high-range frequency sounds.

SOUND LEVELS

DECIBEL SCALE A **decibel (dB)** is a measure of sound power, and it is the faintest sound a human can hear in the midband frequencies. The dB scale is not linear (straight line) but logarithmic, meaning that a small change in the dB reading results in a large change in volume of noise. An increase of 10 dB in sound pressure is equal to doubling the perceived volume. Therefore, a small difference in dB rating means a big difference in the sound volume of the speaker.

EXAMPLES Some examples of decibel sound levels include:

■ Quiet, faint	30 dB: whisper, quiet library
	40 dB: quiet room
■ Moderate	50 dB: moderate range sound
	60 dB: normal conversation
■ Loud	70 dB: vacuum cleaner, city traffic
	80 dB: busy noisy traffic, vacuum cleaner
■ Extremely loud	90 dB: lawnmower, shop tools
	100 dB: chain saw, air drill
■ Hearing loss possible	110 dB: loud rock music

CROSSOVERS

DEFINITION A **crossover** is designed to separate the frequency of a sound and send a certain frequency range, such as low bass sounds, to a woofer designed to reproduce these low-frequency sounds. There are two types of crossovers: passive and active.

PASSIVE CROSSOVER A passive crossover does not use an external power source. Rather it uses a coil and a capacitor to block certain frequencies that a particular type of speaker cannot handle and allow just those frequencies that it can handle to be applied to the speaker. For example, a 6.6 millihenry coil and a 200 microfarad capacitor can effectively pass 100 Hz frequency sound to a large 10 in. subwoofer. This type of passive crossover is called a **low-pass filter**, because it passes (transfers) only the low-frequency sounds to the speaker and blocks all other frequencies. A **high-pass filter** is used to transfer higher frequency (over 100 Hz) to smaller speakers.

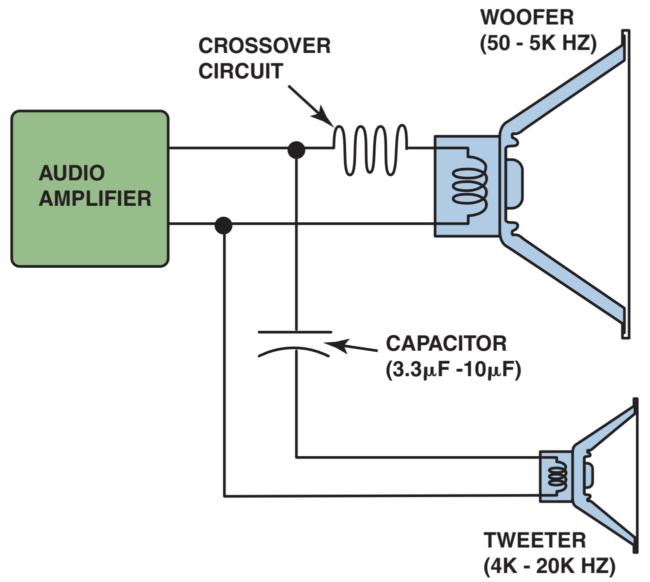


FIGURE 26–14 Crossovers are used in audio systems to send high-frequency sounds to the small (tweeter) speakers and low-frequency sounds to larger (woofer) speakers.

ACTIVE CROSSOVER **Active crossovers** use an external power source and produce superior performance. An active crossover is also called an *electronic crossover* or *crossover network.* These units include many powered filters and are considerably more expensive than passive crossovers. Two amplifiers are necessary to fully benefit from an active crossover. One amplifier is for the higher frequencies and midrange and the other amplifier is for the subwoofers. If you are on a budget and plan to use just one amplifier, then use passive crossover. If you can afford to use two or more amplifiers, then consider using the electronic (active) crossover. ● **SEE FIGURE 26–14** for an example of crossovers used in factory-installed systems.

AFTERMARKET SOUND SYSTEM UPGRADE

POWER AND GROUND UPGRADES If adding an amplifier and additional audio components, be sure to include the needed power and ground connections. These upgrades can include:

- A separate battery for the audio system
- An inline fuse near the battery to protect the wiring and the components

FIGURE 26–15 Two capacitors connected in parallel provide the necessary current flow to power large subwoofer speakers.

- Wiring that is properly sized to the amperage draw of the system and the length of wire (The higher the output wattage the greater the amperage required and the larger the wire gauge needed. The longer the distance between the battery and the components, the larger the wire gauge needed for best performance.)
- Ground wires at least the same gauge as the power side wiring (Some experts recommend using extra ground wires for best performance.)

Read, understand, and follow all instructions that come with audio system components.

POWERLINE CAPACITOR A **powerline capacitor**, also called a **stiffening capacitor**, refers to a large capacitor (often abbreviated CAP) of 0.25 farad or larger connected to an amplifier power wire. The purpose and function of this capacitor is to provide the electrical reserve energy needed by the amplifier to provide deep bass notes. ● **SEE FIGURE 26–15.**

Battery power is often slow to respond; and when the amplifier attempts to draw a large amount of current, the capacitor will try to stabilize the voltage level at the amplifier by discharging stored current as needed.

A rule of thumb is to connect a capacitor with a capacity of 1 farad for each 1,000 watts of amplifier power. ● **SEE CHART 26–1.**

CAPACITOR INSTALLATION A powerline capacitor connects to the power leads between the inline fuse and the amplifier. ● **SEE FIGURE 26–16.**

If the capacitor were connected to the circuit as shown without "precharging," the capacitor would draw so much current that it would blow the inline fuse. To safely connect a large capacitor, it must be *precharged.* To precharge the capacitor, follow these steps.

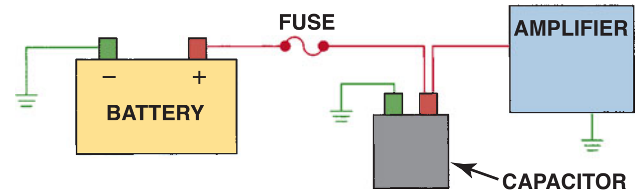


FIGURE 26–16 A powerline capacitor should be connected through the power wire to the amplifier as shown. When the amplifier requires more electrical power (watts) than the battery can supply, the capacitor will discharge into the amplifier and supply the necessary current for the fraction of a second it is needed by the amplifier. At other times when the capacitor is not needed, it draws current from the battery to keep it charged.

POWERLINE CAPACITOR USAGE GUIDE

WATTS (AMPLIFIER)	RECOMMENDED CAPACITOR IN FARADS (MICROFARADS)
100 W	0.10 farad (100,000 µF)
200 W	0.20 farad (200,000 µF)
250 W	0.25 farad (250,000 µF)
500 W	0.50 farad (500,000 µF)
750 W	0.75 farad (750,000 µF)
1,000 W	1.00 farad (1,000,000 µF)

CHART 26–1

The rating of the capacitor needed to upgrade an audio system is directly related to the wattage of the system.

STEP 1 Connect the negative (−) terminal of the capacitor to a good chassis ground.

STEP 2 Insert an automotive 12 V light bulb, such as a headlight or parking light, between the positive (+) terminal of the capacitor and the positive terminal of the battery. The light will light as the capacitor is being charged and then go out when the capacitor is fully charged.

STEP 3 Disconnect the light from the capacitor, then connect the power lead to the capacitor. The capacitor is now fully charged and ready to provide the extra power necessary to supplement battery power to the amplifier.

VOICE RECOGNITION

PARTS AND OPERATION **Voice recognition** is an expanding technology. It allows the driver of a vehicle to perform tasks, such as locate an address in a navigation system by using voice commands rather than buttons. In the past, users had to say the exact words to make it work such as the

FREQUENTLY ASKED QUESTION

What Do the Amplifier Specifications Mean?

RMS power	**RMS** means root-mean-square and is the rating that indicates how much power the amplifier is capable of producing continuously.
RMS power at 2 ohms	This specification in watts indicates how much power the amplifier delivers into a 2 ohm speaker load. This 2 ohm load is achieved by wiring two 4 ohm speakers in parallel or by using 2 ohm speakers.
Peak power	Peak power is the maximum wattage an amplifier can deliver in a short burst during a musical peak.
THD	**Total harmonic distortion (THD)** represents the amount of change of the signal as it is being amplified. The lower the number, the better the amplifier (e.g., a 0.01% rating is better than a 0.07% rating).
Signal-to-noise ratio	This specification is measured in decibels (dB) and compares the strength of the signal with the level of the background noise (hiss). A higher volume indicates less background noise (e.g., a 105 dB rating is better than a 100 dB rating).

following examples listed from an owner manual for a vehicle equipped with a voice-actuated navigation system.

"Go home"

"Repeat guidance"

"Nearest ATM"

The problem with these simple voice commands was that the exact wording had to be spoken. The voice recognition software would compare the voice command to a specific list of words or phrases stored in the system in order for a match to occur. Newer systems recognize speech patterns and take action based on learned patterns. Voice recognition can be used for the following functions.

1. Navigation system operation (● **SEE FIGURE 26–17.**)
2. Sound system operation
3. Climate control system operation
4. Telephone dialing and other related functions (● **SEE FIGURE 26–18.**)

FIGURE 26–17 Voice commands can be used to control many functions, including navigation systems, climate control, telephone, and radio.

FIGURE 26–18 The voice command icon on the steering wheel of a Cadillac.

A microphone is usually placed in the driver's side sun visor or in the overhead console in the center top portion of the windshield area.

DIAGNOSIS AND SERVICE Voice recognition is usually incorporated into many functions of the vehicle. If a problem occurs with the system, perform the following steps.

1. Verify the customer complaint (concern). Check the owner manual or service information for the proper voice commands and verify that the system is not functioning correctly.
2. Check for any aftermarket accessories that may interfere or were converted to components used by the voice recognition system, such as remote start units, MP3 players, or any other electrical component.
3. Check for stored diagnostic trouble codes (DTCs) using a scan tool.
4. Follow the recommended troubleshooting procedures as stated in service information.

BLUETOOTH

OPERATION **Bluetooth** is a (radio frequency) standard for short-range communications. The range of a typical Bluetooth device is 33 ft (10 m) and it operates in the ISM (industrial, scientific, and medical) band between 2.4000 and 2.4835 MHz.

Bluetooth is a wireless standard that works on two levels.

- It provides physical communication using low power, requiring only about 1 milliwatt (1/1,000 of a watt) of electrical power, making it suitable for use with small handheld or portable devices, such as an ear-mounted speaker/microphone.
- It provides a standard protocol for how bits of data are sent and received.

The Bluetooth standard is an advantage because it is wireless, low cost, and automatic. The automotive use of Bluetooth technology is in the operation of a cellular telephone being tied into the vehicle. The vehicle allows the use of hands-free telephone usage. A vehicle that is Bluetooth telephone equipped has the following components.

- A Bluetooth receiver can be built into the navigation or existing sound system.
- A microphone allows the driver to use voice commands as well as telephone conversations from the vehicle to the cell via Bluetooth wireless connections.

Many cell phones are equipped with Bluetooth which may allow the caller to use an ear-mounted microphone and speaker. ● **SEE FIGURE 26–19.**

If the vehicle and the cell phone are equipped with Bluetooth, the speaker and microphone can be used as a hands-free telephone when the phone is in the vehicle. The cell phone can be activated in the vehicle by using voice commands.

FIGURE 26–19 Bluetooth earpiece that contains a microphone and speaker unit that is paired to a cellular phone. The telephone has to be within 33 ft (10 m) of the earpiece.

FREQUENTLY ASKED QUESTION

Where Did Bluetooth Get Its Name?

The early adopters of the standard used the term Bluetooth, and they named it for Harold Bluetooth, the king of Denmark in the late 900s. The king was able to unite Denmark and part of Norway into a single kingdom.

FREQUENTLY ASKED QUESTION

Can Two Bluetooth Telephones Be Used in a Vehicle?

Usually. In order to use two telephones, the second phone needs to be given a name. When both telephones enter the vehicle, check which one is recognized. Say "phone status" and the system will tell you to which telephone the system is responding. If it is not the one you want, simply say, "next phone" and it will move to the other one.

SATELLITE RADIO

PARTS AND OPERATION Satellite radio, also called **Satellite Digital Audio Radio Services** or **SDARS**, is a fee-based system that uses satellites to broadcast high-quality radio. SDARS broadcasts on the S-band of 2.1320 to 2.345 GHz.

SIRIUS/XM RADIO Sirius/XM radio is standard equipment or optional in most vehicles. XM radio uses two satellites launched in 2001 called Rock (XM-2) and Roll (XM-1) in a geosynchronous orbit above North America. Two replacement satellites, Rhythm (XM-3) and Blues (XM-4) were launched in 2006. Sirius and XM radio combined in 2008 and now share some programming. The two types of satellite radios use different protocols and, therefore, require separate radios unless a combination unit is purchased.

RECEPTION Reception from satellites can be affected by tall buildings and mountains. To help ensure consistent reception, both SDARS providers do the following:

- Include in the radio itself a buffer circuit that can store several seconds of broadcasts to provide service when traveling out of a service area
- Provide land-based repeater stations in most cities (● **SEE FIGURE 26–20.**)

ANTENNA To be able to receive satellite radio, the antenna needs to be able to receive signals from both the satellite and the repeater stations located in many large cities. There are

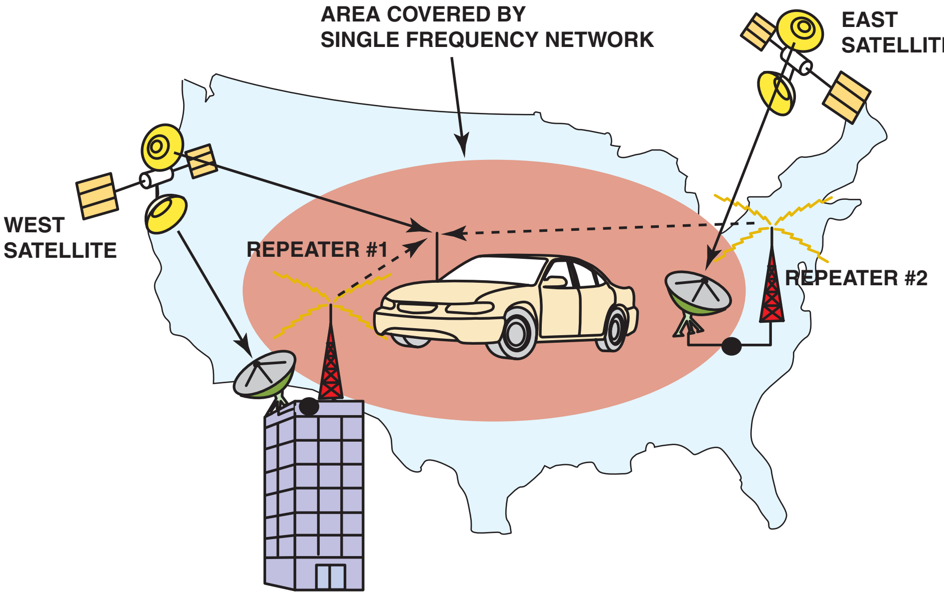


FIGURE 26–20 SDARS uses satellites and repeater stations to broadcast radio.

FIGURE 26–21 An aftermarket XM radio antenna mounted on the rear deck lid. The deck lid acts as the ground plane for the antenna.

FIGURE 26–22 A shark-fin-type factory antenna used for both XM and OnStar.

various types and shapes of antennas, including those shown in ● **FIGURES 26–21 AND 26–22.**

DIAGNOSIS AND SERVICE The first step in any diagnosis is to verify the customer complaint (concern). If no satellite service is being received, first check with the customer to verify that the monthly service fee has been paid and the account is up to date. If poor reception is the cause, carefully check the antenna for damage or faults with the lead-in wire. The antennas must be installed on a metal surface to provide the proper ground plane.

For all other satellite radio fault problems, check service information for the exact tests and procedures. Always follow the factory recommended procedures. Check the following websites for additional information.

- **www.xmradio.com**
- **www.sirius.com**
- **www.siriusxm.com**

RADIO INTERFERENCE

DEFINITION Radio interference is caused by variations in voltage in the powerline or picked up by the antenna. A "whine" that increases in frequency with increasing engine speed is usually referred to as an **alternator whine** and is eliminated by installing a radio choke or a filter capacitor in the power feed wire to the radio. ● **SEE FIGURE 26–23.**

CAPACITOR USAGE Ignition noise is usually a raspy sound that varies with the speed of the engine. This noise is usually eliminated by the installation of a capacitor on the positive side of the ignition coil. The capacitor should be connected to the power feed wire to either the radio or the amplifier, or both. The capacitor *has* to be grounded. A capacitor allows AC interference to pass through to ground while blocking the flow of DC current.

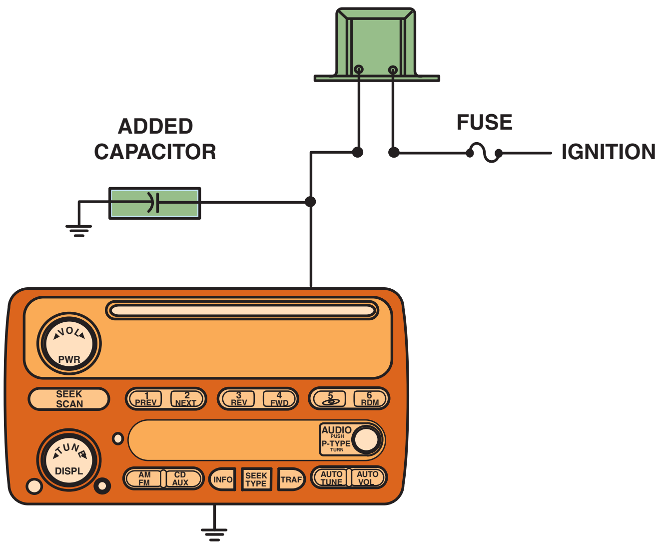


FIGURE 26–23 A radio choke and/or a capacitor can be installed in the power feed lead to any radio, amplifier, or equalizer.

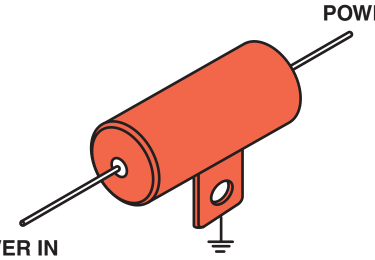


FIGURE 26–24 Many automobile manufacturers install a coaxial capacitor, like this one, in the power feed wire to the blower motor to eliminate interference caused by the blower motor.

Use a 470 μF, 50 volt electrolytic capacitor, which is readily available from most radio supply stores. A special coaxial capacitor can also be used in the powerline. ● **SEE FIGURE 26–24.**

RADIO CHOKE A **radio choke**, which is a coil of wire, can also be used to reduce or eliminate radio interference. Again, the radio choke is installed in the power feed wire to the radio equipment. Radio interference being picked up by the antenna can best be eliminated by stopping the source of the interference and making certain that all units containing a coil, such as electric motors, have a capacitor or diode attached to the power-side wire.

BRAIDED GROUND WIRE Using a braided ground wire is usually specified when electrical noise is a concern. The radio-frequency signals travel on the surface of a conductor rather than through the core of the wire. A braided ground strap is used because the overlapped wires short out any radio-frequency signals traveling on the surface.

FREQUENTLY ASKED QUESTION

What Does ESN Mean?

ESN means electronic serial number. This is necessary information to know when reviewing satellite radio subscriptions. Each radio has its own unique ESN, often found on a label at the back or bottom of the unit. It is also often shown on scan tools or test equipment designed to help diagnose faults in the units.

TECH TIP

The Separate Battery Trick

Whenever diagnosing sound system interference, try running separate 14 gauge wire(s) from the sound system power lead and ground to a separate battery outside of the vehicle. If the noise is still heard, the interference is *not* due to an alternator diode or other source in the wiring of the vehicle.

AUDIO NOISE SUMMARY In summary:

- Radio noise can be broadcast or caused by noise (voltage variations) in the power circuit to the radio.
- Most radio interference complaints come when someone installs an amplifier, power booster, equalizer, or other radio accessory.
- *A major cause of this interference is the variation in voltage through the ground circuit wires. To prevent or reduce this interference, make sure all ground connections are clean and tight.*
- Placing a capacitor in the ground circuit also may be beneficial.

CAUTION: Amplifiers sold to boost the range or power of an antenna often increase the level of interference and radio noise to a level that disturbs the driver.

Capacitor and/or radio chokes are the most commonly used components. Two or more capacitors can be connected in parallel to increase the capacity of the original capacitor. A "sniffer" can be used to locate the source of the radio noise. A sniffer is a length of antenna wire with a few inches of insulation removed from the antenna end. The sniffer is attached to the antenna input terminal of the radio, and the radio is turned on and set to a weak station. The other end of the sniffer is then

FIGURE 26–25 A "sniffer" can be made from an old antenna lead-in cable by removing about 3 in. of the outer shielding from the end. Plug the lead-in cable into the antenna input of the radio and tune the radio to a weak station. Move the end of the antenna wire around the vehicle dash area. The sniffer is used to locate components that may not be properly shielded or grounded and can cause radio interference through the case (housing) of the radio itself.

moved around areas of the dash to locate where the source of the interference originates. The radio noise will greatly increase if the end of the sniffer comes close to where electromagnetic leakage is occurring. ● **SEE FIGURE 26–25.**

● **SEE CHART 26–2.**

FIGURE 26–26 The tip of this antenna was struck by lightning.

REAL WORLD FIX

Lightning Damage

A radio failed to work in a vehicle that was outside during a thunderstorm. The technician checked the fuses and verified that power was reaching the radio. Then the technician noticed the antenna. It had been struck by lightning. Obviously, the high voltage from the lightning strike traveled to the radio receiver and damaged the circuits. Both the radio and the antenna were replaced to correct the problem.

● **SEE FIGURE 26–26.**

AUDIO NOISE CONTROL SYMPTOM CHART

NOISE SOURCE	WHAT IT SOUNDS LIKE	WHAT TO TRY
Alternator	A whine whose pitch changes with engine speed	Install a capacitor to a ground at the alternator output
Ignition	Ticking that changes with engine speed	Use a sniffer to further localize the source of the problem
Turn signals	Popping in time with the turn signals	Install a capacitor across the turn signal flasher
Brake lights	Popping whenever the brake pedal is depressed	Install a capacitor across the brake light switch contacts
Blower motor	Ticking in time with the blower motor	Install a capacitor to ground at the motor hot lead
Dash lamp dimmer	A buzzy whine whose pitch changes with the dimmer setting	Install a capacitor to ground at the dimmer hot lead
Horn switch	Popping when the horn is sounded	Install a capacitor between the hot lead and horn lead at the horn relay
Horn	Buzzing synchronized with the horn	Install a capacitor to ground at each horn hot lead
Amplifier power supply	A buzz, not affected by engine speed	Ground the amplifier chassis using a braided ground strap

CHART 26–2

Radio noise can have various causes, and knowing where or when the noise occurs helps pin down the location.

REAL WORLD FIX

The General Motors Security Radio Problem

A customer replaced the battery in a General Motors vehicle and now the radio display shows "LOC." This means that the radio is locked and there is a customer code stored in the radio.

Other displays and their meaning include:

"InOP" This display indicates that too many incorrect codes have been entered and the radio must be kept powered for one hour and the ignition turned on before any more attempts can be made.

"SEC" This display means there is a customer's code stored and the radio is unlocked, secured and operable.

"---" This means there is no customer code stored and the radio is unlocked.

"REP" This means the customer's code has been entered once and the radio now is asking that the code be repeated to verify it was entered correctly the first time.

To unlock the radio, the technician used the following steps (the code number being used is 4321).

STEP 1 Press the "HR" (hour) button: "000" is displayed.
STEP 2 Set the first two digits using the hour button: "4300" is displayed.
STEP 3 Set the last two digits of the code using the "MIN" (minutes) button: "4321" is displayed.
STEP 4 Press the AM-FM button to enter the code. The radio is unlocked and the clock displays "1:00."

Thankfully, the owner had the security code. If the owner had lost the code, the technician would have to secure a scrambled factory backup code from the radio and then call a toll-free number to obtain another code for the customer. The code will only be given to authorized dealers or repair facilities.

SUMMARY

1. Radios receive AM (amplitude modulation) and FM (frequency modulation) signals that are broadcast through the air.
2. The radio antenna is used to induce a very small voltage signal as an input into the radio from the electromagnetic energy via the broadcast station.
3. AM requires an antenna whereas FM may be heard from a radio without an antenna.
4. Speakers reproduce the original sound, and the impedance of all speakers should be equally matched.
5. Crossovers are used to block certain frequencies to allow each type of speaker to perform its job better. A low-pass filter is used to block high-frequency sounds being sent to large woofer speakers, and a high-pass filter blocks low-frequency sounds being sent to tweeters.
6. Radio interference can be caused by many different things, such as a defective alternator, a fault in the ignition system, a fault in a relay or solenoid, or a poor electrical ground connection.

REVIEW QUESTIONS

1. Why do AM signals travel farther than FM signals?
2. What are the purpose and function of the ground plane?
3. How do you match the impedance of speakers?
4. What two items may need to be added to the wiring of a vehicle to control or reduce radio noise?

CHAPTER QUIZ

1. Technician A says that a radio can receive AM signals, but not FM signals, if the antenna is defective. Technician B says that a good antenna should give a reading of about 500 ohms when tested with an ohmmeter between the center antenna wire and ground. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. An antenna lead-in wire should have how many ohms of resistance between the center terminal and the grounded outer covering?
   a. Less than 5 ohms
   b. 5 to 50 ohms
   c. 300 to 500 ohms
   d. Infinity (OL)
3. Technician A says that a braided ground wire is best to use for audio equipment to help reduce interference. Technician B says to use insulated 14 gauge or larger ground wire to reduce interference. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. What maintenance should be performed to a power antenna to help keep it working correctly?
   a. Remove it from the vehicle and lubricate the gears and cable.
   b. Clean the mast with a soft cloth and lubricate with a light oil.
   c. Disassemble the mast and pack the mast with silicone grease (or equal).
   d. Loosen and then retighten the retaining nut.
5. If two 4 ohm speakers are connected in parallel, meaning positive (+) to positive (+) and negative (−) to negative (−), the total impedance will be ________.
   a. 8 ohms
   b. 4 ohms
   c. 2 ohms
   d. 1 ohm
6. If two 4 ohm speakers are connected in series, meaning the positive (+) of one speaker connected to the negative (−) of the other speaker, the total impedance will be ________.
   a. 8 ohms
   b. 4 ohms
   c. 5 ohms
   d. 1 ohm
7. An aftermarket satellite radio has poor reception. Technician A says that a lack of a proper ground plane on the antenna could be the cause. Technician B says that mountains or tall buildings can interfere with reception. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. 100,000 μF means ________.
   a. 0.10 farad
   b. 0.01 farad
   c. 0.001 farad
   d. 0.0001 farad
9. A radio choke is actually a ________.
   a. Resistor
   b. Capacitor
   c. Coil (inductor)
   d. Transistor
10. What device passes AC interference to ground and blocks DC voltage, and is used to control radio interference?
   a. Resistor
   b. Capacitor
   c. Coil (inductor)
   d. Transistor

chapter 27

ON-BOARD DIAGNOSIS

OBJECTIVES: After studying Chapter 27, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "D" (Emission Control Systems Diagnosis and Repair including OBD II). • Explain the purpose and function of onboard diagnosis. • List the various duties of the diagnostic executive (task master). • List five continuous monitors. • List five noncontinuous monitors.

KEY TERMS: California Air Resources Board (CARB) 400 • Component identification (CID) 407 • Comprehensive component monitor (CCM) 401 • Diagnostic executive 401 • Enable criteria 403 • Exponentially weighted moving average (EWMA) monitor 403 • Federal Test Procedure (FTP) 401 • Freeze-frame 401 • Functionality 402 • Malfunction indicator lamp (MIL) 400 • Monitor identification (MID) 408 • On-board diagnosis (OBD) 400 • Parameter identification (PID) 407 • Rationality 402 • Society of Automotive Engineers (SAE) 404 • Task manager 401 • Test identification (TID) 407

ON-BOARD DIAGNOSTICS GENERATION-II (OBD-II) SYSTEMS

PURPOSE AND FUNCTION OF OBD II During the 1980s, most manufacturers began equipping their vehicles with full-function control systems capable of alerting the driver of a malfunction and of allowing the technician to retrieve codes that identify circuit faults. These early diagnostic systems were meant to reduce emissions and speed up vehicle repair.

The automotive industry calls these systems **On-Board Diagnostics (OBDs).** The **California Air Resources Board (CARB)** developed the first regulation requiring manufacturers selling vehicles in that state to install OBD. OBD Generation I (OBD I) applies to all vehicles sold in California beginning with the 1988 model year. It specifies the following requirements:

1. An instrument panel warning lamp able to alert the driver of certain control system failures, now called a **malfunction indicator lamp (MIL).** ● **SEE FIGURE 27–1.**
2. The system's ability to record and transmit diagnostic trouble codes (DTCs) for emission-related failures.
3. Electronic system monitoring of the HO2S, EGR valve, and evaporative purge solenoid. Although not U.S. EPA-required, during this time most manufacturers also equipped vehicles sold outside of California with OBD I.

By failing to monitor the catalytic converter, the evaporative system for leaks, and the presence of engine misfire, OBD I did not do enough to lower automotive emissions. This led the CARB and the EPA to develop OBD Generation II (OBD II).

FIGURE 27–1 A typical malfunction indicator lamp (MIL) often labeled "check engine" or "service engine soon" (SES).

OBD-II OBJECTIVES Generally, the CARB defines an OBD-II-equipped vehicle by its ability to do the following:

1. Detect component degradation or a faulty emission-related system that prevents compliance with federal emission standards.
2. Alert the driver of needed emission-related repair or maintenance.
3. Use standardized DTCs and accept a generic scan tool.

These requirements apply to all 1996 and later model light-duty vehicles. The Clean Air Act of 1990 directed the EPA to develop new regulations for OBD. The primary purpose of OBD II is emission-related, whereas the primary purpose of OBD I (1988) was to detect faults in sensors or sensor circuits. OBD-II regulations require that not only sensors be tested but also all exhaust emission control devices, and that they be verified for proper operation.

All new vehicles must pass the **Federal Test Procedure (FTP)** for exhaust emissions while being tested for 1874 seconds on dynamometer rollers that simulate the urban drive cycle around downtown Los Angeles.

NOTE: IM 240 is simply a shorter 240-second version of the federal test procedure.

The regulations for OBD-II vehicles state that the vehicle computer must be capable of testing for, and determining, if the exhaust emissions are within 1.5 times the FTP limits. To achieve this goal, the computer must do the following:

1. Test all exhaust emission system components for correct operation.
2. Actively operate the system and measure the results.
3. Continuously monitor all aspects of the engine operation to be certain that the exhaust emissions do not exceed 1.5 times the FTP limit.
4. Check engine operation for misfire.
5. Turn on the MIL (check engine) if the computer senses a fault in a circuit or system.
6. Record a **freeze-frame,** which is a snapshot of important engine data at the time the DTC was set.
7. Flash the MIL if an engine misfire occurs that could damage the catalytic converter.

DIAGNOSTIC EXECUTIVE AND TASK MANAGER

On OBD-II systems, the powertrain control module (PCM) incorporates a special segment of software. On Ford and GM systems, this software is called the **diagnostic executive.** On Chrysler systems, it is called the **task manager.** This software program is designed to manage the operation of all OBD-II monitors by controlling the sequence of steps necessary to execute the diagnostic tests and monitors.

MONITORS

A monitor is an organized method of testing a specific part of the system. Monitors are simply tests that the computer performs to evaluate components and systems. If a component or system failure is detected while a monitor is running, a DTC will be stored and the MIL illuminated during the second trip. The two types of monitors are continuous and noncontinuous.

CONTINUOUS MONITORS As required conditions are met, continuous monitors begin to run. These continuous monitors will run for the remainder of the vehicle drive cycle. The three continuous monitors are as follows:

- **Comprehensive component monitor (CCM).** This monitor watches the sensors and actuators in the OBD-II system. Sensor values are constantly compared with known-good values stored in the PCM's memory.

  The CCM is an internal program in the PCM designed to monitor a failure in any electronic component or circuit (including emission-related and non-emission-related circuits) that provide input or output signals to the PCM. The PCM considers that an input or output signal is inoperative when a failure exists due to an open circuit, out-of-range value, or if an onboard rationality check fails. If an emission-related fault is detected, the PCM will set a code and activate the MIL (requires two consecutive trips).

  Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices are only tested by the CCM after the engine meets certain engine conditions. The number of times the CCM must detect a fault before it will activate the MIL depends upon the manufacturer, but most require two consecutive trips to activate the MIL. The components tested by the CCM include:

  Four-wheel-drive low switch
  Brake switch
  Camshaft (CMP) and crankshaft (CKP) sensors
  Clutch switch (manual transmissions/transaxles only)
  Cruise servo switch
  Engine coolant temperature (ECT) sensor
  EVAP purge sensor or switch
  Fuel composition sensor
  Intake air temperature (IAT) sensor
  Knock sensor (KS)
  Manifold absolute pressure (MAP) sensor
  Mass airflow (MAF) sensor
  Throttle-position (TP) sensor
  Transmission temperature sensor
  Transmission turbine speed sensor
  Vacuum sensor
  Vehicle speed (VS) sensor
  EVAP canister purge and EVAP purge vent solenoid
  Idle air control (IAC)
  Ignition control system
  Transmission torque converter clutch solenoid
  Transmission shift solenoids

- **Misfire monitor.** This monitor watches for engine misfire. The PCM uses the information received from the crankshaft position sensor (CKP) to calculate the time between the edges of the reluctor, as well as the rotational speed and acceleration. By comparing the acceleration of each firing event, the PCM can determine if a cylinder is not firing correctly.

Misfire type A. Upon detection of a misfire type A (200 revolutions), which would cause catalyst damage, the MIL will blink once per second during the actual misfire, and a DTC will be stored.

Misfire type B. Upon detection of a misfire type B (1,000 revolutions), which will exceed 1.5 times the EPA federal test procedure (FTP) standard or cause a vehicle to fail an inspection and maintenance tailpipe emissions test, the MIL will illuminate and a DTC will be stored.

The DTC associated with multiple cylinder misfire for a type A or type B misfire is DTC P0300. The DTCs associated with an individual cylinder misfire for a type A or type B misfire are DTCs P0301, P0302, P0303, P0304, P0305, P0306, P0307, P0308, P0309, and P0310.

- **Fuel trim monitor.** The PCM continuously monitors short- and long-term fuel trim. Constantly updated adaptive fuel tables are stored in long-term memory (KAM), and used by the PCM for compensation due to wear and aging of the fuel system components. The MIL will illuminate when the PCM determines the fuel trim values have reached and stayed at their limits.

NONCONTINUOUS MONITORS Noncontinuous monitors run (at most) once per vehicle drive cycle. The noncontinuous monitors are as follows:

O2S monitor
O2S heater monitor
Catalyst monitor
EGR monitor
EVAP monitor
Secondary AIR monitor
Transmission monitor
PCV system monitor
Thermostat monitor

Once a noncontinuous monitor has run to completion, it will not be run again until the conditions are met during the next vehicle drive cycle. Also after a noncontinuous monitor has run to completion, the readiness status on your scan tool will show “complete” or “done” for that monitor. Monitors that have not run to completion will show up on your scanner as “incomplete.”

OBD-II MONITOR INFORMATION

COMPREHENSIVE COMPONENT MONITOR The circuits and components covered by the comprehensive component monitor (CCM) do not include those directly monitored by another monitor.

However, OBD II also requires that inputs from powertrain components to the PCM be tested for **rationality,** and that outputs to powertrain components from the PCM be tested for **functionality.** Both inputs and outputs are to be checked electrically. Rationality checks refer to a PCM comparison of input values to values from other sensors to determine if they make sense and are normal (rational).

Example:

TPS	3 V
MAP	18 in./Hg
RPM	700 RPM
PRNDL	Park

NOTE: Comprehensive component monitors are continuous. Therefore enabling conditions do not apply.

- Monitor runs continuously
- Monitor includes sensors, switches, relays, solenoids, and PCM hardware
- All are checked for opens, shorts-to-ground, and shorts-to-voltage
- Inputs are checked for rationality
- Outputs are checked for functionality
- Most are one-trip DTCs
- Freeze-frame is priority 3
- Three consecutive good trips are used to extinguish the MIL
- Forty warm up cycles are necessary to self erase the DTC and freeze frame.
- Two minutes run time without reoccurrence of the fault constitutes a “good trip”

CONTINUOUS RUNNING MONITORS Continuous monitors run continuously and only stop if they fail and include:

- Fuel system: rich/lean
- Misfire: catalyst damaging/FTP (emissions)
- Two-trip faults (except early generation catalyst damaging misfire)
- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 2 on first trip
- Freeze-frame is priority 4 on maturing trip
- Three consecutive good trips in a similar condition window are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame (80 to erase one-trip failure if similar conditions cannot be met)

ONCE PER TRIP MONITORS

- Monitor runs once per trip, pass or fail
- O_2 response, O_2 heaters, EGR, purge flow EVAP leak, secondary air, catalyst
- Two-trip DTCs

- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 1 on first trip
- Freeze-frame is priority 3 on maturing trip
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame

EXPONENTIALLY WEIGHTED MOVING AVERAGE (EWMA) MONITORS The **exponentially weighted moving average (EWMA) monitor** is a mathematical method used to determine performance.

This method smooths out any variables in the readings over time and results in a running average. This method is used by some vehicle manufacturers for two monitors.

1. Catalyst monitor
2. EGR monitor

ENABLING CRITERIA

With so many different tests (monitors) to run, the PCM needs an internal director to keep track of when each monitor should run. As mentioned, different manufacturers have different names for this director, such as the diagnostic executive or the task manager. Each monitor has enabling criteria. These criteria are a set of conditions that must be met before the task manager will give the go-ahead for each monitor to run. Most enabling criteria follow simple logic, for example:

- The task manager will not authorize the start of the O2S monitor until the engine has reached operating temperature and the system has entered closed loop.
- The task manager will not authorize the start of the EGR monitor when the engine is at idle, because the EGR is always closed at this time.

There may be a conflict if two monitors were to run at the same time. The results of one monitor might also be tainted if a second monitor were to run simultaneously. In such cases, the task manager decides which monitor has a higher priority. Some monitors also depend on the results of other monitors before they can run.

A monitor may be classified as pending if a failed sensor or other system fault is keeping it from running on schedule.

The task manager may suspend a monitor if the conditions are not correct to continue. For example, if the catalyst monitor is running during a road test and the PCM detects a misfire, the catalyst monitor will be suspended for the duration of the misfire.

TRIP A trip is defined as a key-on condition that contains the necessary conditions for a particular test to be performed followed by a key-off. These conditions are called the **enable criteria.** For example, for the EGR test to be performed, the engine must be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

FREQUENTLY ASKED QUESTION

What is a Drive Cycle?

A drive cycle is a vehicle being driven under specified speed and times that will allow all monitors to run. In other words, the powertrain control module (PCM) is looking at a series of data points representing speed and time and determines from these data points when the conditions are right to perform a monitor or a test of a component. These data points and therefore the drive cycle are vehicle specific and are not the same for each vehicle. Some common conditions for a drive cycle to successfully run all of the monitors include:

1. Cold start with intake air temperature (IAT) and engine coolant temperature (ECT) close to each other indicating that the engine has cooled to the temperature of the surrounding air temperature.
2. Fuel level within a certain range usually between 15% and 85%.
3. Vehicle speed within a certain speed range for an certain amount of time usually 4 to 12 minutes.
4. Stop and idle for a certain time.

Each monitor requires its own set of parameters needed to run the test and sometimes these conditions cannot be met. For example, some evaporate emissions control (EVAP) systems require a temperature that may not be possible in winter months in a cold climatic area.

A typical universal drive cycle that works for many vehicles includes the following steps.

MIL must be off.

No DTCs present.

Fuel fill between 15% and 85%.

Cold start—Preferred = 8-hour soak at 68°F to 86°F.

Alternative = ECT below 86°F.

STEP 1 With the ignition off, connect scan tool.
STEP 2 Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
STEP 3 Stop and idle for 40 seconds, gradually accelerate to 55 mph.
STEP 4 Maintain 55 mph for 4 minutes using a steady throttle input.
STEP 5 Stop and idle for 30 seconds, then accelerate to 30 mph.
STEP 6 Maintain 30 mph for 12 minutes.
STEP 7 Repeat steps 4 and 5 four times.

Using scan tool, check readiness. Always check service information for the exact drive cycle conditions for the vehicle being serviced for best results.

READINESS INDICATORS Indicators of monitors running or not, are used by most states as an emission test along with a MIL check. Readiness indicators stay in PCM memory until power or ground is interrupted or until DTCs are cleared using a scan tool.

WARM-UP CYCLE Once a MIL is deactivated, the original code will remain in memory until 40 warm-up cycles are completed without the fault reappearing. A warm-up cycle is defined as a trip with an engine temperature increase of at least 40°F and where engine temperature reaches at least 160°F (71°C).

MIL CONDITION: OFF This condition indicates that the PCM has not detected any faults in an emissions-related component or system, or that the MIL circuit is not working.

MIL CONDITION: ON STEADY This condition indicates a fault in an emissions-related component or system that could affect the vehicle emission levels. The MIL is also turned on at key on, engine off (KOEO) for at least 20 seconds as a bulb check.

MIL CONDITION: FLASHING This condition indicates a misfire or fuel control system fault that could damage the catalytic converter.

NOTE: In a misfire condition with the MIL on steady, if the driver reaches a vehicle speed and load condition with the engine misfiring at a level that could cause catalyst damage, the MIL would start flashing. It would continue to flash until engine speed and load conditions caused the level of misfire to subside. Then the MIL would go back to the on-steady condition. This situation might result in a customer complaint of a MIL with an intermittent flashing condition.

MIL: OFF The PCM will turn off the MIL if any of the following actions or conditions occur:

- The codes are cleared with a scan tool.
- Power to the PCM is removed at the battery or with the PCM power fuse for an extended period of time (may be up to several hours or longer).
- A vehicle is driven on three consecutive trips with a warm-up cycle and meets all code set conditions without the PCM detecting any faults.

The PCM will record a failure if a fault is detected that could cause tailpipe emissions to exceed 1.5 times the FTP standard. For one trip failures the MIL is immediately illuminated and a DTC stored. For two trip faults, the MIL is not illuminated nor is the DTC matured until the component has been tested and failed on the next trip. Many failures require that the vehicle be driven under similar RPM, temperature, and load conditions to be given a good trip. Without entering a *similar conditions window (SCW),* the MIL will remain illuminated.

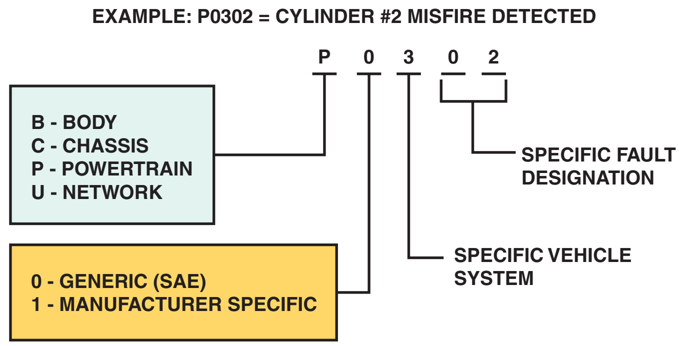


FIGURE 27–2 OBD-II DTC identification format.

OBD-II DTC NUMBERING DESIGNATION

A scan tool is required to retrieve DTCs from an OBD-II vehicle. Every OBD-II scan tool will be able to read all generic **Society of Automotive Engineers (SAE)** DTCs from any vehicle. ● **SEE FIGURE 27–2** for definitions and explanations of OBD alphanumeric DTCs. The diagnostic trouble codes (DTCs) are grouped into major categories, depending on the location of the fault on the system involved.

Pxxx codes—powertrain DTCs (engine, transmission-related faults)

Bxxx codes—body DTCs (accessories, interior-related faults)

Cxxx codes—chassis DTCs (suspension and steering-related faults)

Uxxx codes—network DTCs (module communication-related faults)

DTC NUMBERING EXPLANATION The number in the hundredth position indicates the specific vehicle system or subgroup that failed. This position should be consistent for P0xxx and P1xxx type codes. The following numbers and systems were established by SAE:

- P0100—Air metering and fuel system fault
- P0200—Fuel system (fuel injector only) fault
- P0300—Ignition system or misfire fault
- P0400—Emission control system fault
- P0500—Idle speed control, vehicle speed (VS) sensor fault
- P0600—Computer output circuit (relay, solenoid, etc.) fault
- P0700—Transaxle, transmission faults

NOTE: The number of the last two digits indicate the specific fault within the vehicle system.

TYPES OF DTCS Not all OBD-II DTCs are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer will only turn on the MIL for emissions-related DTCs.

TYPE A CODES A type A DTC is emission-related and will cause the MIL to be turned on the first trip if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, would cause a type A DTC. These codes alert the driver to an emission problem that may cause damage to the catalytic converter.

TYPE B CODES A type B code will be stored and the MIL will be turned on during the second consecutive trip, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and B codes are emission-related codes that will cause the lighting of the malfunction indicator lamp (MIL), usually labeled "check engine" or "service engine soon."

TYPE C AND D CODES Type C and D codes are for use with non-emission-related diagnostic tests; they will cause the lighting of a "service" lamp (if the vehicle is so equipped). Type C codes are also called type C1 codes and D codes are also called type C0 codes.

DIAGNOSTIC TROUBLE CODE PRIORITY CARB has also mandated that all diagnostic trouble codes (DTCs) be stored according to individual priority. DTCs with a higher priority overwrite those with a lower priority. The OBD-II System DTC Priority is listed below.

Priority 0—Non-emission-related codes

Priority 1—One-trip failure of two-trip fault for non-fuel, non-misfire codes

Priority 2—One-trip failure of two-trip fault for fuel or misfire codes

Priority 3—Two-trip failure or matured fault of non-fuel, non-misfire codes

Priority 4—Two-trip failure or matured fault for fuel or misfire codes

OBD-II FREEZE-FRAME

To assist the service technician, OBD II requires the computer to take a "snapshot" or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving this enhanced data usually requires the use of the vehicle-specific scan tool.

Freeze-frame items include:

- Calculated load value
- Engine speed (RPM)
- Short-term and long-term fuel trim percent
- Fuel system pressure (on some vehicles)
- Vehicle speed (mph)
- Engine coolant temperature
- Intake manifold pressure
- Closed-open-loop status
- Fault code that triggered the freeze-frame
- If a misfire code is set, identify which cylinder is misfiring

A DTC should not be cleared from the vehicle computer memory unless the fault has been corrected and the technician is so directed by the diagnostic procedure. If the problem that caused the DTC to be set has been corrected, the computer will automatically clear the DTC after 40 consecutive warm-up cycles with no further faults detected. It requires 80 warm-up cycles to erase the pending fault if similar conditions window cannot be met. The codes can also be erased by using a scan tool. **SEE CHART 27–1.**

NOTE: Disconnecting the battery may not erase OBD-II DTCs or freeze-frame data. Most vehicle manufacturers recommend using a scan tool to erase DTCs rather than disconnecting the battery, because the memory for the radio, seats, and learned engine operating parameters is lost if the battery is disconnected.

> **? FREQUENTLY ASKED QUESTION**
>
> **What Are Pending Codes?**
>
> Pending codes are set when operating conditions are met and the component or circuit is not within the normal range, yet the conditions have not yet been met to set a DTC. For example, a sensor may require two consecutive faults before a DTC is set. If a scan tool displays a pending code or a failure, a driveability concern could also be present. The pending code can help the technician to determine the root cause before the customer complains of a check engine light indication.

ENABLING CONDITIONS

These are the exact engine operating conditions required for a diagnostic monitor to run.

Example:

Specific RPM

Specific ECT, MAP, run time, etc.

PENDING Under some situations the PCM will not run a monitor if the MIL is illuminated and a fault is stored from another monitor. In these situations, the PCM postpones monitors pending a resolution of the original fault. The PCM does not run the test until the problem is remedied.

For example, when the MIL is illuminated for an oxygen sensor fault, the PCM does not run the catalyst monitor until the oxygen sensor fault is remedied. Since the catalyst monitor is based on signals from the oxygen sensor, running the test would produce inaccurate results.

MONITOR NAME	MONITOR TYPE (HOW OFTEN IT COMPLETES)	NUMBER OF FAULTS ON SEPARATE TRIPS TO SET A PENDING DTC	NUMBER OF SEPARATE CONSECUTIVE TRIPS TO LIGHT MIL, STORE A DTC	NUMBER OF TRIPS WITH NO FAULTS TO ERASE A PENDING DTC	NUMBER OF TRIPS WITH NO FAULT TO TURN THE MIL OFF	NUMBER OF WARM-UP CYCLES TO ERASE DTC AFTER MIL IS TURNED OFF
CCM	Continuous (when trip conditions allow it)	1	2	1	3–Trips	40
Catalyst	Once per drive cycle	1	3	1	3–Trips	40
Misfire Type A	Continuous		1		3–Similar conditions	40
Misfire Type B	Continuous	1	2	1	3–Similar conditions	40
Fuel System	Continuous	1	2	1	3–Similar conditions	40
Oxygen Sensor	Once per trip	1	2	1	3–Trips	40
EGR	Once per trip	1	2	1	3–Trips	40
EVAP	Once per trip	1	1	1	3–Trips	40
AIR	Once per trip	1	2	1	3–Trips	40

CHART 27–1

PCM Determination of Faults Chart

CONFLICT There are also situations when the PCM does not run a monitor if another monitor is in progress. In these situations, the effects of another monitor running could result in an erroneous failure. If this conflict is present, the monitor is not run until the conflicting condition passes. Most likely, the monitor will run later after the conflicting monitor has passed.

For example, if the fuel system monitor is in progress, the PCM does not run the EGR monitor. Since both tests monitor changes in air–fuel ratio and adaptive fuel compensation, the monitors conflict with each other.

SUSPEND Occasionally, the PCM may not allow a two-trip fault to mature. The PCM will suspend the maturing fault if a condition exists that may induce erroneous failure. This prevents illuminating the MIL for the wrong fault and allows more precise diagnosis.

For example, if the PCM is storing a one-trip fault for the oxygen sensor and the EGR monitor, the PCM may still run the EGR monitor but will suspend the results until the oxygen sensor monitor either passes or fails. At that point, the PCM can determine if the EGR system is actually failing or if an oxygen sensor is failing.

PCM TESTS

RATIONALITY TEST While input signals to the PCM are constantly being monitored for electrical opens and shorts, they are also tested for rationality. This means that the input signal is compared against other inputs and information to see if it makes sense under the current conditions.

PCM sensor inputs that are checked for rationality include:

- MAP sensor
- O_2 sensor
- ECT
- Camshaft position sensor (CMP)
- VS sensor
- Crankshaft position sensor (CKP)
- IAT sensor
- TP sensor
- Ambient air temperature sensor
- Power steering switch
- O_2 sensor heater
- Engine controller
- Brake switch
- P/N switch (range switch)
- Transmission controls

FUNCTIONALITY TEST A functionality test refers to PCM inputs checking the operation of the outputs.

Example:

PCM commands the IAC open; expected change in engine RPM is not seen
IAC 60 counts
RPM 700 RPM

PCM outputs that are checked for functionality include:

- EVAP canister purge solenoid
- EVAP purge vent solenoid
- Cooling fan
- Idle air control solenoid
- Ignition control system
- Transmission torque converter clutch solenoid
- Transmission shift solenoids (A,B,1–2, etc.)

ELECTRICAL TEST Refers to the PCM check of both input and outputs for the following:

- Open
- Shorts
- Ground

Example:

ECT
Shorted high (input to PCM) above capable voltage, i.e., 5-volt sensor with 12-volt input to PCM would indicate a short to voltage.

Monitor Type	Conditions to Set DTC and Illuminate MIL	Extinguish MIL	Clear DTC Criteria	Applicable DTC
Continuous 1-trip monitor	(See note below) Input and output failure—rationally, functionally, electrically	3 consecutive pass trips	40 warm-up cycles	P0123

NOTE: The number of times the comprehensive component monitor must detect a fault depends on the vehicle manufacturer. On some vehicles, the comprehensive component monitor will activate the MIL as soon as it detects a fault. On other vehicles, the comprehensive component monitor must fail two times in a row.

- Freeze-frame captured on first-trip failure.
- Enabling conditions: Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices (ECT, idle speed control) are only tested by the comprehensive component monitor after the engine meets particular engine conditions.
- Pending: No pending condition
- Conflict: No conflict conditions
- Suspend: No suspend conditions

GLOBAL OBD-II

All OBD-II vehicles must be able to display data on a global (also called *generic*) scan tool under nine different modes of operation. These modes include:

Mode One Current powertrain data (**parameter identification** display or **PID**)

Mode Two Freeze-frame data

Mode Three Diagnostic trouble codes

Mode Four Clear and reset diagnostic trouble codes (DTCs), freeze-frame data, and readiness status monitors for noncontinuous monitors only

Mode Five Oxygen sensor monitor test results

Mode Six Onboard monitoring of test results for noncontinuously monitored systems

Mode Seven Onboard monitoring of test results for continuously monitored systems

Mode Eight Bidirectional control of onboard systems

Mode Nine Module identification

The global (generic) data is used by most state emission programs. Global OBD-II displays often use hexadecimal numbers, which use 16 numbers instead of 10. The numbers 0 to 9 (zero counts as a number) make up the first 10 and then capital letters A to F complete the 16 numbers. To help identify the number as being in a hexadecimal format, a dollar sign ($) is used in front of the number or letter. The first digit is multiplied by 16 and the second digit added at face value. For example $FF = 255 where the value of F is 15: $15 \times 16 = 240 + 15 = 255$. See the conversion chart below:

Decimal Number	Hexadecimal Code
0	$0
1	$1
2	$2
3	$3
4	$4
5	$5
6	$6
7	$7
8	$8
9	$9
10	$A
11	$B
12	$C
13	$D
14	$E
15	$F

Hexadecimal coding is also used to identify tests (**test identification [TID]**, called **monitor identification [MID]** on CAN equipped vehicles and **component identification [CID]**).

? FREQUENTLY ASKED QUESTION

How Can You Tell Generic from Factory?

When using a scan tool on an OBD-II-equipped vehicle, if the display asks for make, model, and year, then the factory or enhanced part of the PCM is being accessed. If the generic or global part of the PCM is being scanned, then there is no need to know the vehicle identification details.

DIAGNOSING PROBLEMS USING MODE SIX

Mode six information can be used to diagnose faults by following three steps:

1. Check the monitor status before starting repairs. This step will show how the system failed.
2. Look at the component or parameter that triggered the fault. This step will help pin down the root cause of the failure.
3. Look to the monitor enable criteria, which will show what it takes to fail or pass the monitor.

Many scan tools display all of the parameters and **information** needed so that additional mode $06 data is not needed. Many vehicle manufacturers post mode $06 information on the service information websites. This information is often free, unlike other service information. Refer to the National Automotive Service Task Force (NASTF) website for the website address of all vehicle manufacturers' service information sites (*www.NASTF.org*). Two examples include: *http://service.gm.com* (free access to mode $06 information) *www.motorcraftservice.com* (search for mode $06 free access)

SUMMARY

1. If the MIL is on, retrieve the DTC and follow the manufacturer's recommended procedure to find the root cause of the problem.
2. All monitors must have the enable criteria achieved before a test is performed.
3. OBD-II vehicles use common generic DTCs.
4. OBD II includes generic (SAE), as well as vehicle manufacturer-specific DTCs, and data display.

REVIEW QUESTIONS

1. What does the PCM do during a trip to test emission-related components?
2. What is the difference between a type A and type B OBD-II DTC?
3. What is the difference between a trip and a warm-up cycle?
4. What could cause the MIL to flash?

CHAPTER QUIZ

1. A freeze-frame is generated on an OBD-II vehicle ________.
   - **a.** When a type C or D diagnostic trouble code is set
   - **b.** When a type A or B diagnostic trouble code is set
   - **c.** Every other trip
   - **d.** When the PCM detects a problem with the O2S
2. An ignition misfire or fuel mixture problem is an example of what type of DTC?
   - **a.** Type A
   - **b.** Type B
   - **c.** Type C
   - **d.** Type D
3. The comprehensive component monitor checks computer-controlled devices for ________.
   - **a.** opens
   - **b.** rationality
   - **c.** shorts-to-ground
   - **d.** All of the above
4. OBD II has been on all passenger vehicles in the United States since ________.
   - **a.** 1986
   - **b.** 1991
   - **c.** 1996
   - **d.** 2000
5. Which is a continuous monitor?
   - **a.** Fuel system monitor
   - **b.** EGR monitor
   - **c.** Oxygen sensor monitor
   - **c.** Catalyst monitor
6. DTC P0302 is a ________.
   - **a.** Generic DTC
   - **b.** Vehicle manufacturer-specific DTC
   - **c.** Idle speed-related DTC
   - **d.** Transmission/transaxle-related DTC
7. Global (generic) OBD II contains some data in what format?
   - **a.** Plain English
   - **b.** Hexadecimal
   - **c.** Roman numerals
   - **d.** All of the above
8. By looking at the way diagnostic trouble codes are formatted, which DTC could indicate that the gas cap is loose or defective?
   - **a.** P0221
   - **b.** P1301
   - **c.** P0442
   - **d.** P1603
9. The computer will automatically clear a DTC if there are no additional detected faults after ________.
   - **a.** Forty consecutive warm-up cycles
   - **b.** Eighty warm-up cycles
   - **c.** Two consecutive trips
   - **d.** Four key-on/key-off cycles
10. A pending code is set when a fault is detected on ________.
    - **a.** A one-trip fault item
    - **b.** The first fault of a two-trip failure
    - **c.** The catalytic converter efficiency
    - **d.** Thermostat problem (too long to closed-loop status)

chapter 28 TEMPERATURE SENSORS

OBJECTIVES: **After studying Chapter 28, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Explain the purpose and function of the ECT and IAT temperature sensors. • Describe how to test temperature sensors. • Discuss how automatic transmission fluid temperature sensor values can affect transmission operation.

KEY TERMS: Cylinder head temperature (CHT) 417 • Engine coolant temperature (ECT) 409 • Engine fuel temperature (EFT) 417 • Negative temperature coefficient (NTC) 409 • Throttle-body temperature (TBT) 415 • Transmission fluid temperature (TFT) 416

ENGINE COOLANT TEMPERATURE SENSORS

PURPOSE AND FUNCTION Computer-equipped vehicles use an **engine coolant temperature (ECT)** sensor. When the engine is cold, the fuel mixture must be richer to prevent stalling and engine stumble. When the engine is warm, the fuel mixture can be leaner to provide maximum fuel economy with the lowest possible exhaust emissions. Because the computer controls spark timing and fuel mixture, it will need to know the engine temperature. An engine coolant temperature (ECT) sensor installed into the engine coolant passage will provide the computer with this information. ● **SEE FIGURE 28–1**. This will be the most important (high-authority) sensor while the engine is cold. The ignition timing can also be tailored to engine (coolant) temperature. A hot engine cannot have the spark timing as far advanced as can a cold engine. The ECT sensor is also used as an important input for the following:

- Idle air control (IAC) position
- Oxygen sensor closed-loop status
- Canister purge on/off times
- Idle speed

ECT SENSOR CONSTRUCTION Engine coolant temperature sensors are constructed of a semiconductor material that decreases in resistance as the temperature of the sensor increases. Coolant sensors have very high resistance when the coolant is cold and low resistance when the coolant is hot. This is referred to as having a **negative temperature coefficient (NTC),** which is opposite to the situation with most other electrical components. ● **SEE FIGURE 28–2**. Therefore, if the coolant sensor has a poor connection (high resistance) at the wiring connector,

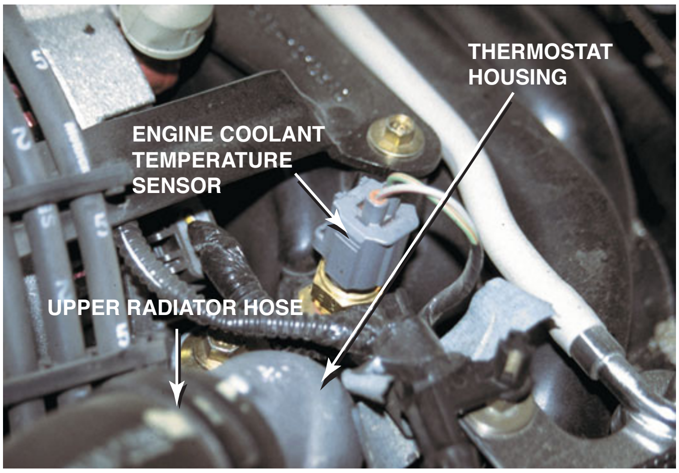


FIGURE 28–1 A typical engine coolant temperature (ECT) sensor. ECT sensors are located near the thermostat housing on most engines.

the computer will supply a richer-than-normal fuel mixture based on the resistance of the coolant sensor. Poor fuel economy and a possible-rich code can be caused by a defective sensor or high resistance in the sensor wiring. If the sensor was shorted or defective and had too low a resistance, a leaner-than-normal fuel mixture would be supplied to the engine. A too-lean fuel mixture can cause driveability problems and a possible-lean computer code.

STEPPED ECT CIRCUITS Some vehicle manufacturers use a step-up resistor to effectively broaden the range of the ECT sensor. Chrysler and General Motors vehicles use the same sensor as a non-stepped ECT circuit, but instead apply the sensor voltage through two different resistors.

- When the temperature is cold, usually below 120°F (50°C), the ECT sensor voltage is applied through a high-value resistor inside the PCM.

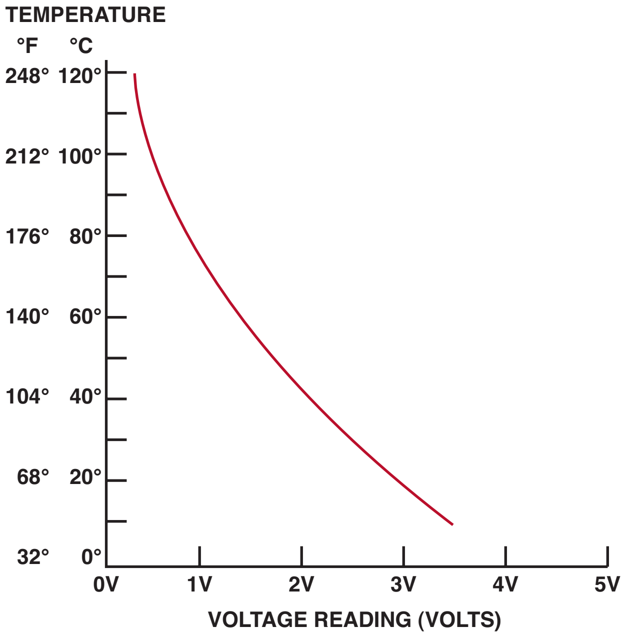


FIGURE 28–2 A typical ECT sensor temperature versus voltage curve.

- When the temperature is warm, usually above 120°F (50°C), the ECT sensor voltage is applied through a much lower resistance value inside the PCM. ● **SEE FIGURE 28–3.**

The purpose of this extra circuit is to give the PCM a more accurate reading of the engine coolant temperature compared to the same sensor with only one circuit. ● **SEE FIGURE 28–4.**

TESTING THE ENGINE COOLANT TEMPERATURE SENSOR

TESTING THE ENGINE COOLANT TEMPERATURE BY VISUAL INSPECTION The correct functioning of the engine coolant temperature (ECT) sensor depends on the following items that should be checked or inspected:

- **Properly filled cooling system.** Check that the radiator reservoir bottle is full and that the radiator itself is filled to the top.

  CAUTION: Be sure that the radiator is cool before removing the radiator cap to avoid being scalded by hot coolant.

  The ECT sensor must be submerged in coolant to be able to indicate the proper coolant temperature.

- **Proper pressure maintained by the radiator cap.** If the radiator cap is defective and cannot allow the cooling system to become pressurized, air pockets could develop. These air pockets could cause the engine to operate at a hotter-than-normal temperature and prevent proper temperature measurement, especially if the air pockets occur around the sensor.

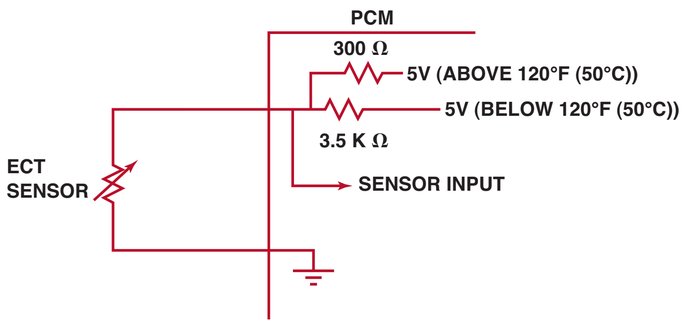


FIGURE 28–3 A typical two-step ECT circuit showing that when the coolant temperature is low, the PCM applies a 5-volt reference voltage to the ECT sensor through a higher resistance compared to when the temperature is higher.

- **Proper antifreeze–water mixture.** Most vehicle manufacturers recommend a 50/50 mixture of antifreeze and water as the best compromise between freezing protection and heat transfer ability.
- **Proper operation of the cooling fan.** If the cooling fan does not operate correctly, the engine may overheat.

TESTING THE ECT USING A MULTIMETER Both the resistance (in ohms) and the voltage drop across the sensor can be measured and compared with specifications. ● **SEE FIGURE 28–5.** See the following charts showing examples of typical engine coolant temperature sensor specifications. Some vehicles use the PCM to attach another resistor in the ECT circuit to provide a more accurate measure of the engine temperature. ● **SEE FIGURE 28–6.**

If resistance values match the approximate coolant temperature and there is still a coolant sensor trouble code, the problem is generally in the wiring between the sensor and the computer. Always consult the manufacturers' recommended procedures for checking this wiring. If the resistance values do not match, the sensor may need to be replaced.

General Motors ECT Sensor with Pull-up Resistor

°F	°C	Ohms	Voltage Drop Across Sensor
−40	−40	100,000 +	4.95
18	−8	14,628	4.68
32	0	9,420	4.52
50	10	5,670	4.25
68	20	3,520	3.89
86	30	2,238	3.46
104	40	1,459	2.97
122	50	973	2.47
140	60	667	2.00
158	70	467	1.59
176	80	332	1.25
194	90	241	0.97
212	100	177	0.75

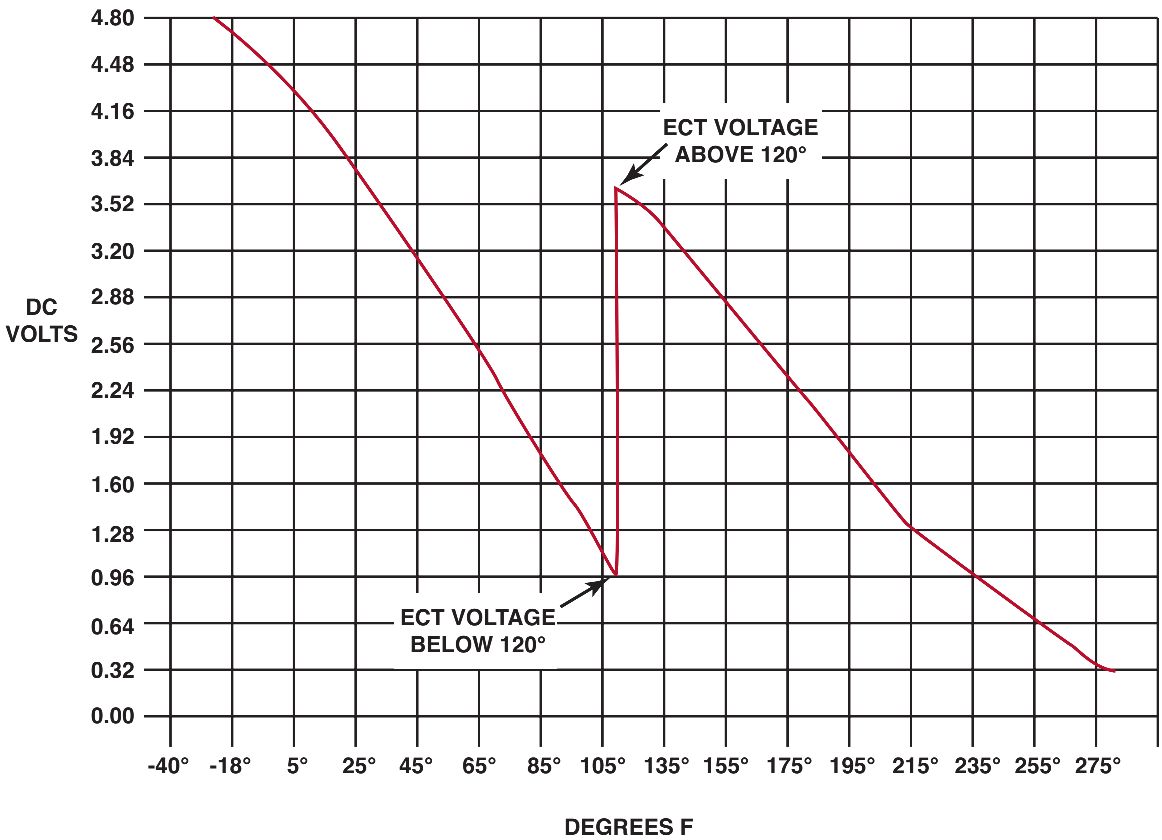


FIGURE 28–4 The transition between steps usually occurs at a temperature that would not interfere with cold engine starts or the cooling fan operation. In this example, the transition occurs when the sensor voltage is about 1 volt and rises to about 3.6 volts.

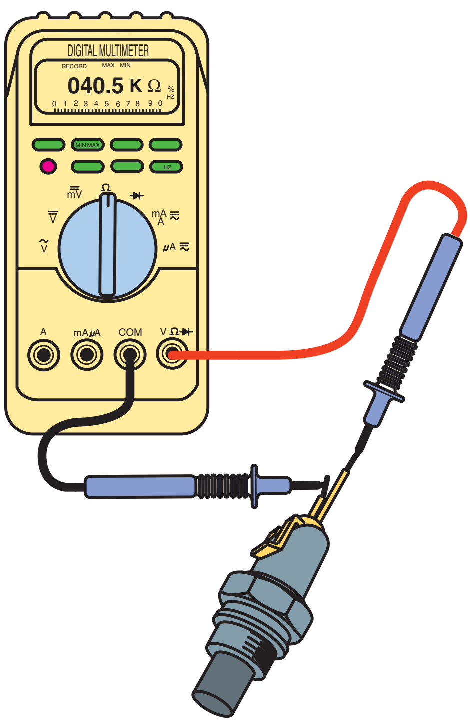


FIGURE 28–5 Measuring the resistance of the ECT sensor. The resistance measurement can then be compared with specifications. *(Courtesy of Fluke Corporation)*

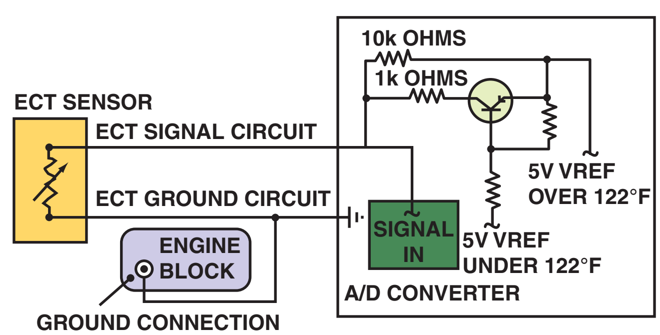


FIGURE 28–6 When the voltage drop reaches approximately 1.20 volts, the PCM turns on a transistor. The transistor connects a 1-kΩ resistor in parallel with the 10-kΩ resistor. Total circuit resistance now drops to around 909 ohms. This function allows the PCM to have full binary control at cold temperatures up to approximately 122°F, and a second full binary control at temperatures greater than 122°F.

General Motors ECT Sensor without Pull-up Resistor			
°F	°C	Ohms	Voltage Drop Across Sensor
−40	−40	100,000	5
−22	−30	53,000	4.78
−4	−20	29,000	4.34
14	−10	16,000	3.89
32	0	9,400	3.45
50	10	5,700	3.01
68	20	3,500	2.56
86	30	2,200	1.80
104	40	1,500	1.10
122	50	970	3.25
140	60	670	2.88
158	70	470	2.56
176	80	330	2.24
194	90	240	1.70
212	100	177	1.42
230	110	132	1.15
248	120	100	.87

Ford ECT Sensor			
°F	°C	Resistance (Ω)	Voltage (V)
50	10	58,750	3.52
68	20	37,300	3.06
86	30	24,270	2.26
104	40	16,150	2.16
122	50	10,970	1.72
140	60	7,600	1.35
158	70	5,370	1.04
176	80	3,840	0.80
194	90	2,800	0.61
212	100	2,070	0.47
230	110	1,550	0.36
248	120	1,180	0.28

Chrysler ECT Sensor without Pull-up Resistor		
°F	°C	Voltage (V)
130	54	3.77
140	60	3.60
150	66	3.40
160	71	3.20
170	77	3.02
180	82	2.80
190	88	2.60
200	93	2.40
210	99	2.20
220	104	2.00
230	110	1.80
240	116	1.62
250	121	1.45

Chrysler ECT Sensor with Pull-up Resistor		
°F	°C	Volts
−20	−29	4.70
−10	−23	4.57
0	−18	4.45
10	−12	4.30
20	−7	4.10
30	−1	3.90
40	4	3.60
50	10	3.30
60	16	3.00
70	21	2.75
80	27	2.44
90	32	2.15
100	38	1.83
		Pull-up Resistor Switched by PCM
110	43	4.20
120	49	4.10
130	54	4.00
140	60	3.60
150	66	3.40
160	71	3.20
170	77	3.02
180	82	2.80
190	88	2.60
200	93	2.40
210	99	2.20
220	104	2.00
230	110	1.80
240	116	1.62
250	121	1.45

Nissan ECT Sensor		
°F	°C	Resistance (Ω)
14	−10	7,000–11,400
68	20	2,100–2,900
122	50	680–1,000
176	80	260–390
212	100	180–200

Mercedes ECT		
°F	°C	Voltage (DCV)
60	20	3.5
86	30	3.1
104	40	2.7
122	50	2.3
140	60	1.9
158	70	1.5
176	80	1.2
194	90	1.0
212	100	0.8

European Bosch ECT Sensor		
°F	°C	Resistance (Ω)
32	0	6,500
50	10	4,000
68	20	3,000
86	30	2,000
104	40	1,500
122	50	900
140	60	650
158	70	500
176	80	375
194	90	295
212	100	230

Honda ECT Sensor (Resistance Chart)		
°F	°C	Resistance (Ω)
0	−18	15,000
32	0	5,000
68	20	3,000
104	40	1,000
140	60	500
176	80	400
212	100	250

Honda ECT Sensor (Voltage Chart)		
°F	°C	Voltage (V)
0	−18	4.70
10	−12	4.50
20	−7	4.29
30	−1	4.10
40	4	3.86
50	10	3.61
60	16	3.35
70	21	3.08
80	27	2.81
90	32	2.50
100	38	2.26
110	43	2.00
120	49	1.74
130	54	1.52
140	60	1.33
150	66	1.15
160	71	1.00
170	77	0.88
180	82	0.74
190	88	0.64
200	93	0.55
210	99	0.47

Normal operating temperature varies with vehicle make and model. Some vehicles are equipped with a thermostat with an opening temperature of 180°F (82°C), whereas other vehicles use a thermostat that is 195°F (90°C) or higher. Before replacing the ECT sensor, be sure that the engine is operating at the temperature specified by the manufacturer. Most manufacturers recommend checking the ECT sensor after the cooling fan has cycled twice, indicating a fully warmed engine. To test for voltage at the ECT sensor, select DC volts on a digital meter and carefully back probe the sensor wire and read the voltage. ● **SEE FIGURE 28–7**.

TESTING THE ECT SENSOR USING A SCAN TOOL

Follow the scan tool manufacturer's instructions and connect a scan tool to the data link connector (DLC) of the vehicle. Comparing the temperature of the engine coolant as displayed on a scan tool with the actual temperature of the engine is an excellent method to test an engine coolant temperature sensor.

1. Record the scan tool temperature of the coolant (ECT).
2. Measure the actual temperature of the coolant using an infrared pyrometer or contact-type temperature probe.

NOTE: Often the coolant temperature gauge in the dash of the vehicle can be used to compare with the scan tool temperature. Although not necessarily accurate, it may

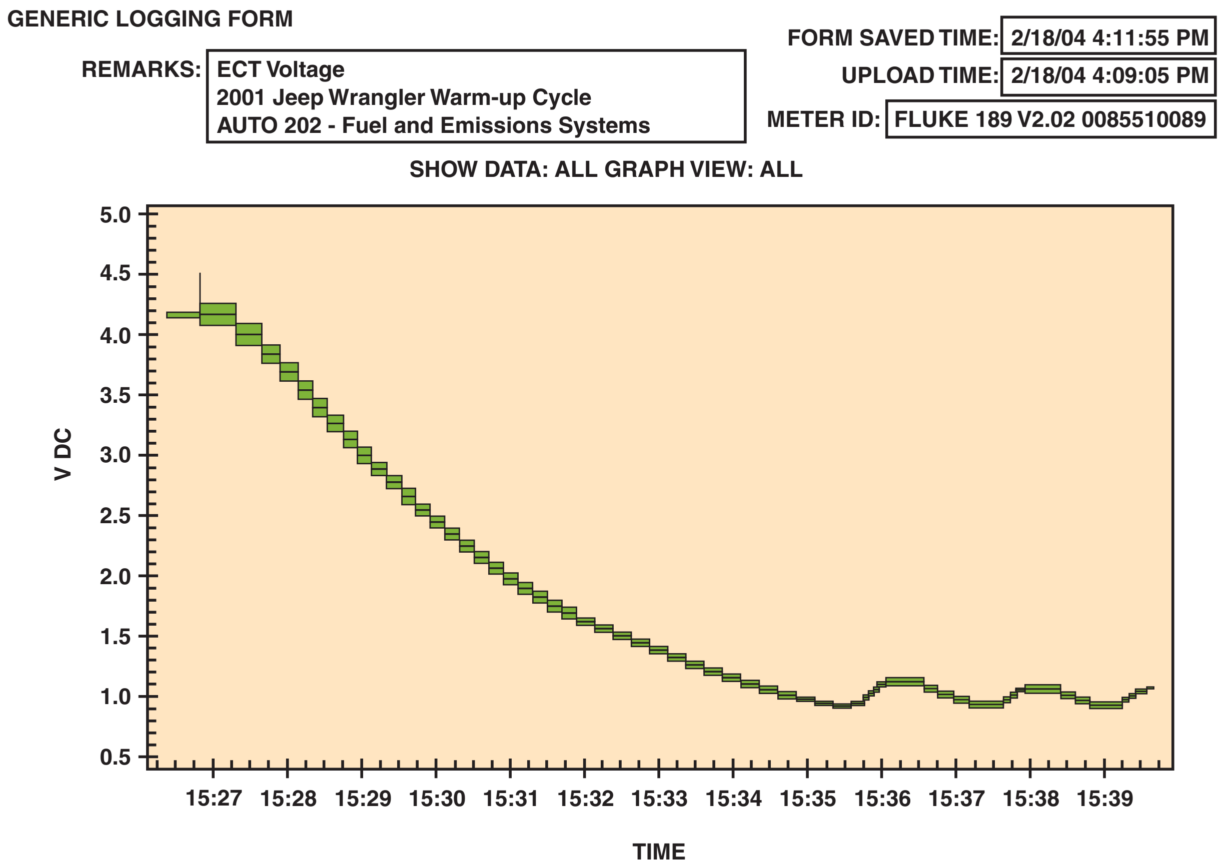


FIGURE 28–7 An ECT sensor being tested using a digital meter set to DC volts and in record mode. A chart showing the voltage decrease of the ECT sensor as the temperature increases from a cold start. The bumps at the bottom of the waveform represent temperature decreases when the thermostat opens and is controlling coolant temperature.

help to diagnose a faulty sensor, especially if the temperature shown on the scan tool varies greatly from the temperature indicated on the dash gauge.

The maximum difference between the two readings should be 10°F (5°C). If the actual temperature varies by more than 10°F from the temperature indicated on the scan tool, check the ECT sensor wiring and connector for damage or corrosion. If the connector and wiring are okay, check the sensor with a DVOM for resistance and compare to the actual engine temperature chart. If that checks out okay, check the computer.

NOTE: Some manufacturers use two coolant sensors, one for the dash gauge and another one for the computer.

INTAKE AIR TEMPERATURE SENSOR

PURPOSE AND FUNCTION The intake air temperature (IAT) sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases. The IAT sensor can be located in one of the following locations:

- In the air cleaner housing
- In the air duct between the air filter and the throttle body, as shown in ● **FIGURE 28–8**
- Built into the mass air flow (MAF) or airflow sensor
- Screwed into the intake manifold where it senses the temperature of the air entering the cylinders

NOTE: An IAT installed in the intake manifold is the most likely to suffer damage due to an engine backfire, which can often destroy the sensor.

The purpose and function of the intake air temperature sensor is to provide the engine computer (PCM) the temperature of the air entering the engine. The IAT sensor information is used for fuel control (adding or subtracting fuel) and spark timing, depending on the temperature of incoming air.

- If the air temperature is cold, the PCM will modify the amount of fuel delivery and add fuel.
- If the air temperature is hot, the PCM will subtract the calculated amount of fuel.

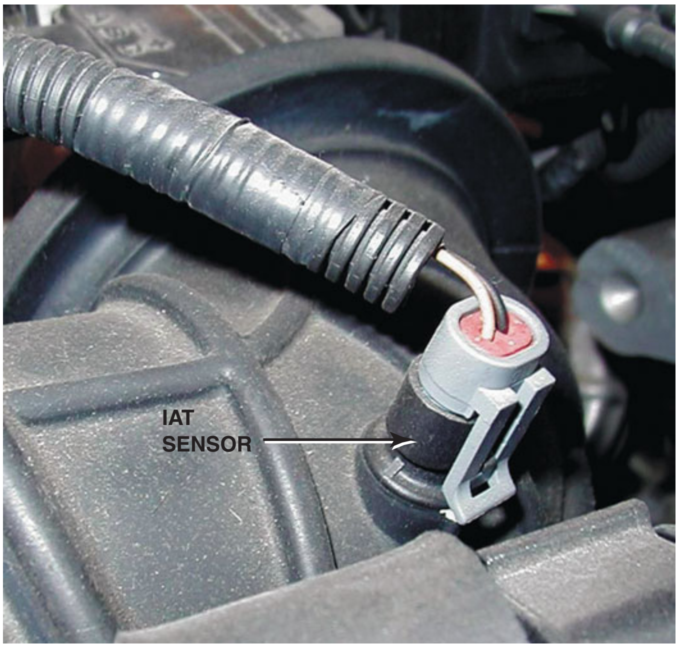


FIGURE 28–8 The IAT sensor on this General Motors 3800 V-6 engine is in the air passage duct between the air cleaner housing and the throttle body.

TECH TIP

Quick and Easy ECT Test

To check that the wiring and the computer are functioning, regarding the ECT sensor, connect a scan tool and look at the ECT temperature display.

STEP 1 Unplug the connector from the ECT sensor. The temperature displayed on the scan tool should read about −40.

NOTE: −40° Celsius is also −40° Fahrenheit. This is the point where both temperature scales meet.

STEP 2 With the connector still removed from the ECT sensor, use a fused jumper lead and connect the two terminals of the connector together. The scan tool should display about 285°F (140°C).

This same test procedure will work for the IAT and most other temperature sensors.

- Spark timing is also changed, depending on the temperature of the air entering the engine. The timing is advanced if the temperature is cold and retarded from the base-programmed timing if the temperature is hot.
- Cold air is more dense, contains more oxygen, and therefore requires a richer mixture to achieve the proper air–fuel mixture. Air at 32°F (0°C) is 14% denser than air at 100°F (38°C).
- Hot air is less dense, contains less oxygen, and therefore requires less fuel to achieve the proper air–fuel mixture.

The IAT sensor is a low-authority sensor and is used by the computer to modify the amount of fuel and ignition timing as determined by the engine coolant temperature sensor.

The IAT sensor is used by the PCM as a backup in the event that the ECT sensor is determined to be inoperative.

NOTE: Some engines use a throttle-body temperature (TBT) sensor to sense the temperature of the air entering the engine, instead of an intake air temperature sensor.

Engine temperature is most accurately determined by looking at the engine coolant temperature (ECT) sensor. In certain conditions, the IAT has an effect on performance and driveability. One such condition is a warm engine being stopped in very cold weather. In this case, when the engine is restarted, the ECT may be near normal operating temperature such as 200°F (93°C) yet the air temperature could be −20°F (−30°C). In this case, the engine requires a richer mixture due to the cold air than the ECT would seem to indicate.

TECH TIP

Poor Fuel Economy? Black Exhaust Smoke? Look at the IAT

If the intake air temperature sensor is defective, it may be signaling the computer that the intake air temperature is extremely cold when in fact it is warm. In such a case the computer will supply a mixture that is much richer than normal.

If a sensor is physically damaged or electrically open, the computer will often set a diagnostic trouble code (DTC). This DTC is based on the fact that the sensor temperature did not change for a certain amount of time, usually about 8 minutes. If, however, the wiring or the sensor itself has excessive resistance, a DTC will not be set and the result will be lower-than-normal fuel economy, and in serious cases, black exhaust smoke from the tailpipe during acceleration.

TESTING THE INTAKE AIR TEMPERATURE SENSOR

If the intake air temperature sensor circuit is damaged or faulty, a diagnostic trouble code (DTC) is set and the malfunction indicator lamp (MIL) may or may not turn on depending on the condition and the type and model of the vehicle. To diagnose the IAT sensor follow these steps:

STEP 1 After the vehicle has been allowed to cool for several hours, use a scan tool, observe the IAT temperature, and compare it to the engine coolant temperature (ECT). The two temperatures should be within 5°F of each other.

STEP 2 Perform a thorough visual inspection of the sensor and the wiring. If the IAT is screwed into the intake manifold, remove the sensor and check for damage.

STEP 3 Check the voltage and compare to the following chart.

Intake Air Temperature Sensor Temperature vs. Resistance and Voltage Drop (Approximate)

°F	°C	Ohms	Voltage Drop Across the Sensor
−40	−40	100,000	4.95
+18	−8	15,000	4.68
32	0	9,400	4.52
50	10	5,700	4.25
68	20	3,500	3.89
86	30	2,200	3.46
104	40	1,500	2.97
122	50	1,000	2.47
140	60	700	2.00
158	70	500	1.59
176	80	300	1.25
194	90	250	0.97
212	100	200	0.75

TRANSMISSION FLUID TEMPERATURE SENSOR

The **transmission fluid temperature (TFT),** also called *transmission oil temperature (TOT),* sensor is an important sensor for the proper operation of the automatic transmission. A TFT sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases.

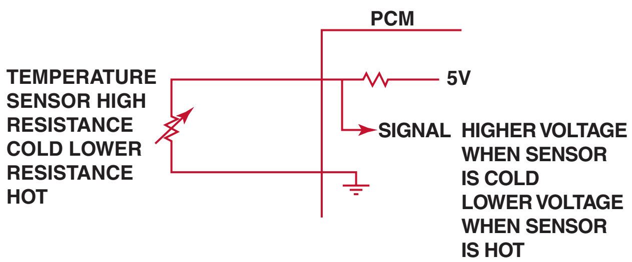


FIGURE 28–9 A typical temperature sensor circuit.

? FREQUENTLY ASKED QUESTION

What Exactly Is an NTC Sensor?

A negative temperature coefficient (NTC) thermistor is a semiconductor whose resistance decreases as the temperature increases. In other words, the sensor becomes more electrically conductive as the temperature increases. Therefore, when a voltage is applied, typically 5 volts, the signal voltage is high when the sensor is cold because the sensor has a high resistance and little current flows through to ground. ● **SEE FIGURE 28–9**.

However, when the temperature increases, the sensor becomes more electrically conductive and takes more of the 5 volts to ground, resulting in a lower signal voltage as the sensor warms.

General Motors
Transaxle Sensor—Temperature to Resistance (approximate)

°F	°C	Resistance Ohms
32	0	7,987–10,859
50	10	4,934–6,407
68	20	3,106–3,923
86	30	1,991–2,483
104	40	1,307–1,611
122	50	878–1,067
140	60	605–728
158	70	425–507
176	80	304–359
194	90	221–259
212	100	163–190

°F	°C	Resistance Ohms
Chrysler *Sensor Resistance (Ohms)—Transmission Temperature Sensor*		
−40	−40	291,490–381,710
−4	−20	85,850–108,390
14	−10	49,250–61,430
32	0	29,330–35,990
50	10	17,990–21,810
68	20	11,370–13,610
77	25	9,120–10,880
86	30	7,370–8,750
104	40	4,900–5,750
122	50	3,330–3,880
140	60	2,310–2,670
158	70	1,630–1,870
176	80	1,170–1,340
194	90	860–970
212	100	640–720
230	110	480–540
248	120	370–410

°F	°C	Resistance Ohms
Ford *Transmission Fluid Temperature*		
−40 to −4	−40 to −20	967K–284K
−3 to 31	−19 to −1	284K–100K
32 to 68	0 to 20	100K–37K
69 to 104	21 to 40	37K–16K
105 to 158	41 to 70	16K–5K
159 to 194	71 to 90	5K–2.7K
195 to 230	91 to 110	2.7K–1.5K
231 to 266	111 to 130	1.5K–0.8K
267 to 302	131 to 150	0.8K–0.54K

The transmission fluid temperature signal is used by the Powertrain Control Module (PCM) to perform certain strategies based on the temperature of the automatic transmission fluid. For example:

- If the temperature of the automatic transmission fluid is low (typically below 32°F [0°C]), the shift points may be delayed and overdrive disabled. The torque converter clutch also may not be applied to assist in the heating of the fluid.
- If the temperature of the automatic transmission fluid is high (typically above 260°F [130°C]), the overdrive is disabled and the torque converter clutch is applied to help reduce the temperature of the fluid.

NOTE: Check service information for the exact shift strategy based on high and low transmission fluid temperatures for the vehicle being serviced.

CYLINDER HEAD TEMPERATURE SENSOR

Some vehicles are equipped with **cylinder head temperature (CHT)** sensors.

VW Golf

14°F (−10°C) = 11,600 Ω

68°F (20°C) = 2,900 Ω

176°F (80°C) = 390 Ω

ENGINE FUEL TEMPERATURE (EFT) SENSOR

Some vehicles, such as many Ford vehicles that are equipped with an electronic returnless type of fuel injection, use an **engine fuel temperature (EFT)** sensor to give the PCM information regarding the temperature and, therefore, the density of the fuel.

EXHAUST GAS RECIRCULATION (EGR) TEMPERATURE SENSOR

Some engines, such as Toyota, are equipped with exhaust gas recirculation (EGR) temperature sensors. EGR is a well-established method for reduction of NO_x emissions in internal combustion engines. The exhaust gas contains unburned hydrocarbons, which are recirculated in the combustion process. Recirculation is controlled by valves, which operate as a function of exhaust gas speed, load, and temperature. The gas reaches a temperature of about 850°F (450°C) for which a special heavy-duty glass-encapsulated NTC sensor is available.

The PCM monitors the temperature in the exhaust passage between the EGR valve and the intake manifold. If the temperature increases when the EGR is commanded on, the PCM can determine that the valve or related components are functioning.

ENGINE OIL TEMPERATURE SENSOR

Engine oil temperature sensors are used on many General Motors vehicles and are used as an input to the oil life monitoring system. The computer program inside the PCM calculates engine oil life based on run time, engine RPM, and oil temperature.

TEMPERATURE SENSOR DIAGNOSTIC TROUBLE CODES

The OBD-II diagnostic trouble codes that relate to temperature sensors include both high- and low-voltage codes, as well as intermittent codes.

Diagnostic Trouble Code	Description	Possible Causes
P0112	IAT sensor low voltage	• IAT sensor internally shorted-to-ground • IAT sensor wiring shorted-to-ground • IAT sensor damaged by backfire (usually associated with IAT sensors that are mounted in the intake manifold) • Possible defective PCM
P0113	IAT sensor high voltage	• IAT sensor internally (electrically) open • IAT sensor signal, circuit, or ground circuit open • Possible defective PCM
P0117	ECT sensor low voltage	• ECT sensor internally shorted-to-ground • The ECT sensor circuit wiring shorted-to-ground • Possible defective PCM
P0118	ECT sensor high voltage	• ECT sensor internally (electrically) open • ECT sensor signal, circuit, or ground circuit open • Engine operating in an overheated condition • Possible defective PCM

SUMMARY

1. The ECT sensor is a high-authority sensor at engine start-up and is used for closed-loop control, as well as idle speed.
2. All temperature sensors decrease in resistance as the temperature increases. This is called negative temperature coefficient (NTC).
3. The ECT and IAT sensors can be tested visually, as well as by using a digital multimeter or a scan tool.
4. Some vehicle manufacturers use a stepped ECT circuit inside the PCM to broaden the accuracy of the sensor.
5. Other temperature sensors include transmission fluid temperature (TFT), engine fuel temperature (EFT), exhaust gas recirculation (EGR) temperature, and engine oil temperature.

REVIEW QUESTIONS

1. How does a typical NTC temperature sensor work?
2. What is the difference between a stepped and a non-stepped ECT circuit?
3. What temperature should be displayed on a scan tool if the ECT sensor is unplugged with the key on, engine off?
4. What are the three ways that temperature sensors can be tested?
5. If the transmission fluid temperature (TFT) sensor were to fail open (as if it were unplugged), what would the PCM do to the transmission shifting points?

CHAPTER QUIZ

1. The sensor that most determines fuel delivery when a fuel-injected engine is first started is the ______________.
   a. O2S
   b. ECT sensor
   c. Engine MAP sensor
   d. IAT sensor
2. What happens to the voltage measured at the ECT sensor when the thermostat opens?
   a. Increases slightly
   b. Increases about 1 volt
   c. Decreases slightly
   d. Decreases about 1 volt
3. Two technicians are discussing a stepped ECT circuit. Technician A says that the sensor used for a stepped circuit is different than one used in a non-stepped circuit. Technician B says that a stepped ECT circuit uses different internal resistance inside the PCM. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. When testing an ECT sensor on a vehicle, a digital multimeter can be used and the signal wires back probed. What setting should the technician use to test the sensor?
   a. AC volts
   b. DC volts
   c. Ohms
   d. Hz (hertz)
5. When testing the ECT sensor with the connector disconnected, the technician should select what position on the DMM?
   a. AC volts
   b. DC volts
   c. Ohms
   d. Hz (hertz)
6. When checking the ECT sensor with a scan tool, about what temperature should be displayed if the connector is removed from the sensor with the key on, engine off?
   a. 284°F (140°C)
   b. 230°F (110°C)
   c. 120°F (50°C)
   d. −40°F (−40°C)
7. Two technicians are discussing the IAT sensor. Technician A says that the IAT sensor is more important to the operation of the engine (higher authority) than the ECT sensor. Technician B says that the PCM will add fuel if the IAT indicates that the incoming air temperature is cold. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. A typical IAT or ECT sensor reads about 3,000 ohms when tested using a DMM. This resistance represents a temperature of about ______________.
   a. −40°F (−40°C)
   b. 70°F (20°C)
   c. 120°F (50°C)
   d. 284°F (140°C)
9. If the transmission fluid temperature (TFT) sensor indicates cold automatic transmission fluid temperature, what would the PCM do to the shifts?
   a. Normal shifts and normal operation of the torque converter clutch
   b. Disable torque converter clutch; normal shift points
   c. Delayed shift points and torque converter clutch disabled
   d. Normal shifts but overdrive will be disabled
10. A P0118 DTC is being discussed. Technician A says that the ECT sensor could be shorted internally. Technician B says that the signal wire could be open. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 29

THROTTLE POSITION (TP) SENSORS

OBJECTIVES: After studying Chapter 29, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how throttle position sensors work. • List the methods that can be used to test TP sensors. • Describe the symptoms of a failed TP sensor. • List how the operation of the TP sensor affects vehicle operation. • Discuss TP sensor rationality tests.

KEY TERMS: Potentiometer 420 • Skewed 423 • Throttle position (TP) sensor 420

THROTTLE POSITION SENSOR CONSTRUCTION

Most computer-equipped engines use a **throttle position (TP) sensor** to signal to the computer the position of the throttle. ● **SEE FIGURE 29–1**. The TP sensor consists of a **potentiometer,** a type of variable resistor.

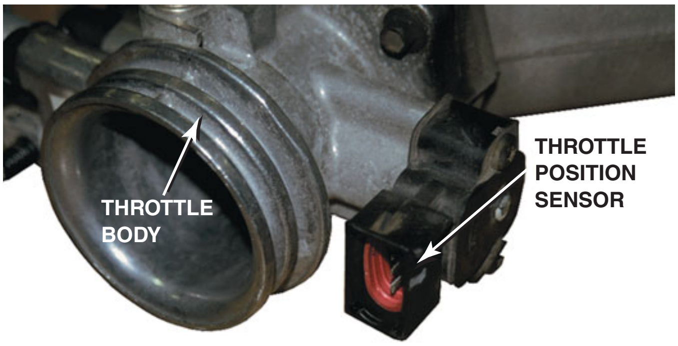


FIGURE 29–1 A typical TP sensor mounted on the throttle plate of this port-injected engine.

POTENTIOMETERS A potentiometer is a variable-resistance sensor with three terminals. One end of the resistor receives reference voltage, while the other end is grounded. The third terminal is attached to a movable contact that slides across the resistor to vary its resistance. Depending on whether the contact is near the supply end or the ground end of the resistor, return voltage is high or low. ● **SEE FIGURE 29–2**.

Throttle position (TP) sensors are among the most common potentiometer-type sensors. The computer uses their input to determine the amount of throttle opening and the rate of change.

A typical sensor has three wires:

- A 5-volt reference feed wire from the computer
- Signal return (A ground wire back to the computer)
- A voltage signal wire back to the computer; as the throttle is opened, the voltage to the computer changes

Normal throttle position voltage on most vehicles is about 0.5 volt at idle (closed throttle) and 4.5 volts at wide-open throttle (WOT).

NOTE: The TP sensor voltage at idle is usually about 10% of the TP sensor voltage when the throttle is wide open, but can vary from as low as 0.3 volt to 1.2 volts, depending on the make and model of vehicle.

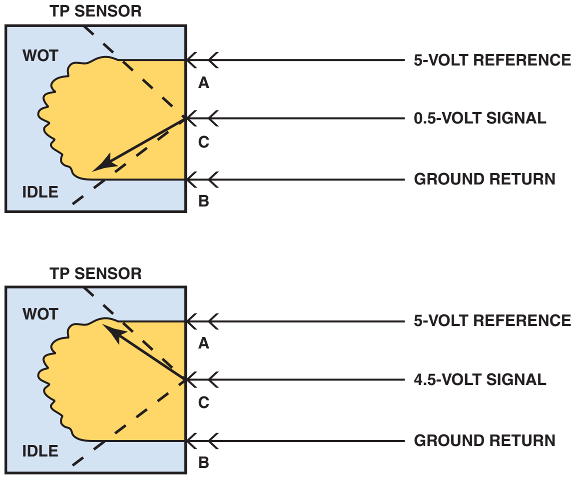


FIGURE 29–2 The signal voltage from a throttle position increases as the throttle is opened because the wiper arm is closer to the 5-volt reference. At idle, the resistance of the sensor winding effectively reduces the signal voltage output to the computer.

TP SENSOR COMPUTER INPUT FUNCTIONS

- The computer senses any change in throttle position and changes the fuel mixture and ignition timing. The actual change in fuel mixture and ignition timing is also partly determined by the other sensors, such as the manifold pressure (engine vacuum), engine RPM, the coolant temperature, and oxygen sensor(s). Some throttle position sensors are adjustable and should be set according to the exact engine manufacturer's specifications.
- The throttle position (TP) sensor used on fuel-injected vehicles acts as an "electronic accelerator pump." This means that the computer will pulse additional fuel from the injectors when the throttle is depressed. Because the air can quickly flow into the engine when the throttle is opened, additional fuel must be supplied to prevent the air–fuel mixture from going lean, causing the engine to hesitate when the throttle is depressed. If the TP sensor is unplugged or defective, the engine may still operate satisfactorily, but hesitate upon acceleration.
- The PCM supplies the TP sensor with a regulated voltage that ranges from 4.8 to 5.1 volts. This reference voltage is usually referred to as a 5-volt reference or "Vref." The TP output signal is an input to the PCM, and the TP sensor ground also flows through the PCM.

See the Ford throttle position (TP) sensor chart for an example of how sensor voltage changes with throttle angle.

Ford Throttle Position (TP) Sensor Chart

Throttle Angle (Degrees)	Voltage (V)
0	0.50
10	0.97
20	1.44
30	1.90
40	2.37
50	2.84
60	3.31
70	3.78
80	4.24

NOTE: Generally, any reading higher than 80% represents wide-open throttle to the computer.

PCM USES FOR THE TP SENSOR

The TP sensor is used by the Powertrain Control Module (PCM) for the following reasons.

CLEAR FLOOD MODE If the throttle is depressed to the floor during engine cranking, the PCM will either greatly reduce or entirely eliminate any fuel-injector pulses to aid in cleaning a flooded engine. If the throttle is depressed to the floor and the engine is not flooded with excessive fuel, the engine may not start.

TORQUE CONVERTER CLUTCH ENGAGEMENT AND RELEASE The torque converter clutch will be released if the PCM detects rapid acceleration to help the transmission deliver maximum torque to the drive wheels. The torque converter clutch is applied when the vehicle is lightly accelerating and during cruise conditions to help improve fuel economy.

RATIONALITY TESTING FOR MAP AND MAF SENSORS As part of the rationality tests for the MAP and/or MAF sensor, the TP sensor signal is compared to the reading from other sensors to determine if they match. For example, if the throttle position sensor is showing wide-open throttle (WOT), the MAP and/or MAF reading should also indicate that this engine is under a heavy load. If not, a diagnostic trouble code could be set for the TP, as well as the MAP and/or MAF sensors.

AUTOMATIC TRANSMISSION SHIFT POINTS The shift points are delayed if the throttle is opened wide to allow the engine speed to increase, thereby producing more power and aiding in the acceleration of the vehicle. If the throttle is barely open, the shift point occurs at the minimum speed designed for the vehicle.

TARGET IDLE SPEED (IDLE CONTROL STRATEGY) When the TP sensor voltage is at idle, the PCM then controls idle speed using the idle air control (IAC) and/or spark timing variation to maintain the commanded idle speed. If the TP sensor indicates that the throttle has moved off idle, fuel delivery and spark timing are programmed for acceleration. Therefore, if the throttle linkage is stuck or binding, the idle speed may not be correct.

AIR-CONDITIONING COMPRESSOR OPERATION The TP sensor is also used as an input sensor for air-conditioning compressor operation. If the PCM detects that the throttle is at or close to wide open, the air-conditioning compressor is disengaged.

BACKS UP OTHER SENSORS The TP sensor is used as a backup to the MAP sensor and/or MAF in the event the PCM detects that one or both are not functioning correctly. The PCM then calculates fuel needs and spark timing based on the engine speed (RPM) and throttle position.

FIGURE 29–3 A meter lead connected to a T-pin that was gently pushed along the signal wire of the TP sensor until the point of the pin touched the metal terminal inside the plastic connector.

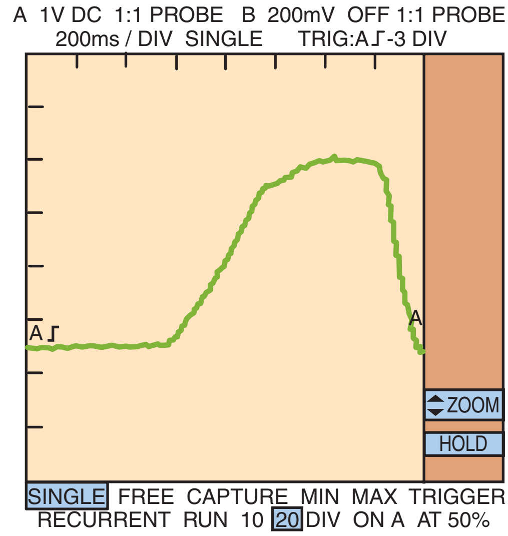


FIGURE 29–4 A typical waveform of a TP sensor signal as recorded on a DSO when the accelerator pedal was depressed with the ignition switch on (engine off). Clean transitions and the lack of any glitches in this waveform indicate a good sensor. *(Courtesy of Fluke Corporation)*

TESTING THE THROTTLE POSITION SENSOR

A TP sensor can be tested using one or more of the following tools:

- A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back probing using T-pins or other recommended tool that will not cause harm to the connector or wiring.
- A scan tool or a specific tool recommended by the vehicle manufacturer.
- A breakout box that is connected in series between the computer and the wiring harness connector(s). A typical breakout box includes test points at which TP voltages can be measured with a digital voltmeter.
- An oscilloscope.

Use jumper wires, T-pins to back-probe the wires, or a breakout box to gain electrical access to the wiring to the TP sensor. ● **SEE FIGURE 29–3.**

NOTE: The procedure that follows is the usual method used by many manufacturers. Always refer to service information for the exact recommended procedure and specifications for the vehicle being tested.

The procedure for testing the sensor using a digital multimeter is as follows:

1. Turn the ignition switch on (engine off).
2. Set the digital meter to read to DC volts and measure the voltage between the signal wire and ground (reference low) wire. The voltage should be about 0.5 volt.

NOTE: Consult the service information for exact wire colors or locations.

3. With the engine still not running (but with the ignition still on), slowly increase the throttle opening. The voltage signal from the TP sensor should also increase. Look for any "dead spots" or open circuit readings as the throttle is increased to the wide-open position. ● **SEE FIGURE 29–4** for an example of how a good TP sensor would look when tested with a digital storage oscilloscope (DSO).

NOTE: Use the accelerator pedal to depress the throttle because this applies the same forces on the TP sensor as the driver does during normal driving. Moving the throttle by hand under the hood may not accurately test the TP sensor.

4. With the voltmeter still connected, slowly return the throttle down to the idle position. The voltage from the TP sensor should also decrease evenly on the return to idle.

The TP sensor voltage at idle should be within the acceptable range as specified by the manufacturer. Some TP sensors can be adjusted by loosening their retaining screws and moving the sensor in relation to the throttle opening. This movement changes the output voltage of the sensor.

All TP sensors should also provide a smooth transition voltage reading from idle to WOT and back to idle. Replace the TP sensor if erratic voltage readings are obtained or if the correct setting at idle cannot be obtained.

FIGURE 29–5 Checking the 5-volt reference from the computer being applied to the TP sensor with the ignition switch on (engine off). The reading for this vehicle (5.02 volts DC) is within the normal range for the 5-volt reference voltage of 4.9 to 5.1 volts.

TECH TIP

Check Power and Ground Before Condemning a Bad Sensor

Most engine sensors use a 5-volt reference and a ground. If the 5 volts to the sensor is too high (shorted to voltage) or too low (high resistance), then the sensor output will be **skewed** or out of range. Before replacing the sensor that did not read correctly, measure both the 5-volt reference and ground. To measure the ground, simply turn the ignition on (engine off) and touch one test lead of a DMM set to read DC volts to the sensor ground and the other to the negative terminal of the battery. Any reading higher than 0.2 volt (200 mV) represents a poor ground. ● **SEE FIGURES 29–5 AND 29–6.**

TESTING A TP SENSOR USING THE MIN/MAX FUNCTION

Many digital multimeters are capable of recording voltage readings over time and then displaying the minimum, maximum, and average readings. To perform a MIN/MAX test of the TP sensor, manually set the meter to read higher than 4 volts.

FIGURE 29–6 Checking the voltage drop between the TP sensor ground and a good engine ground with the ignition on (engine off). A reading of greater than 0.2 volt (200 mV) represents a bad computer ground.

STEP 1 Connect the red meter lead to the signal wire and the black meter lead to a good ground or the ground return wire at the TP sensor.

STEP 2 With the ignition on, engine off, slowly depress and release the accelerator pedal from inside the vehicle.

STEP 3 Check the minimum and maximum voltage reading on the meter display. Any 0- or 5-volt reading would indicate a fault or short in the TP sensor.

TESTING THE TP SENSOR USING A SCAN TOOL

A scan tool can be used to check for proper operation of the throttle position sensor using the following steps.

STEP 1 With the key on, engine off, the TP sensor voltage display should be about 0.5 volt, but can vary from as low as 0.3 volt to as high as 1.2 volts.

STEP 2 Check the scan tool display for the percentage of throttle opening. The reading should be zero and gradually increase in percentage as the throttle is depressed.

STEP 3 The idle air control (IAC) counts should increase as the throttle is opened and decrease as the throttle is closed. Start the engine and observe the IAC counts as the throttle is depressed.

STEP 4 Start the engine and observe the TP sensor reading. Use a wedge at the throttle stop to increase the throttle opening slightly. The throttle percentage reading should increase. Shut off and restart the engine. If the percentage of throttle opening returns to 0%, the PCM determines that the increased throttle opening is now the new minimum and resets the idle position of the TP sensor. Remove the wedge and cycle the ignition key. The throttle position sensor should again read zero percentage.

NOTE: Some engine computers are not capable of resetting the throttle position sensor.

TP SENSOR DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the throttle position sensor include the following.

Diagnostic Trouble Code	Description	Possible Causes
P0122	TP sensor low voltage	• TP sensor internally shorted-to-ground • TP sensor wiring shorted-to-ground • TP sensor or wiring open
P0123	TP sensor high voltage	• TP sensor internally shorted to 5-volt reference • TP sensor ground open • TP sensor wiring shorted-to-voltage
P0121	TP sensor signal does not agree with MAP	• Defective TP sensor • Incorrect vehicle-speed (VS) sensor signal • MAP sensor out-of-calibration or defective

SUMMARY

1. A throttle position (TP) sensor is a three-wire variable resistor called a potentiometer.
2. The three wires on the TP sensor include a 5-volt reference voltage from the PCM, plus the signal wire to the PCM, and a ground, which also goes to the PCM.
3. The TP sensor is used by the PCM for clear flood mode, torque converter engagement and release, and automotive transmission shift points, as well as for rationality testing for the MAP and MAF sensors.
4. The TP sensor signal voltage should be about 0.5 volt at idle and increase to about 4.5 volts at wide-open throttle (WOT).
5. A TP sensor can be tested using a digital multimeter, a digital storage oscilloscope (DSO), or a scan tool.

REVIEW QUESTIONS

1. What is the purpose of each of the three wires on a typical TP sensor?
2. What all does the PCM do with the TP sensor signal voltage?
3. What is the procedure to follow when checking the 5-volt reference and TP sensor ground?
4. How can a TP sensor be diagnosed using a scan tool?

CHAPTER QUIZ

1. Which sensor is generally considered to be the electronic accelerator pump of a fuel-injected engine?
   a. O2S
   b. ECT sensor
   c. Engine MAP sensor
   d. TP sensor
2. Typical TP sensor voltage at idle is about ______________.
   a. 2.50 to 2.80 volts
   b. 0.5 volt or 10% of WOT TP sensor voltage
   c. 1.5 to 2.8 volts
   d. 13.5 to 15.0 volts
3. A TP sensor is what type of sensor?
   a. Rheostat
   b. Voltage generating
   c. Potentiometer
   d. Piezoelectric
4. Most TP sensors have how many wires?
   a. 1
   b. 2
   c. 3
   d. 4

5. Which sensor does the TP sensor back up if the PCM determines that a failure has occurred?
   a. Oxygen sensor
   b. MAF sensor
   c. MAP sensor
   d. Either b or c
6. Which wire on a TP sensor should be back-probed to check the voltage signal to the PCM?
   a. 5-volt reference (Vref)
   b. Signal
   c. Ground
   d. Meter should be connected between the 5-volt reference and the ground
7. After a TP sensor has been tested using the MIN/MAX function on a DMM, a reading of zero volts is displayed. What does this reading indicate?
   a. The TP sensor is open at one point during the test.
   b. The TP sensor is shorted.
   c. The TP sensor signal is shorted to 5-volt reference.
   d. Both b and c are possible.
8. After a TP sensor has been tested using the MIN/MAX function on a DMM, a reading of 5 volts is displayed. What does this reading indicate?
   a. The TP sensor is open at one point during the test.
   b. The TP sensor is shorted.
   c. The TP sensor signal is shorted to 5-volt reference.
   d. Both b and c are possible.
9. A technician attaches one lead of a digital voltmeter to the ground terminal of the TP sensor and the other meter lead to the negative terminal of the battery. The ignition is switched to on, engine off and the meter displays 37.3 mV. Technician A says that this is the signal voltage and is a little low. Technician B says that the TP sensor ground circuit has excessive resistance. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A P0122 DTC is retrieved using a scan tool. This DTC means ______________.
    a. The TP sensor voltage is low
    b. The TP sensor could be shorted-to-ground
    c. The TP sensor signal circuit could be shorted-to-ground
    d. All of the above are correct.

chapter 30

MAP/BARO SENSORS

OBJECTIVES: **After studying Chapter 30, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how MAP sensors work. • List the methods that can be used to test MAP sensors. • Describe the symptoms of a failed MAP sensor. • List how the operation of the MAP sensor affects vehicle operation. • Discuss MAP sensor rationality tests. • Describe how the BARO sensor is used to determine altitude.

KEY TERMS: Barometric manifold absolute pressure (BMAP) sensor 431 • Barometric pressure (BARO) sensor 431 • Manifold absolute pressure (MAP) sensor 426 • Piezoresistivity 428 • Pressure differential 426 • Speed density 429 • Vacuum 426

AIR PRESSURE—HIGH AND LOW

Think of an internal combustion engine as a big air pump. As the pistons move up and down in the cylinders, they pump in air and fuel for combustion and pump out exhaust gases. They do this by creating a difference in air pressure. The air outside an engine has weight and exerts pressure, as does the air inside an engine.

As a piston moves down on an intake stroke with the intake valve open, it creates a larger area inside the cylinder for the air to fill. This lowers the air pressure within the engine. Because the pressure inside the engine is lower than the pressure outside, air flows into the engine to fill the low-pressure area and equalize the pressure.

The low pressure within the engine is called **vacuum.** Vacuum causes the higher-pressure air on the outside to flow into the low-pressure area inside the cylinder. The difference in pressure between the two areas is called a **pressure differential.** ● **SEE FIGURE 30–1.**

PRINCIPLES OF PRESSURE SENSORS

Intake manifold pressure changes with changing throttle positions. At wide-open throttle, manifold pressure is almost the same as atmospheric pressure. On deceleration or at idle, manifold pressure is below atmospheric pressure, thus creating a vacuum. In cases where turbo- or supercharging is used, under part- or full-load condition, intake manifold pressure rises above atmospheric pressure. Also, oxygen content and barometric pressure change with differences in altitude, and the computer must be able to compensate by making changes in the flow of fuel entering the engine. To provide the computer with changing airflow information, a fuel-injection system may use the following:

- Manifold absolute pressure (MAP) sensor
- Manifold absolute pressure (MAP) sensor plus barometric absolute pressure (BARO) sensor
- Barometric and manifold absolute pressure sensors combined (BMAP)

The **manifold absolute pressure (MAP) sensor** may be a ceramic capacitor diaphragm, an aneroid bellows, or a piezoresistive crystal. It has a sealed vacuum reference input on one side; the other side is connected (vented) to the intake manifold. This sensor housing also contains signal conditioning circuitry. ● **SEE FIGURE 30–2.** Pressure changes in the manifold cause the sensor to deflect, varying its analog or digital return signal to the computer. As the air pressure increases, the MAP sensor generates a higher voltage or frequency return signal to the computer.

CONSTRUCTION OF MANIFOLD ABSOLUTE PRESSURE (MAP) SENSORS

The manifold absolute pressure (MAP) sensor is used by the engine computer to sense engine load. The typical MAP sensor consists of a ceramic or silicon wafer sealed on one side with a perfect vacuum and exposed to intake manifold vacuum on the other side.

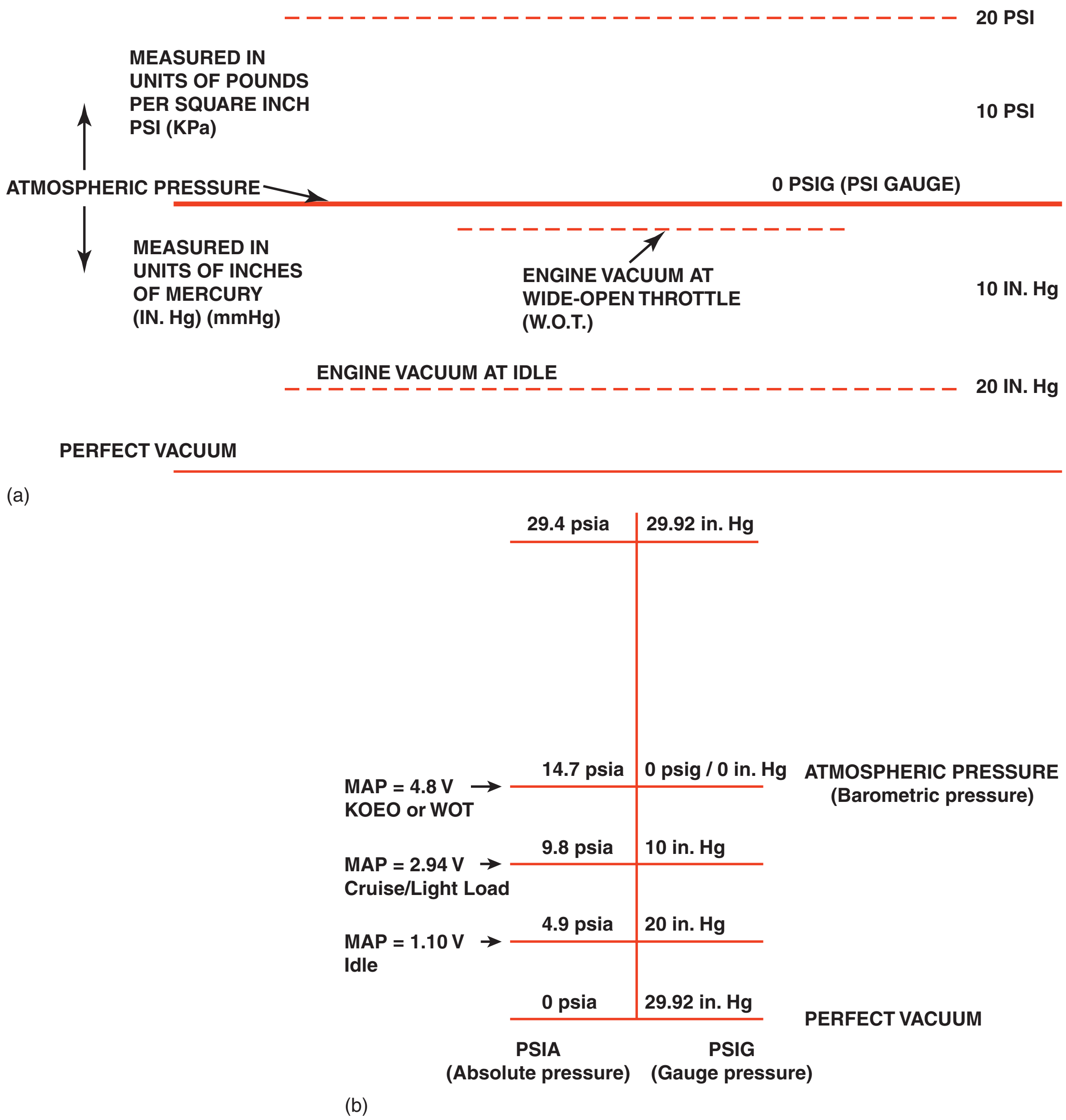


FIGURE 30–1 (a) As an engine is accelerated under a load, the engine vacuum drops. This drop in vacuum is actually an increase in absolute pressure in the intake manifold. A MAP sensor senses all pressures greater than that of a perfect vacuum. (b) The relationship between absolute pressure, vacuum, and gauge pressure.

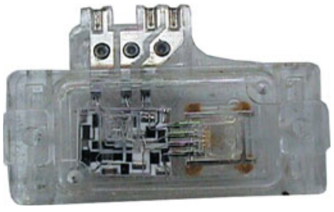


FIGURE 30–2 A clear plastic MAP sensor used for training purposes showing the electronic circuit board and electrical connections.

As the engine vacuum changes, the pressure difference on the wafer changes the output voltage or frequency of the MAP sensor.

A manifold absolute pressure (MAP) sensor is used on many engines for the PCM to determine the load on the engine.

The relationship among barometer pressure, engine vacuum, and MAP sensor voltage includes:

- Absolute pressure is equal to barometric pressure minus intake manifold vacuum.
- A decrease in manifold vacuum means an increase in manifold pressure.
- The MAP sensor compares manifold vacuum to a perfect vacuum.
- Barometric pressure minus MAP sensor reading equals intake manifold vacuum. Normal engine vacuum is 17–21 in. Hg.
- Supercharged and turbocharged engines require a MAP sensor that is calibrated for pressures above atmospheric, as well as for vacuum.

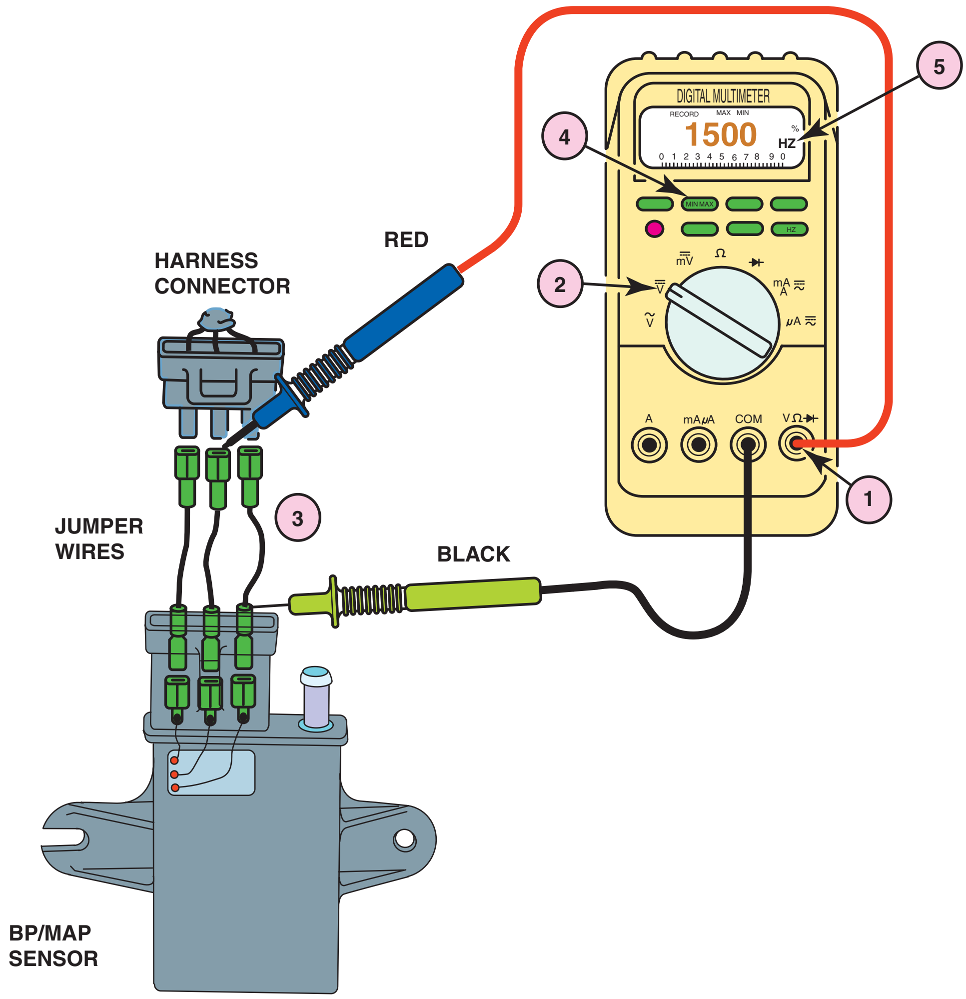


FIGURE 30–3 MAP sensors use three wires: 1. 5-volt reference from the PCM 2. Sensor signal (output signal) 3. Ground. A DMM set to test a MAP sensor. (1) Connect the red meter lead to the V meter terminal and the black meter lead to the COM meter terminal. (2) Select DC volts. (3) Connect the test leads to the sensor signal wire and the ground wire. (4) Select hertz (Hz) if testing a MAP sensor whose output is a varying frequency; otherwise keep it on DC volts. (5) Read the change of voltage (frequency) as the vacuum is applied to the sensor. Compare the vacuum reading and the frequency (or voltage) reading to the specifications. *(Courtesy of Fluke Corporation)*.

SILICON-DIAPHRAGM STRAIN GAUGE MAP SENSOR

This is the most commonly used design for a MAP sensor and the output is a DC analog (variable) voltage. One side of a silicon wafer is exposed to engine vacuum and the other side is exposed to a perfect vacuum.

There are four resistors attached to the silicon wafer, which changes in resistance when strain is applied to the wafer. This change in resistance due to strain is called **piezoresistivity.** The resistors are electrically connected to a Wheatstone bridge circuit and then to a differential amplifier, which creates a voltage in proportion to the vacuum applied.

A typical General Motors MAP sensor voltage varies from 0.88 to 1.62 at engine idle.

- 17 in. Hg is equal to about 1.62 volts
- 21 in. Hg is equal to about 0.88 volts

Therefore, a good reading should be about 1.0 volt from the MAP sensor on a sound engine at idle speed. See the following chart that shows engine load, engine vacuum, and MAP.

Engine Load	Manifold Vacuum	Manifold Absolute Pressure	MAP Sensor Volt Signal
Heavy (WOT)	Low (almost 0 in. Hg)	High (almost atmospheric)	High (4.6–4.8 V)
Light (idle)	High (17–21 in. Hg)	Low (lower than atmospheric)	Low (0.8–1.6 V)

CAPACITOR-CAPSULE MAP SENSOR

A capacitor-capsule is a type of MAP sensor used by Ford which uses two ceramic (alumina) plates with an insulating washer spacer in the center to create a capacitor. Changes in engine vacuum cause the plates to deflect, which changes the capacitance. The electronics in the sensor then generate a varying digital frequency output signal, which is proportional to the engine vacuum. ● **SEE FIGURE 30–3.** ● **SEE FIGURE 30–4** for a scope waveform of a digital MAP sensor. Also see the Ford MAP sensor chart.

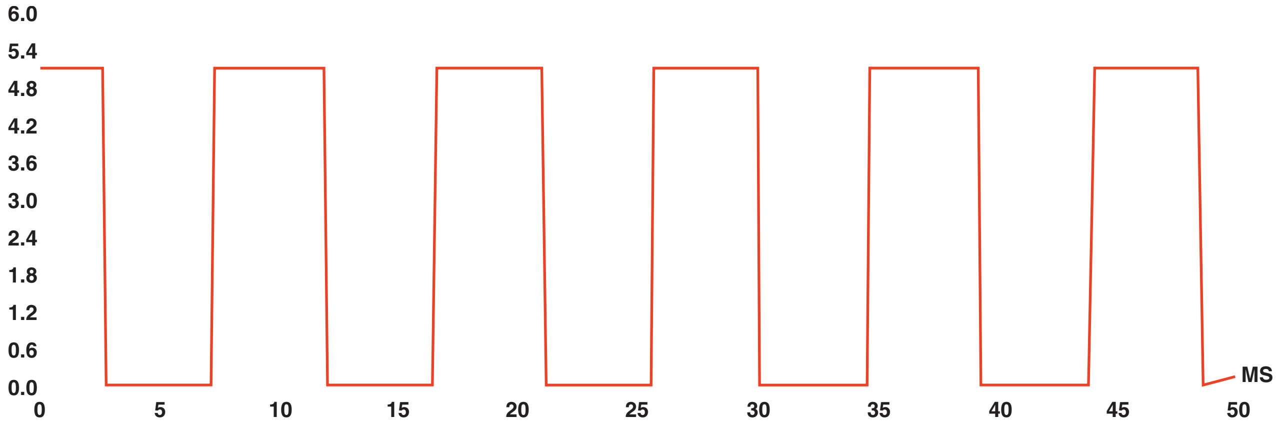


FIGURE 30–4 A waveform of a typical digital MAP sensor.

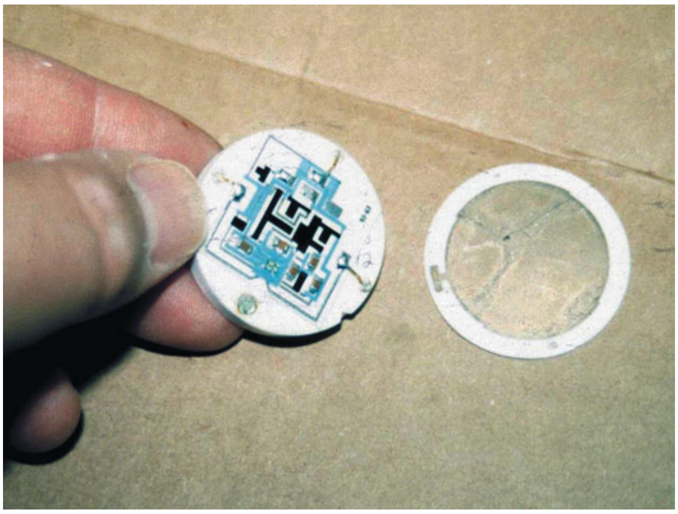


FIGURE 30–5 Shown is the electronic circuit inside a ceramic disc MAP sensor used on many Chrysler engines. The black areas are carbon resistors that are applied to the ceramic, and lasers are used to cut lines into these resistors during testing to achieve the proper operating calibration.

Ford MAP Sensor Chart

MAP Sensor Output (Hz)	Engine Operating Conditions	Intake Manifold Vacuum (in. Hg)
156–159 Hz	Key on, engine off	0 in. Hg
102–109 Hz	Engine at idle (sea level)	17–21 in. Hg
156–159 Hz	Engine at wide-open throttle (WOT)	About 0 in. Hg

CERAMIC DISC MAP SENSOR The ceramic disc MAP sensor is used by Chrysler and it converts manifold pressure into a capacitance discharge. The discharge controls the amount of voltage delivered by the sensor to the PCM. The output is the same as the previously used strain gauge/Wheatstone bridge design and is interchangeable. ● **SEE FIGURE 30–5.** See the Chrysler MAP sensor chart.

TECH TIP

If It's Green, It's a Signal Wire

Ford-built vehicles usually use a green wire as the signal wire back to the computer from the sensors. It may not be a solid green, but if there is green somewhere on the wire, then it is the signal wire. The other wires are the power and ground wires to the sensor.

Chrysler MAP Sensor Chart

Vacuum (in. Hg)	MAP Sensor Signal Voltage (V)
0.5	4.8
1.0	4.6
3.0	4.1
5.0	3.8
7.0	3.5
10.0	2.9
15.0	2.1
20.0	1.2
25.0	0.5

PCM USES OF THE MAP SENSOR

The PCM uses the MAP sensor to determine the following:

- **The load on the engine.** The MAP sensor is used on a **speed density**-type fuel-injection system to determine the load on the engine, and therefore the amount of fuel needed. On engines equipped with a mass air flow (MAF)

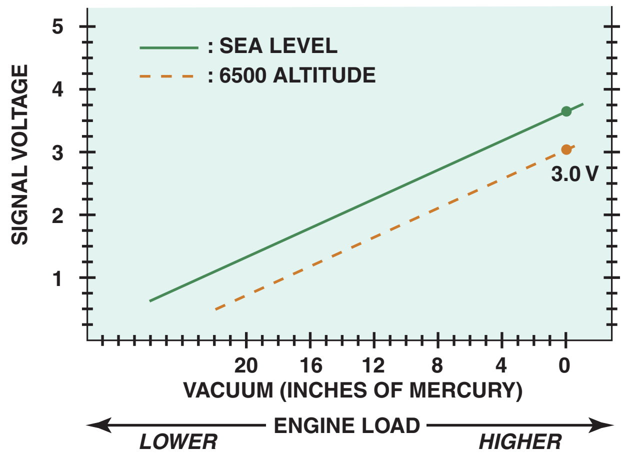


FIGURE 30–6 Altitude affects the MAP sensor voltage.

sensor, the MAP is used as a backup to the MAF, for diagnosis of other sensors, and systems such as the EGR system.

- **Altitude, fuel, and spark control calculations.** At key on, the MAP sensor determines the altitude (acts as a BARO sensor) and adjusts the fuel delivery and spark timing accordingly.
  - If the altitude is high, generally over 5,000 feet (1,500 meters), the PCM will reduce fuel delivery and advance the ignition timing.
  - The altitude is also reset when the engine is accelerated to wide-open throttle and the MAP sensor is used to reset the altitude reading. ● **SEE FIGURE 30–6.**
- **EGR system operation.** As part of the OBD-II standards, the exhaust gas recirculation (EGR) system must be checked for proper operation. One method used by many vehicle manufacturers is to command the EGR valve on and then watch the MAP sensor signal. The opening of the EGR pintle should decrease engine vacuum. If the MAP sensor does not react with the specified drop in manifold vacuum (increase in manifold pressure), an EGR flow rate problem diagnostic trouble code is set.
- **Detect deceleration (vacuum increases).** The engine vacuum rises when the accelerator is released, which changes the MAP sensor voltage. When deceleration is detected by the PCM, fuel is either stopped or greatly reduced to improve exhaust emissions.
- **Monitor engine condition.** As an engine wears, the intake manifold vacuum usually decreases. The PCM is programmed to detect the gradual change in vacuum and is able to keep the air–fuel mixture in the correct range. If the PCM were not capable of making adjustments for engine wear, the lower vacuum could be interpreted as increased load on the engine, resulting in too much

TECH TIP

Use the MAP Sensor as a Vacuum Gauge

A MAP sensor measures the pressure inside the intake manifold compared with absolute zero (perfect vacuum). For example, an idling engine that has 20 inches of mercury (in. Hg) of vacuum has a lower pressure inside the intake manifold than when the engine is under a load and the vacuum is at 10 in. Hg. A decrease in engine vacuum results in an increase in manifold pressure. A normal engine should produce between 17 and 21 in. Hg at idle. Comparing the vacuum reading with the voltage reading output of the MAP sensor indicates that the reading should be between 1.62 and 0.88 volt or 109 to 102 Hz or lower on Ford MAP sensors. Therefore, a digital multimeter (DMM), scan tool, or scope can be used to measure the MAP sensor voltage and be used instead of a vacuum gauge.

NOTE: This chart was developed by testing a MAP sensor at a location about 600 feet above sea level. For best results, a chart based on your altitude should be made by applying a known vacuum, and reading the voltage of a known-good MAP sensor. Vacuum usually drops about 1 inch per 1,000 feet of altitude.

Vacuum (in. Hg)	GM (DC volts)	Ford (Hz)
0	4.80	156–159
1	4.52	
2	4.46	
3	4.26	
4	4.06	
5	3.88	141–143
6	3.66	
7	3.50	
8	3.30	
9	3.10	
10	2.94	127–130
11	2.76	
12	2.54	
13	2.36	
14	2.20	
15	2.00	114–117
16	1.80	
17	1.62	
18	1.42	108–109
19	1.20	
20	1.10	102–104
21	0.88	
22	0.66	

fuel being injected, thereby reducing fuel economy and increasing exhaust emissions.

- **Load detection for returnless-type fuel injection.** On fuel delivery systems that do not use a return line back to the fuel tank, the engine load calculation for the fuel needed is determined by the signals from the MAP sensor.
- **Altitude and MAP sensor values.** On an engine equipped with a speed-density-type fuel injection, the MAP sensor is the most important sensor needed to determine injection pulse width. Changes in altitude change the air density as well as weather conditions. Barometric pressure and altitude are inversely related:
  - As altitude increases—barometric pressure decreases
  - As altitude decreases—barometric pressure increases

  As the ignition switch is turned from off to the start position, the PCM reads the MAP sensor value to determine atmospheric and air pressure conditions. This barometric pressure reading is updated every time the engine is started and whenever wide-open throttle is detected. The barometric pressure reading at that time is updated. See the chart that compares altitude to MAP sensor voltage.

Altitude and MAP Sensor Voltage

Altitude	MAP Sensor Voltage (key on, engine off)
Sea level	4.6 to 4.8 volts
2,500 (760 m)	4.0 volts
5,000 (1,520 m)	3.7 volts
7,500 (2,300 m)	3.35 volts
10,000 (3,050 m)	3.05 volts
12,500 (3,800 m)	2.80 volts
15,000 (4,600 m)	2.45 volts

REAL WORLD FIX

The Cavalier Convertible Story

The owner of a Cavalier convertible stated to a service technician that the “check engine” (MIL) was on. The technician found a diagnostic trouble code (DTC) for a MAP sensor. The technician removed the hose at the MAP sensor and discovered that gasoline had accumulated in the sensor and dripped out of the hose as it was being removed. The technician replaced the MAP sensor and test drove the vehicle to confirm the repair. Almost at once the check engine light came on with the same MAP sensor code. After several hours of troubleshooting without success in determining the cause, the technician decided to start over again. Almost at once, the technician discovered that no vacuum was getting to the MAP sensor where a vacuum gauge was connected with a T-fitting in the vacuum line to the MAP sensor. The vacuum port in the base of the throttle body was clogged with carbon. After a thorough cleaning, and clearing the DTC, the Cavalier again performed properly and the check engine light did not come on again. The technician had assumed that if gasoline was able to reach the sensor through the vacuum hose, surely vacuum could reach the sensor. The technician learned to stop assuming when diagnosing a vehicle and concentrate more on testing the simple things first.

BAROMETRIC PRESSURE SENSOR

A **barometric pressure (BARO) sensor** is similar in design, but senses more subtle changes in barometric absolute pressure (atmospheric air pressure). It is vented directly to the atmosphere. The **barometric manifold absolute pressure (BMAP) sensor** is actually a combination of a BARO and MAP sensor in the same housing. The BMAP sensor has individual circuits to measure barometric and manifold pressure. This input not only allows the computer to adjust for changes in atmospheric pressure due to weather, but also is the primary sensor used to determine altitude.

NOTE: A MAP sensor and a BARO sensor are usually the same sensor, but the MAP sensor is connected to the manifold and a BARO sensor is open to the atmosphere. The MAP sensor is capable of reading barometric pressure just as the ignition switch is turned to the on position before the engine starts. Therefore, altitude and weather changes are available to the computer. During mountainous driving, it may be an advantage to stop and then restart the engine so that the engine computer can take another barometric pressure reading and recalibrate fuel delivery based on the new altitude. See the Ford/BARO altitude chart for an example of how altitude affects intake manifold pressure. The computer on some vehicles will monitor the throttle position sensor and use the MAP sensor reading at wide-open throttle (WOT) to update the BARO sensor if it has changed during driving.

Ford MAP/BARO Altitude Chart

Altitude (feet)	Volts (V)
0	1.59
1,000	1.56
2,000	1.53
3,000	1.50
4,000	1.47
5,000	1.44
6,000	1.41
7,000	1.39

NOTE: Some older Chrysler brand vehicles were equipped with a combination BARO and IAT sensor. The sensor was mounted on the bulkhead (firewall) and sensed the underhood air temperature.

TESTING THE MAP SENSOR

Most pressure sensors operate on 5 volts from the computer and return a signal (voltage or frequency) based on the pressure (vacuum) applied to the sensor. If a MAP sensor is being tested, make certain that the vacuum hose and hose fittings are sound and making a good, tight connection to a manifold vacuum source on the engine.

Four different types of test instruments can be used to test a pressure sensor:

1. A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back-probe the terminals.
2. A scope connected to the sensor output, power, and ground.
3. A scan tool or a specific tool recommended by the vehicle manufacturer.
4. A breakout box connected in series between the computer and the wiring harness connection(s). A typical breakout box includes test points at which pressure sensor values can be measured with a digital voltmeter set on DC volts (or frequency counter, if a frequency-type MAP sensor is being tested).

NOTE: Always check service information for the exact testing procedures and specifications for the vehicle being tested.

TESTING THE MAP SENSOR USING A DMM OR SCOPE

Use jumper wires, T-pins to back-probe the connector, or a breakout box to gain electrical access to the wiring to the pressure sensor. Most pressure sensors use three wires:

1. A 5-volt wire from the computer
2. A variable-signal wire back to the computer
3. A ground or reference low wire

TECH TIP

Visual Check of the MAP Sensor

A defective vacuum hose to a MAP sensor can cause a variety of driveability problems including poor fuel economy, hesitation, stalling, and rough idle. A small air leak (vacuum leak) around the hose can cause these symptoms and often set a trouble code in the vehicle computer. When working on a vehicle that uses a MAP sensor, make certain that the vacuum hose travels consistently *downward* on its route from the sensor to the source of manifold vacuum. Inspect the hose, especially if another technician has previously replaced the factory-original hose. It should not be so long that it sags down at any point. Condensed fuel and/or moisture can become trapped in this low spot in the hose and cause all types of driveability problems and MAP sensor codes.

When checking the MAP sensor, if anything comes out of the sensor itself, it should be replaced. This includes water, gasoline, or any other substance.

The procedure for testing the sensor is as follows:

1. Turn the ignition on (engine off)
2. Measure the voltage (or frequency) of the sensor output
3. Using a hand-operated vacuum pump (or other variable vacuum source), apply vacuum to the sensor

A good pressure sensor should change voltage (or frequency) in relation to the applied vacuum. If the signal does not change or the values are out of range according to the manufacturers' specifications, the sensor must be replaced.

TESTING THE MAP SENSOR USING A SCAN TOOL A scan tool can be used to test a MAP sensor by monitoring the injector pulse width (in milliseconds) when vacuum is being applied to the MAP sensor using a hand-operated vacuum pump. ● **SEE FIGURE 30–7.**

STEP 1 Apply about 20 in. Hg of vacuum to the MAP sensor and start the engine.

STEP 2 Observe the injector pulse width. On a warm engine, the injector pulse width will normally be 1.5 to 3.5 ms.

STEP 3 Slowly reduce the vacuum to the MAP sensor and observe the pulse width. A lower vacuum to the MAP sensor indicates a heavier load on the engine and the injector pulse width should increase.

NOTE: If 23 in. Hg or more vacuum is applied to the MAP sensor with the engine running, this high vacuum will often stall the engine. The engine stalls because the high vacuum is interpreted by the PCM to indicate that the engine is being decelerated, which shuts off the fuel. During engine deceleration, the PCM shuts off the fuel injectors to reduce exhaust emissions and increase fuel economy.

FIGURE 30–7 A typical hand-operated vacuum pump.

FUEL-RAIL PRESSURE SENSOR

A fuel-rail pressure (FRP) sensor is used on some vehicles such as Fords that are equipped with electronic returnless fuel injection. This sensor provides fuel pressure information to the PCM for fuel injection pulse width calculations.

MAP/BARO DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the MAP and BARO sensors include:

Diagnostic Trouble Code	Description	Possible Causes
P0106	BARO sensor out-of-range at key on	• MAP sensor fault • MAP sensor O-ring damaged or missing
P0107	MAP sensor low voltage	• MAP sensor fault • MAP sensor signal circuit shorted-to-ground • MAP sensor 5-volt supply circuit open
P0108	Map sensor high voltage	• MAP sensor fault • MAP sensor O-ring damaged or missing • MAP sensor signal circuit shorted-to-voltage

SUMMARY

1. Pressure below atmospheric pressure is called vacuum and is measured in inches of mercury.
2. A manifold absolute pressure sensor uses a perfect vacuum (zero absolute pressure) in the sensor to determine the pressure.
3. Three types of MAP sensors include:
   - Silicon-diaphragm strain gauge
   - Capacitor-capsule design
   - Ceramic disc design
4. A heavy engine load results in low intake manifold vacuum and a high MAP sensor signal voltage.
5. A light engine load results in high intake manifold vacuum and a low MAP sensor signal voltage.
6. A MAP sensor is used to detect changes in altitude, as well as check other sensors and engine systems.
7. A MAP sensor can be tested by visual inspection, testing the output using a digital meter or scan tool.

REVIEW QUESTIONS

1. What is the relationship among atmospheric pressure, vacuum, and boost pressure in PSI?
2. What are two types (construction) of MAP sensors?
3. What is the MAP sensor signal voltage or frequency at idle on a typical General Motors, Chrysler, and Ford engine?
4. What are three uses of a MAP sensor by the PCM?

CHAPTER QUIZ

1. As the load on an engine increases, the manifold vacuum decreases and the manifold absolute pressure ______________.
   a. Increases
   b. Decreases
   c. Changes with barometric pressure only (altitude or weather)
   d. Remains constant (absolute)
2. A typical MAP sensor compares the vacuum in the intake manifold to ______________.
   a. Atmospheric pressure
   b. A perfect vacuum
   c. Barometric pressure
   d. The value of the IAT sensor
3. Which statement is *false?*
   a. Absolute pressure is equal to barometric pressure plus intake manifold vacuum.
   b. A decrease in manifold vacuum means an increase in manifold pressure.
   c. The MAP sensor compares manifold vacuum to a perfect vacuum.
   d. Barometric pressure minus the MAP sensor reading equals intake manifold vacuum.
4. Which design of MAP sensor produces a frequency (digital) output signal?
   a. Silicon-diaphragm strain gauge
   b. Piezoresistivity design
   c. Capacitor-capsule
   d. Ceramic disc
5. The frequency output of a digital MAP sensor is reading 114 Hz. What is the approximate engine vacuum?
   a. Zero
   b. 5 in. Hg
   c. 10 in. Hg
   d. 15 in. Hg
6. Which is *not* a purpose or function of the MAP sensor?
   a. Measures the load on the engine
   b. Measures engine speed
   c. Calculates fuel delivery based on altitude
   d. Helps diagnose the EGR system
7. When measuring the output signal of a MAP sensor on a General Motors vehicle, the digital multimeter should be set to read ______________.
   a. DC V
   b. AC V
   c. Hz
   d. DC A
8. Two technicians are discussing testing MAP sensors. Technician A says that the MAP sensor voltage on a General Motors vehicle at idle should be about 1.0 volt. Technician B says that the MAP sensor frequency on a Ford vehicle at idle should be about 105–108 Hz. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Technician A says that MAP sensors use a 5-volt reference voltage from the PCM. Technician B says that the MAP sensor voltage will be higher at idle at high altitudes compared to when the engine is operating at near sea level. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A P0107 DTC is being discussed. Technician A says that a defective MAP sensor could be the cause. Technician B says that a MAP sensor signal wire shorted-to-ground could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 31 MASS AIR FLOW SENSORS

OBJECTIVES: After studying Chapter 31, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how MAF sensors work. • List the methods that can be used to test MAF sensors. • Describe the symptoms of a failed MAF sensor. • List how the operation of the MAF sensor affects vehicle operation. • Discuss MAF sensor rationality tests.

KEY TERMS: False air 439 • Mass airflow (MAF) sensor 436 • Speed density 435 • Tap test 438 • Vane airflow (VAF) sensor 435

AIRFLOW SENSORS

Electronic fuel injection systems that do not use the "speed density" system for fuel calculation measure the airflow volume delivered to the engine. Older systems use a movable vane in the intake stream called a vane airflow (VAF) sensor. The vane is part of the **vane airflow (VAF) sensor.** The vane is deflected by intake airflow. ● **SEE FIGURE 31–1.**

The vane airflow sensor used in Bosch L-Jetronic, Ford, and most Japanese electronic port fuel-injection systems is a movable vane connected to a laser-calibrated potentiometer. The vane is mounted on a pivot pin and is deflected by intake airflow proportionate to air velocity. As the vane moves, it also moves the potentiometer. This causes a change in the signal voltage supplied to the computer. ● **SEE FIGURE 31–2.** For example, if the reference voltage is 5 volts, the potentiometer's signal to the computer will vary from a 0 voltage signal (no airflow) to almost a 5-volt signal (maximum airflow). In this way, the potentiometer provides the information the computer needs to vary the injector pulse width proportionate to airflow. There is a special "dampening chamber" built into the VAF to smooth out vane pulsations which would be created by intake manifold air-pressure fluctuations caused by the valve opening and closing. Many vane airflow sensors include a switch to energize the electric fuel pump. This is a safety feature that prevents the operation of the fuel pump if the engine stalls.

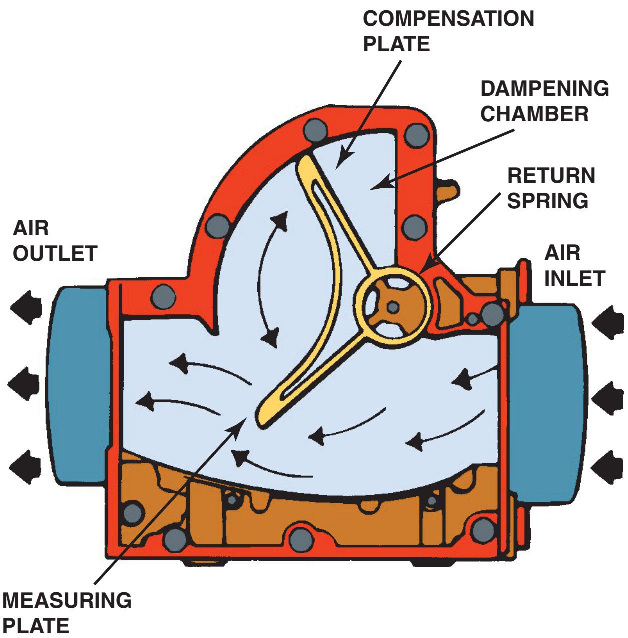


FIGURE 31–1 A vane air flow (VAF) sensor.

MASS AIRFLOW SENSOR TYPES

Most newer fuel injection systems use a **Mass Air Flow (MAF)** sensor to calculate the amount of air volume delivered to the engine.

There are several types of mass airflow sensors.

HOT FILM SENSOR The hot film sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the incoming air. Through the electronics within the sensor, a

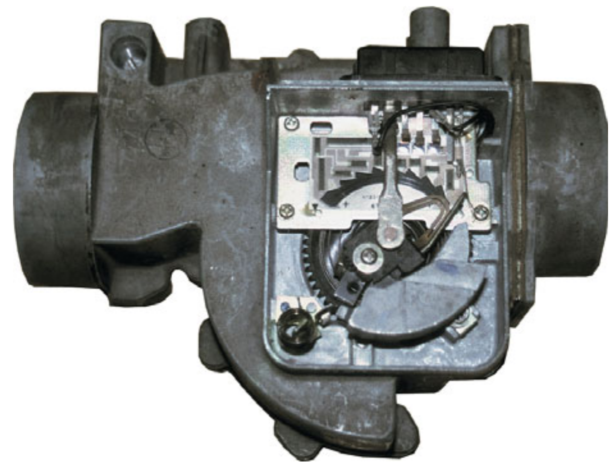


FIGURE 31–2 A typical air vane sensor with the cover removed. The movable arm contacts a carbon resistance path as the vane opens. Many air vane sensors also have contacts that close to supply voltage to the electric fuel pump as the air vane starts to open when the engine is being cranked and air is being drawn into the engine.

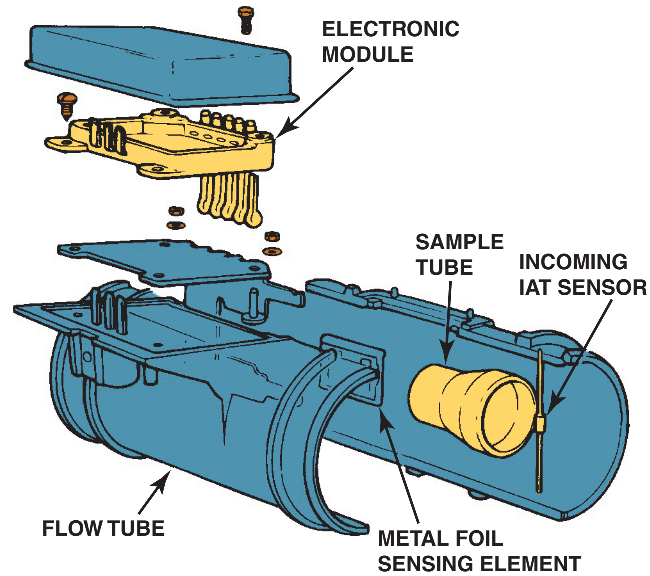


FIGURE 31–3 This five-wire mass air flow sensor consists of a metal foil sensing unit, an intake air temperature (IAT) sensor, and the electronic module.

FREQUENTLY ASKED QUESTION

What Is the Difference Between an Analog and a Digital MAF Sensor?

Some MAF sensors produce a digital DC voltage signal whose frequency changes with the amount of airflow through the sensor. The frequency range also varies with the make of sensor and can range from 0- to 300-Hz for older General Motors MAF sensors to 1,000- to 9,000-Hz for most newer designs.

Some MAF sensors, such as those used by Ford and others, produce a changing DC voltage, rather than frequency, and range from 0- to 5-volts DC.

conductive film is kept at a temperature 70°C above the temperature of the incoming air. ● **SEE FIGURE 31–3.**

Because the amount and density of the air both tend to contribute to the cooling effect as the air passes through the sensor, this type of sensor can actually produce an output based on the mass of the airflow. Mass equals volume times density. For example, cold air is denser than warm air so a small amount of cold air may have the same mass as a larger amount of warm air. Therefore, a mass airflow sensor is designed to measure the mass, not the volume, of the air entering the engine.

The output of this type of sensor is usually a frequency based on the amount of air entering the sensor. The more air that enters the sensor, the more the hot film is cooled. The electronics inside the sensor, therefore, increase the current flow through the hot film to maintain the 70°C temperature differential between the air temperature and the temperature of the hot film. This change in current flow is converted to a frequency output that the computer can use as a measurement of airflow.

FIGURE 31–4 The sensing wire in a typical hot wire mass air flow sensor.

Most of these types of sensors are referred to as **mass airflow (MAF) sensors** because, unlike the air vane sensor, the MAF sensor takes into account relative humidity, altitude, and temperature of the air. The denser the air, the greater the cooling effect on the hot film sensor and the greater the amount of fuel required for proper combustion.

HOT WIRE SENSOR The hot wire sensor is similar to the hot film type, but uses a hot wire to sense the mass airflow instead of the hot film. Like the hot film sensor, the hot wire sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the air entering the sensor. ● **SEE FIGURE 31–4.** The electronic circuitry within the sensor keeps the temperature of the wire at 70°C above the temperature of the incoming air.

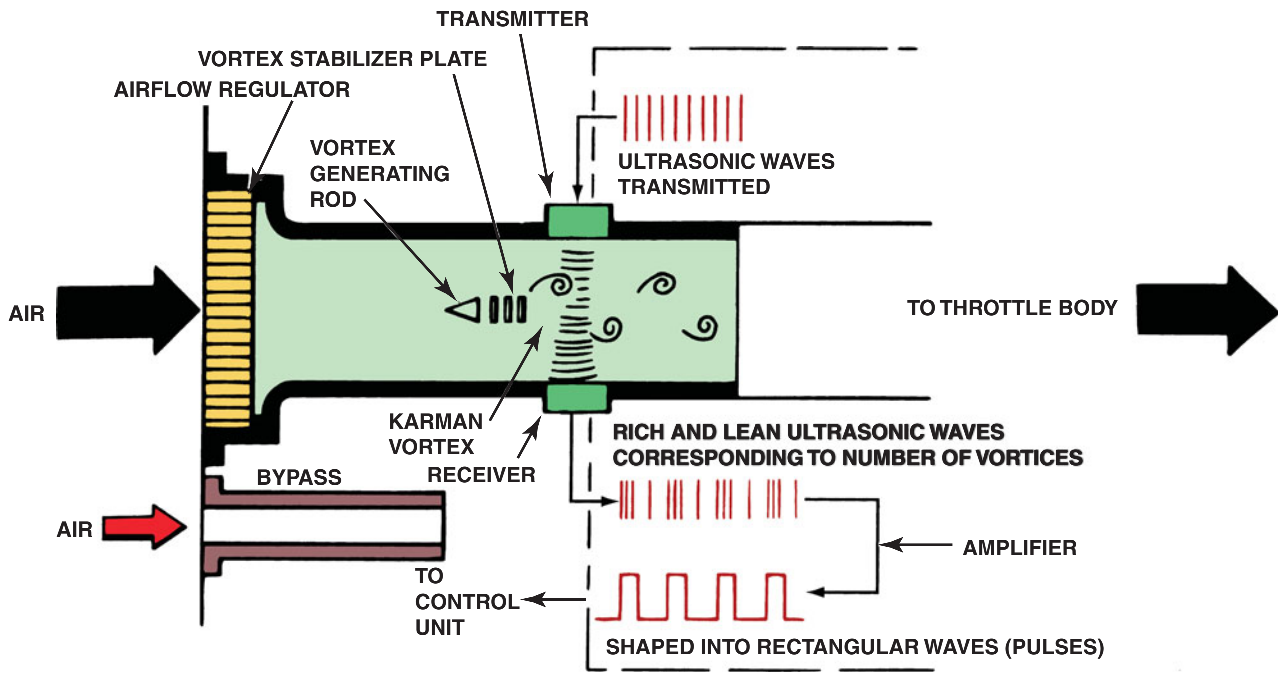


FIGURE 31–5 A Karman Vortex air flow sensor uses a triangle-shaped rod to create vortexes as the air flows through the sensor. The electronics in the sensor itself converts these vortexes to a digital square wave signal.

Both designs operate in essentially the same way. A resistor wire or screen installed in the path of intake airflow is heated to a constant temperature by electric current provided by the computer. Air flowing past the screen or wire cools it. The degree of cooling varies with air velocity, temperature, density, and humidity. These factors combine to indicate the mass of air entering the engine. As the screen or wire cools, more current is required to maintain the specified temperature. As the screen or wire heats up, less current is required. The operating principle can be summarized as follows:

- More intake air volume = cooler sensor, more current.
- Less intake air volume = warmer sensor, less current.

The computer constantly monitors the change in current and translates it into a voltage signal that is used to determine injector pulse width.

BURN-OFF CIRCUIT. Some hot wire-type MAF sensors use a burn-off circuit to keep the sensing wire clean of dust and dirt. A high current is passed through the sensing wire for a short time, but long enough to cause the wire to glow due to the heat. The burn-off circuit is turned on when the ignition switch is switched off after the engine has been operating long enough to achieve normal operating temperature.

KARMAN VORTEX SENSORS

In 1912, a Hungarian scientist named Theodore Van Karman observed that vortexes were created when air passed over a pointed surface. This type of sensor sends a sound wave through the turbulence created by incoming air passing through the sensor. Air mass is calculated based on the time required for the sound waves to cross the turbulent air passage.

There are two basic designs of Karman Vortex air flow sensors. The two types include:

- **Ultrasonic.** This type of sensor uses ultrasonic waves to detect the vortexes that are produced, and produce a digital (on-and-off) signal where frequency is proportional to the amount of air passing through the sensor. ● **SEE FIGURE 31–5.**
- **Pressure-type.** Chrysler uses a pressure-type Karman Vortex sensor that uses a pressure sensor to detect the vortexes. As the airflow through the sensor increases, so do the number of pressure variations. The electronics in the sensor convert these pressure variations to a square wave (digital DC voltage) signal, whose frequency is in proportion to the airflow through the sensor.

PCM USES FOR AIRFLOW SENSORS

The PCM uses the information from the airflow sensor for the following purposes:

- Airflow sensors are used mostly to determine the amount of fuel needed and base pulse-width numbers. The greater the mass of the incoming air, the longer the injectors are pulsed on.

REAL WORLD FIX

The Dirty MAF Sensor Story

The owner of a Buick Park Avenue equipped with a 3800 V-6 engine complained that the engine would hesitate during acceleration, showed lack of power, and seemed to surge or miss at times. A visual inspection found everything to be like new, including a new air filter. There were no stored diagnostic trouble codes (DTCs). A look at the scan data showed airflow to be within the recommended 3 to 7 grams per second. A check of the frequency output showed the problem.

Idle frequency = 2.177 kHz (2,177 Hz)

Normal frequency at idle speed should be 2.37 to 2.52 kHz. Cleaning the hot wire of the MAF sensor restored proper operation. The sensor wire was covered with what looked like fine fibers, possibly from the replacement air filter.

NOTE: Older GM MAF sensors operated at a lower frequency of 32 to 150 Hz, with 32 Hz being the average reading at idle and 150 Hz for wide-open throttle.

? FREQUENTLY ASKED QUESTION

What Is Meant By a "High-Authority Sensor"?

A high-authority sensor is a sensor that has a major influence over the amount of fuel being delivered to the engine. For example, at engine start-up, the engine coolant temperature (ECT) sensor is a high-authority sensor and the oxygen sensor (O2S) is a low-authority sensor. However, as the engine reaches operating temperature, the oxygen sensor becomes a high-authority sensor and can greatly affect the amount of fuel being supplied to the engine. See the chart.

High-Authority Sensors	Low-Authority Sensors
ECT (especially when the engine starts and is warming up)	IAT (intake air temperature) sensors modify and back up the ECT
O2S (after the engine reaches closed-loop operation)	TFT (transmission fluid temperature)
MAP	PRNDL (shift position sensor)
MAF	KS (knock sensor)
TP (high authority during acceleration and deceleration)	EFT (engine fuel temperature)

- Airflow sensors back up the TP sensor in the event of a loss of signal or an inaccurate throttle position sensor signal. If the MAF sensor fails, then the PCM will calculate the fuel delivery needs of the engine based on throttle position and engine speed (RPM).

TESTING MASS AIRFLOW SENSORS

VISUAL INSPECTION Start the testing of a MAF sensor by performing a thorough visual inspection. Look at all the hoses that direct and send air, especially between the MAF sensor and the throttle body. Also check the electrical connector for:

- Corrosion
- Terminals that are bent or pushed out of the plastic connector
- Frayed wiring

MAF SENSOR OUTPUT TEST MAF sensors calculate air mass by weight in a given amount of time usually in grams per second (gm/sec). A digital multimeter, set to read DC volts on the signal wire circuit, can be used to check the MAF sensor. See the chart that shows the voltage output compared with the grams per second of airflow through the sensor. Normal airflow is 3 to 7 grams per second.

Analog MAF Sensor Grams per Second/Voltage Chart

Grams per Second	Sensor Voltage
0	0.2
2	0.7
4	1.0 (typical idle value)
8	1.5
15	2.0
30	2.5
50	3.0
80	3.5
110	4.0
150	4.5
175	4.8

TAP TEST With the engine running at idle speed, gently tap the MAF sensor with the fingers of an open hand. If the engine stumbles or stalls, the MAF sensor is defective. This test is commonly called the **tap test.**

DIGITAL METER TEST OF A MAF SENSOR A digital multimeter can be used to measure the frequency (Hz) output of the sensor and compare the reading with specifications.

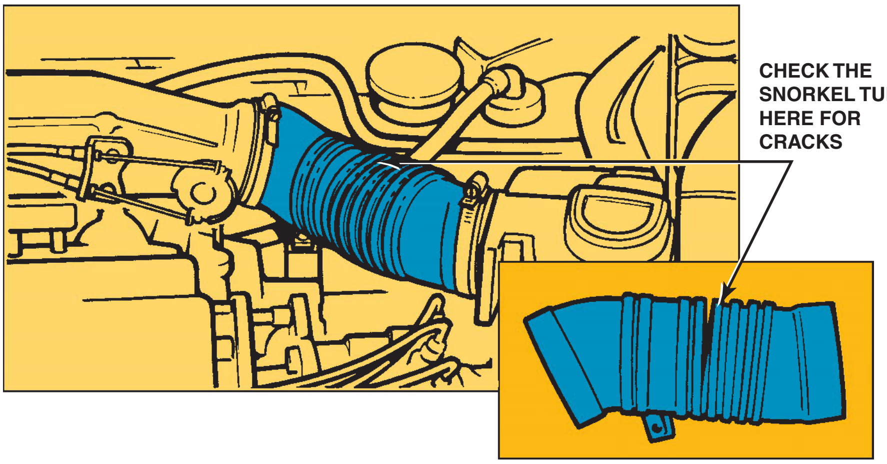


FIGURE 31–6 Carefully check the hose between the MAF sensor and the throttle body assembly for cracks or splits that could create extra (false) air into the engine that is not measured by the MAF sensor.

FREQUENTLY ASKED QUESTION

What Is False Air?

Airflow sensors and mass airflow (MAF) sensors are designed to measure *all* the air entering the engine. If an air hose between the MAF sensor and throttle body was loose or had a hole, extra air could enter the engine without being measured. This extra air is often called **false air**. ● **SEE FIGURE 31–6.** Because this extra air is unmeasured, the computer does not provide enough fuel delivery and the engine operates too lean, especially at idle. A small hole in the air inlet hose would represent a fairly large percentage of false air at idle, but would represent a very small percentage of extra air at highway speeds.

To diagnose for false air, look at long-term fuel trim numbers at idle and at 3000 RPM.

NOTE: If the engine runs well in reverse, yet runs terrible in any forward gear, carefully look at the inlet hose for air leaks that would open when the engine torque moves the engine slightly on its mounts.

The frequency output and engine speed in RPM can also be plotted on a graph to check to see if the frequency and RPM are proportional, resulting in a straight line on the graph.

TECH TIP

The Unplug It Test

If a sensor is defective yet still produces a signal to the computer, the computer will often accept the reading and make the required changes in fuel delivery and spark advance. If, however, the sensor is not reading correctly, the computer will process this wrong information and perform an action assuming that information being supplied is accurate. For example, if a mass airflow (MAF) sensor is telling the computer that 12 grams of air per second is going into the engine, the computer will then pulse the injector for 6.4 ms or whatever figure it is programmed to provide. However, if the air going into the engine is actually 14 grams per second, the amount of fuel supplied by the injectors will not be enough to provide proper engine operation. If the MAF sensor is unplugged, the computer knows that the sensor is not capable of supplying airflow information, so it defaults to a fixed amount of fuel based on the values of other sensors such as the TP and MAP sensors. "If in doubt, take it out."

If the engine operates better with a sensor unplugged, then suspect that the sensor is defective. A sensor that is not supplying the correct information is said to be skewed. The computer will not set a diagnostic trouble code for this condition because the computer can often not detect that the sensor is supplying wrong information.

MAF SENSOR CONTAMINATION

Dirt, oil, silicon, or even spiderwebs can coat the sensing wire. Because it tends to insulate the sensing wire at low airflow rates, a contaminated sensor often overestimates the amount of air entering the engine at idle, and therefore causes the fuel system to go rich. At higher engine speeds near wide-open throttle (WOT), the contamination can cause the sensor to underestimate the amount of air entering the engine. As a result, the fuel system will go lean, causing spark knock and lack of power concerns. To check for contamination, check the fuel trim numbers.

REAL WORLD FIX

The Rich Running Toyota

A Toyota failed an enhanced emission test for excessive carbon monoxide, which is caused by a rich (too much fuel) air–fuel ratio problem. After checking all of the basics and not finding any fault in the fuel system, the technician checked the archives of the International Automotive Technicians Network *(www.iatn.net)* and discovered that a broken spring inside the air flow sensor was a possible cause. The sensor was checked and a broken vane return spring was discovered. Replacing the air flow sensor restored the engine to proper operating conditions and it passed the emission test.

If the fuel trim is negative (removing fuel) at idle, yet is positive (adding fuel) at higher engine speeds, a contaminated MAF sensor is a likely cause. Other tests for a contaminated MAF sensor include:

- At WOT, the grams per second, as read on a scan tool, should exceed 100.
- At WOT, the voltage, as read on a digital voltmeter, should exceed 4 volts for an analog sensor.
- At WOT, the frequency, as read on a meter or scan tool, should exceed 7 kHz for a digital sensor.

If the readings do not exceed these values, then the MAF sensor is contaminated.

MAF-RELATED DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the mass airflow and air vane sensors include:

Diagnostic Trouble Code	Description	Possible Causes
P0100	Mass or volume airflow circuit problems	• Open or short in mass airflow circuit • Defective MAF sensor
P0101	Mass airflow circuit range problems	• Defective MAF sensor (check for false air)
P0102	Mass airflow circuit low output	• Defective MAF sensor • MAF sensor circuit open or shorted-to-ground • Open 12-volt supply voltage circuit
P0103	Mass airflow circuit high output	• Defective MAF sensor • MAF sensor circuit shorted-to-voltage

SUMMARY

1. A mass airflow sensor actually measures the density and amount of air flowing into the engine, which results in accurate engine control.
2. An air vane sensor measures the volume of the air, and the intake air temperature sensor is used by the PCM to calculate the mass of the air entering the engine.
3. A hot wire MAF sensor uses the electronics in the sensor itself to heat a wire 70°C above the temperature of the air entering the engine.

REVIEW QUESTIONS

1. How does a hot film MAF sensor work?
2. What type of voltage signal is produced by a MAF?
3. What change in the signal will occur if engine speed is increased?
4. How is a MAF sensor tested?
5. What is the purpose of a MAF sensor?
6. What are the types of airflow sensors?

CHAPTER QUIZ

1. A fuel-injection system that does not use a sensor to measure the amount (or mass) of air entering the engine is usually called a(n) _____________ type of system.
   - **a.** Air vane-controlled
   - **b.** Speed density
   - **c.** Mass airflow
   - **d.** Hot wire
2. Which type of sensor uses a burn-off circuit?
   - **a.** Hot wire MAF sensor
   - **b.** Hot film MAF sensor
   - **c.** Vane-type airflow sensor
   - **d.** Both a and b
3. Which sensor has a switch that controls the electric fuel pump?
   - **a.** VAF
   - **b.** Hot wire MAF
   - **c.** Hot filter MAF
   - **d.** Karman Vortex sensor
4. Two technicians are discussing Karman Vortex sensors. Technician A says that they contain a burn-off circuit to keep them clean. Technician B says that they contain a movable vane. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. The typical MAF reading on a scan tool with the engine at idle speed and normal operating temperature is _____________.
   - **a.** 1 to 3 grams per second
   - **b.** 3 to 7 grams per second
   - **c.** 8 to 12 grams per second
   - **d.** 14 to 24 grams per second
6. Two technicians are diagnosing a poorly running engine. There are no diagnostic trouble codes. When the MAF sensor is unplugged, the engine runs better. Technician A says that this means that the MAF is supplying incorrect airflow information to the PCM. Technician B says that this indicates that the PCM is defective. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. A MAF sensor on a General Motors 3800 V-6 is being tested for contamination. Technician A says that the sensor should show over 100 grams per second on a scan tool display when the accelerator is depressed to WOT on a running engine. Technician B says that the output frequency should exceed 7,000 Hz when the accelerator pedal is depressed to WOT on a running engine. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Which airflow sensor has a dampening chamber?
   - **a.** A vane airflow
   - **b.** A hot film MAF
   - **c.** A hot wire MAF
   - **d.** A Karman Vortex
9. Air that enters the engine without passing through the airflow sensor is called _____________.
   - **a.** Bypass air
   - **b.** Dirty air
   - **c.** False air
   - **d.** Measured air
10. A P0102 DTC is being discussed. Technician A says that a sensor circuit shorted-to-ground can be the cause. Technician B says that an open sensor voltage supply circuit could be the cause. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

chapter 32

OXYGEN SENSORS

OBJECTIVES: After studying Chapter 32, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how oxygen sensors (O2S) work. • List the methods that can be used to test oxygen sensors. • Describe how a wide-band oxygen sensor works. • List how to test narrow- and wide-band oxygen sensors.

KEY TERMS: Air-fuel ratio sensor 455 • Ambient side electrode 443 • Bias voltage 445 • Closed loop 446 • Cup design 442 • Dual cell 453 • Exhaust side electrode 443 • False lean 448 • False rich 447 • Finger design 442 • Fuel trim 446 • HO2S 444 • Light-off time (LOT) 452 • Nernst cell 453 • Open loop 446 • Oxygen sensors (O2S) 442 • Planar 452 • Pump cell 453 • Reference 453 • Reference electrode 443 • RTV 451 • Signal electrode 443 • Single cell 455 • Thimble design 442 • Titania 444 • Wide-band O2S 452 • Zirconia 442 • ZrO2 442

OXYGEN SENSORS

PURPOSE AND FUNCTION Automotive computer systems use a sensor in the exhaust system to measure the oxygen content of the exhaust. These sensors are called **oxygen sensors (O2S).** The oxygen sensor is installed in the exhaust manifold or located downstream from the manifold in the exhaust pipe. ● **SEE FIGURE 32–1.**

The oxygen sensor is directly in the path of the exhaust gas stream where it monitors oxygen levels in both the exhaust stream and the ambient air. A **zirconia** oxygen sensor is made of **zirconium dioxide (ZrO2),** an electrically conductive material capable of generating a small voltage in the presence of oxygen.

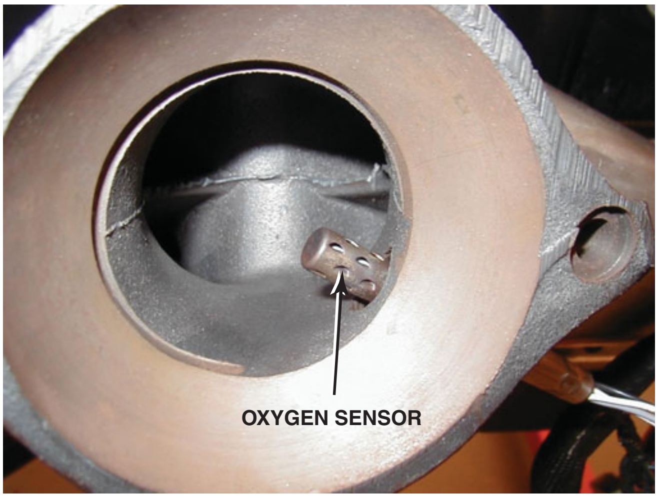


FIGURE 32–1 Many oxygen sensors are located in the exhaust manifold near its outlet so that the sensor can detect the presence or absence of oxygen in the exhaust stream for all cylinders that feed into the manifold.

NARROW BAND A conventional zirconia oxygen sensor (O2S) is only able to detect if the exhaust is richer or leaner than 14.7:1. A conventional oxygen sensor is therefore referred to as the following:

- *Two-step sensor* which is either rich or lean
- *Narrow-band sensor* which informs the PCM whether the exhaust is rich or lean only

The voltage value where a zirconia oxygen sensor switches from rich to lean or from lean to rich is 0.45 V (450 mV).

- Above 0.45 V = rich
- Below 0.45 V = lean

● **SEE FIGURE 32–2.**

CONSTRUCTION A typical zirconia oxygen sensor has the sensing element in the shape of a thimble; therefore, it is often referred to as one of the following:

- **Thimble design**
- **Cup design**
- **Finger design**

● **SEE FIGURE 32–3.**

A typical zirconia oxygen sensor has a heater inside the thimble and does not touch the inside of the sensor. The sensor is similar to a battery that has two electrodes and an electrolyte.

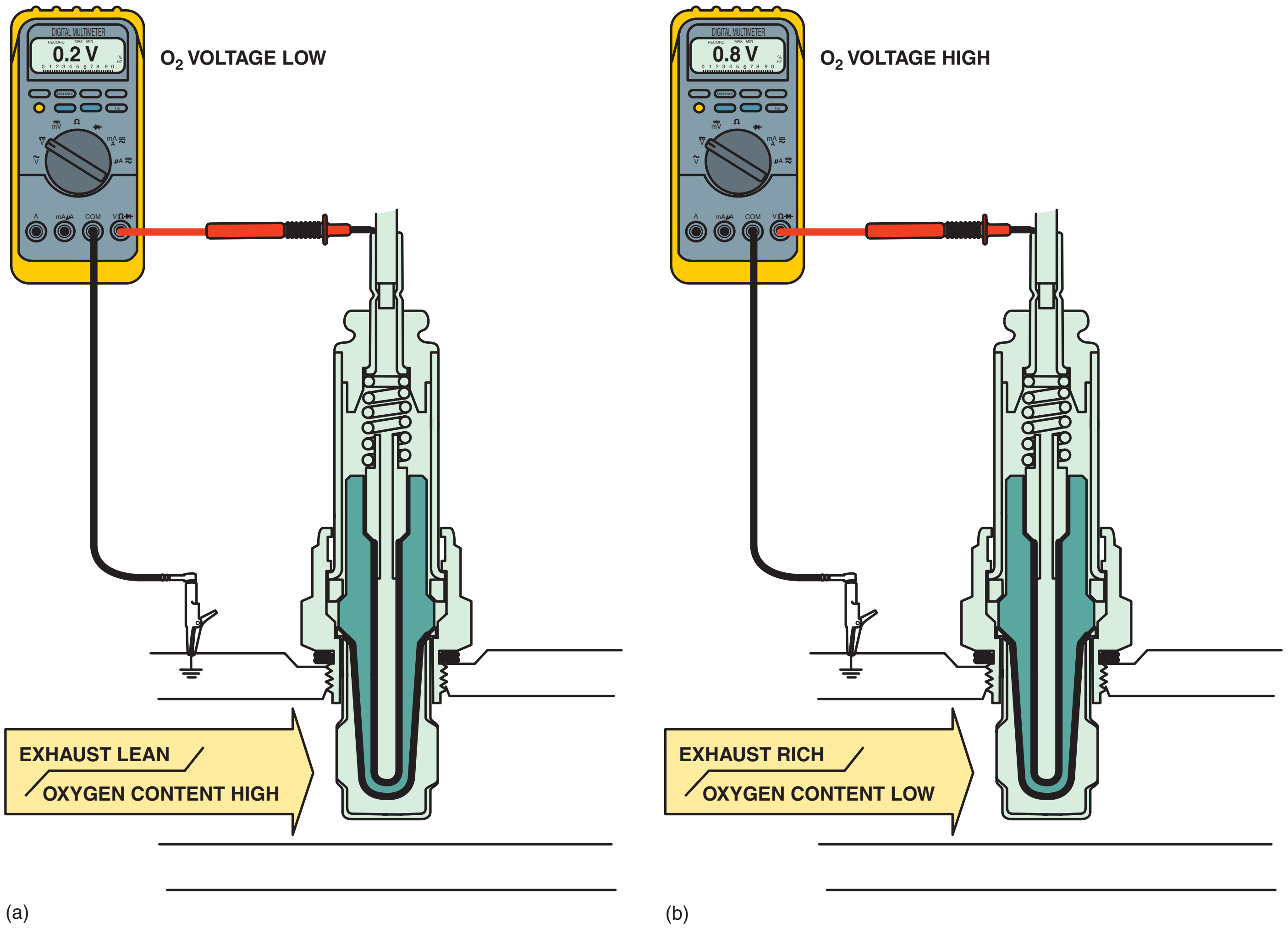


FIGURE 32–2 (a) When the exhaust is lean, the output of a zirconia oxygen sensor is below 450 mV. (b) When the exhaust is rich, the output of a zirconia oxygen sensor is above 450 mV.

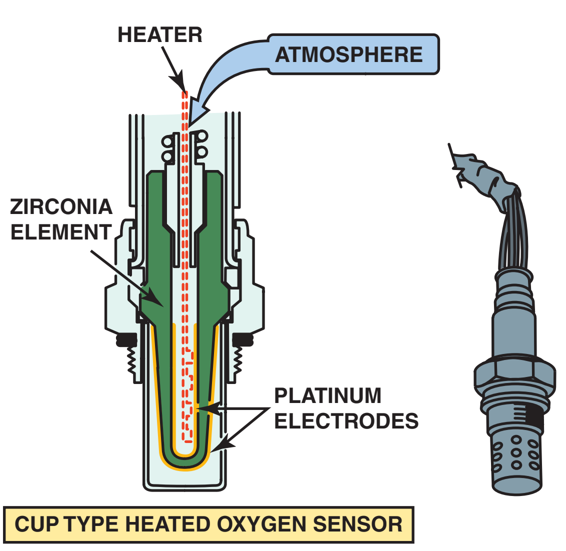


FIGURE 32–3 Most conventional zirconia oxygen sensors and some wide-band oxygen sensors use the cup (finger) type of design.

The electrolyte is solid and is the zirconia (zirconium dioxide). There are also two porous platinum electrodes, which have the following functions.

- **Exhaust side electrode** is exposed to the exhaust stream.
- **Ambient side electrode** is exposed to outside (ambient) air and is the **signal electrode,** also called the **reference electrode.**

● **SEE FIGURE 32–4.**

The electrolyte (zirconia) is able to conduct electrons as follows:

- If the exhaust is rich, O_2 from the reference (inner) electrode wants to flow to the exhaust side electrode, which results in the generation of a voltage.
- If the exhaust is lean, O_2 flow is not needed. As a result, there is little if any electron movement and, therefore, no voltage is produced.

OPERATION Exhaust from the engine passes through the end of the sensor where the gases contact the outer side of the thimble. Atmospheric air enters through the other end of the sensor or

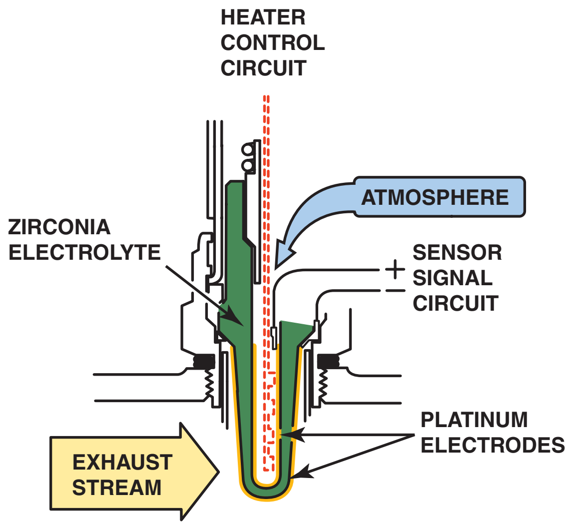


FIGURE 32–4 A typical heated zirconia oxygen sensor, showing the sensor signal circuit that uses the outer (exhaust) electrode as the negative and the ambient air side electrode as the positive.

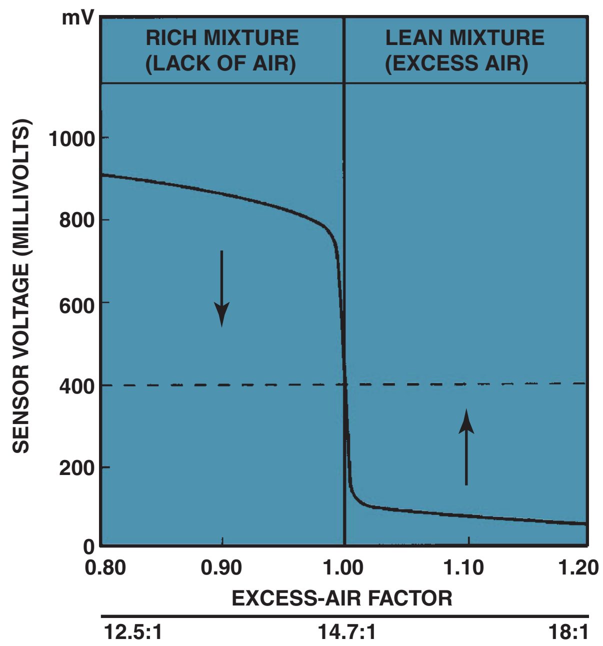


FIGURE 32–5 The oxygen sensor provides a quick response at the stoichiometric air-fuel ratio of 14.7:1.

through the wire of the sensor and contacts the inner side of the thimble. The inner and outer surfaces of the thimble are plated with platinum. The inner surface becomes a negative electrode and the outer surface is a positive electrode. The atmosphere contains a relatively constant 21% of oxygen. Exhaust gases created by burning a rich air-fuel mixture contain little oxygen. Exhaust gases from burning a lean air-fuel mixture contain more oxygen.

Negatively charged oxygen ions are drawn to the thimble where they collect on both the inner and outer surfaces.

Because the oxygen present in the atmosphere exceeds that in the exhaust gases, the air side of the thimble draws more negative oxygen ions than the exhaust side. The difference between the two sides creates an electrical potential, or voltage. When the concentration of oxygen on the exhaust side of the thimble is low, a high voltage (0.60 to 1.0 V) is generated between the electrodes. As the oxygen concentration on the exhaust side increases, the voltage generated drops low (0.0 to 0.3 V).

An O2S does not send a voltage signal until its tip reaches a temperature of about 572°F (300°C). Also, oxygen sensors provide their fastest response to mixture changes at about 1,472°F (800°C). When the engine starts and the O2S is cold, the PCM operates the engine in the open-loop mode, drawing on prerecorded data in the PROM for fuel control on a cold engine, or when O2S output is not within certain limits.

If the exhaust contains very little oxygen, the PCM assumes that the intake charge is rich (too much fuel) and reduces fuel delivery. However, when the oxygen level is high, the PCM assumes that the intake charge is lean (not enough fuel) and increases fuel delivery. ● **SEE FIGURE 32–5.**

There are several different designs of oxygen sensors, including:

- **One-wire oxygen sensor.** The single wire of the one-wire oxygen sensor is the O2S signal wire. The ground for the O2S is through the shell and threads of the sensor and through the exhaust manifold.
- **Two-wire oxygen sensor.** The two-wire sensor has a signal wire and a ground wire for the O2S.
- **Three-wire oxygen sensor.** The three-wire sensor design uses an electric resistance heater to help get the O2S up to temperature more quickly and to help keep the sensor at operating temperature even at idle speeds. The three wires include the O2S signal, the power, and ground for the heater.
- **Four-wire oxygen sensor.** The four-wire sensor is a **heated O2S (HO2S)** that uses an O2S signal wire and signal ground. The other two wires are the power and ground for the heater.

HEATER CIRCUITS The heater circuit on conventional oxygen sensors requires 0.8 to 2.0 amperes and keeps the sensor at about 600°F (315°C).

A wide-band oxygen sensor operates at a higher temperature than a conventional HO2S, from 1,200°F to 1,400°F (650°C to 760°C). The amount of electrical current needed for a wide-band oxygen sensor is about 8 to 10 amperes.

TITANIA OXYGEN SENSOR

The **titania** (titanium dioxide) oxygen sensor does not produce a voltage but rather changes resistance due to the presence of oxygen in the exhaust. All titania oxygen sensors use a four-terminal

FREQUENTLY ASKED QUESTION

What Happens to the Bias Voltage?

Some vehicle manufacturers such as General Motors Corporation have the PCM apply 450 mV (0.45 V) to the O2S signal wire. This voltage is called the **bias voltage** and represents the threshold voltage for the transition from rich to lean.

This bias voltage is displayed on a scan tool when the ignition switch is turned on with the engine off. When the engine is started, the O2S becomes warm enough to produce a usable voltage, and bias voltage "disappears" as the O2S responds to a rich and lean mixture. What happens to the bias voltage that the PCM applies to the O2S? The voltage from the O2S simply overcomes the very weak voltage signal from the PCM. This bias voltage is so weak that even a 20 megohm impedance DMM will affect the strength enough to cause the voltage to drop to 426 mV. Other meters with only 10 megohms of impedance will cause the bias voltage to read less than 400 mV.

Therefore, even though the O2S voltage is relatively low powered, it is more than strong enough to override the very weak bias voltage the PCM sends to the O2S.

REAL WORLD FIX

The Chevrolet Pickup Truck Story

The owner of a 1996 Chevrolet pickup truck complained that the engine ran terribly. It would hesitate and surge, yet there were no diagnostic trouble codes (DTCs). After hours of troubleshooting, the technician discovered while talking to the owner that the problem started after the transmission had been repaired. However, the transmission shop said that the problem was an engine problem and not related to the transmission.

A thorough visual inspection revealed that the front and rear oxygen sensor connectors had been switched. The PCM was trying to compensate for an air-fuel mixture condition that did not exist. Reversing the O2S connectors restored proper operation of the truck.

variable resistance unit with a heating element. A titania sensor samples exhaust air only and uses a reference voltage from the PCM. Titania oxide oxygen sensors use a 14 mm thread and are not interchangeable with zirconia oxygen sensors, which use an 18 mm thread. One volt is applied to the sensor; the changing resistance of the titania oxygen sensor changes the voltage of

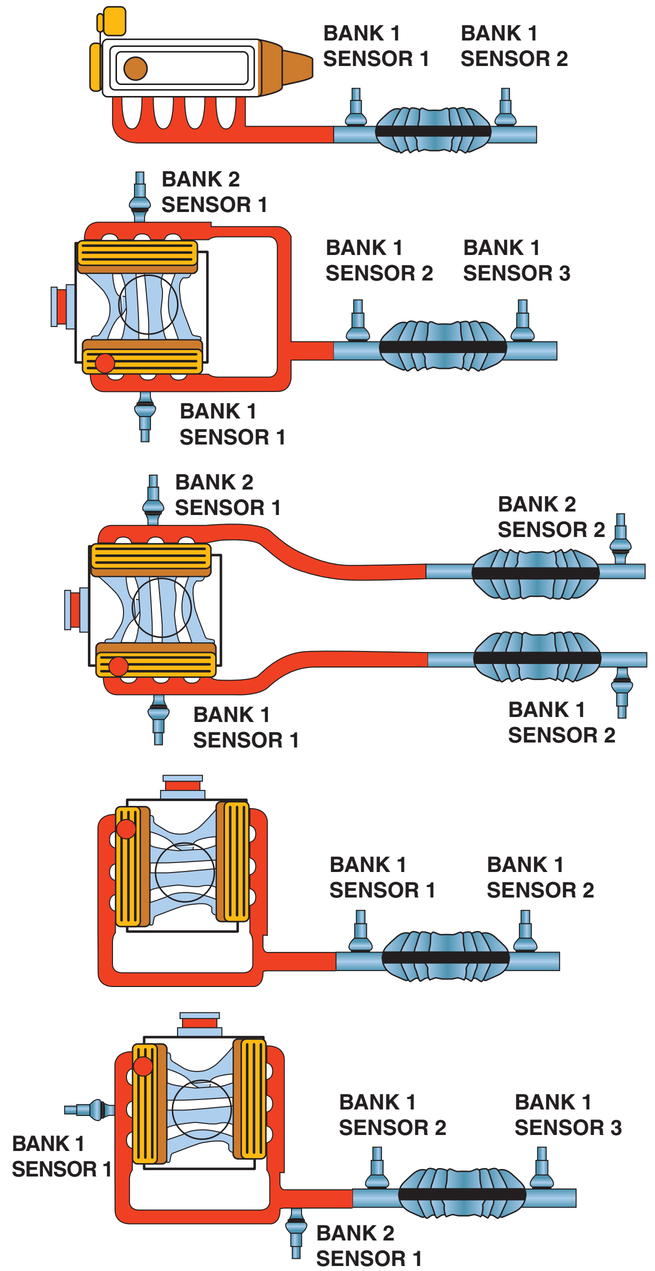


FIGURE 32–6 Number and label designations for oxygen sensors. Bank 1 is the bank where cylinder 1 is located.

FREQUENTLY ASKED QUESTION

Where Is HO2S1?

Oxygen sensors are numbered according to their location in the engine. On a V-type engine, heated oxygen sensor number 1 (HO2S1) is located in the exhaust manifold on the side of the engine where cylinder 1 is located. ● **SEE FIGURE 32–6.**

REAL WORLD FIX

The Oxygen Sensor Is Lying to You

A technician was trying to solve a driveability problem with an older V-6 passenger car. The car idled roughly, hesitated, and accelerated poorly. A thorough visual inspection did not indicate problems and there were no diagnostic trouble codes stored.

The technician checked the oxygen sensor activity using a DMM. The voltage stayed above 600 mV most of the time. If the technician removed a large vacuum hose, the oxygen sensor voltage would temporarily drop to below 450 mV and then return to a reading of over 600 mV. Remember:

- High O2S readings = rich exhaust (low O_2 content in the exhaust)
- Low O2S readings = lean exhaust (high O_2 content in the exhaust)

As part of a thorough visual inspection, the technician removed and inspected the spark plugs. All the spark plugs were white, indicating a lean mixture, not the rich mixture that the oxygen sensor was indicating. The high O2S reading signaled the PCM to reduce the amount of fuel, resulting in an excessively lean operation.

After replacing the oxygen sensor, the engine ran great. But what killed the oxygen sensor? The technician finally learned from the owner that the head gasket had been replaced over a year ago. The silicate and phosphate additives in the antifreeze coolant had coated the oxygen sensor. Because the oxygen sensor was coated, the oxygen content of the exhaust could not be detected, resulting in a false rich signal from the oxygen sensor.

the sensor circuit. As with a zirconia oxygen sensor, the voltage signal is above 450 mV when the exhaust is rich and low (below 450 mV) when the exhaust is lean.

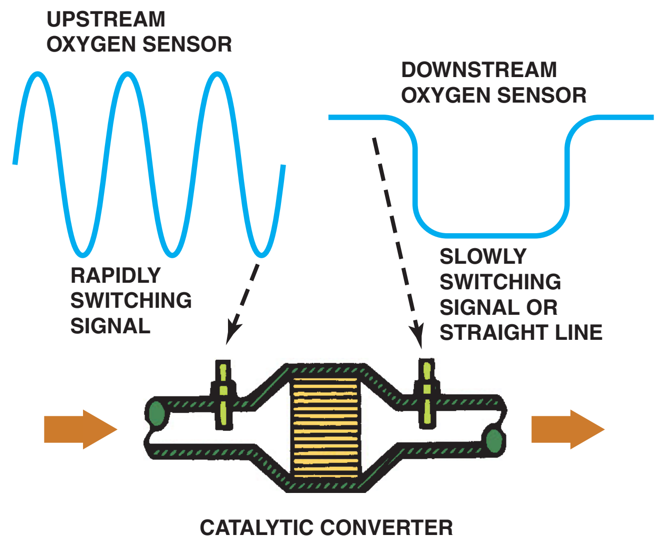


FIGURE 32–7 The OBD-II catalytic converter monitor compares the signals of the upstream and downstream oxygen sensor to determine converter efficiency.

PCM USES OF THE OXYGEN SENSOR

FUEL CONTROL The amount of fuel delivered to an engine is determined by the powertrain control module (PCM) based on inputs from the engine coolant temperature (ECT), throttle position (TP) sensor, and others until the oxygen sensor is capable of supplying a usable signal. When the PCM alone is determining the amount of fuel needed, it is called **open-loop** operation. As soon as the oxygen sensor (O2S) is capable of supplying rich and lean signals, PCM adjustments can be made to fine-tune the correct air-fuel mixture. This checking and adjusting of the PCM is called **closed-loop** operation.

The upstream oxygen sensors are among the high-authority senors used for fuel control while operating in closed loop. Before the oxygen sensors are hot enough to give accurate exhaust oxygen information to the PCM, fuel control is determined by other sensors and the anticipated injector pulse width determined by those sensors. After the control system achieves closed-loop status, the oxygen sensor provides feedback to actual exhaust gas oxygen content.

FUEL TRIM The **fuel trim** numbers are determined from the signals by the oxygen sensor(s). If the engine has been operating too lean, short-term and long-term fuel time programming inside the PCM can cause an increase in the commanded injector pulse width to bring the air-fuel mixture back into the proper range. Fuel trim can be negative (subtracting fuel) or positive (adding fuel).

OXYGEN SENSOR DIAGNOSIS

PCM SYSTEM TESTS The oxygen sensors are used for diagnosis of other systems and components. For example, the exhaust gas recirculation (EGR) system is tested by the PCM, by commanding the EGR valve to open during the test. Some PCMs determine whether enough exhaust gas flows into the engine by looking at the oxygen sensor response (fuel trim numbers). The upstream and downstream oxygen sensors are also used to determine the efficiency of the catalytic converter. Therefore, if a fault occurs with an oxygen sensor, the PCM may not be able to test other systems. ● **SEE FIGURE 32–7.**

REAL WORLD FIX

The Missing Ford

A Ford was being analyzed for poor engine operation. The engine ran perfectly during the following conditions.

1. Engine cold or operating in open loop
2. Engine at idle
3. Engine operating at or near wide-open throttle

After hours of troubleshooting, the technician determined the cause to be a poor ground connection for the oxygen sensor. The engine ran okay during times when the PCM ignored the oxygen sensor. Unfortunately, the service technician did not have a definite plan during the diagnostic process and as a result checked and replaced many unnecessary parts. An oxygen sensor test early in the diagnostic procedure would have indicated that the oxygen (O2S) signal was not correct. The poor ground caused the oxygen sensor voltage level to be too high, indicating to the PCM that the mixture was too rich. The PCM then subtracted fuel which caused the engine to miss and run roughly as the result of the now too lean air-fuel mixture.

VISUAL INSPECTION Whenever an oxygen sensor is replaced, the old sensor should be carefully inspected to help determine the cause of the failure. This is an important step because if the cause of the failure is not discovered, it could lead to another sensor failure.

Inspection may reveal the following:

1. Black sooty deposits usually indicate a rich air-fuel mixture.
2. White chalky deposits are characteristic of silica contamination. Usual causes for this type of sensor failure include silica deposits in the fuel or a technician having used the wrong type of silicone sealant during the servicing of the engine.
3. White sandy or gritty deposits are characteristic of antifreeze (ethylene glycol) contamination. A defective cylinder head or intake manifold gasket could be the cause, or a cracked cylinder head or engine block. Antifreeze may also cause the oxygen sensor to become green as a result of the dye used in antifreeze.
4. Dark brown deposits indicate excessive oil consumption. Possible causes include a defective positive crankcase ventilation (PCV) system or a mechanical engine problem such as defective valve stem seals or piston rings.

DIGITAL VOLTMETER TESTING The oxygen sensor can be checked for proper operation using a digital high-impedance voltmeter.

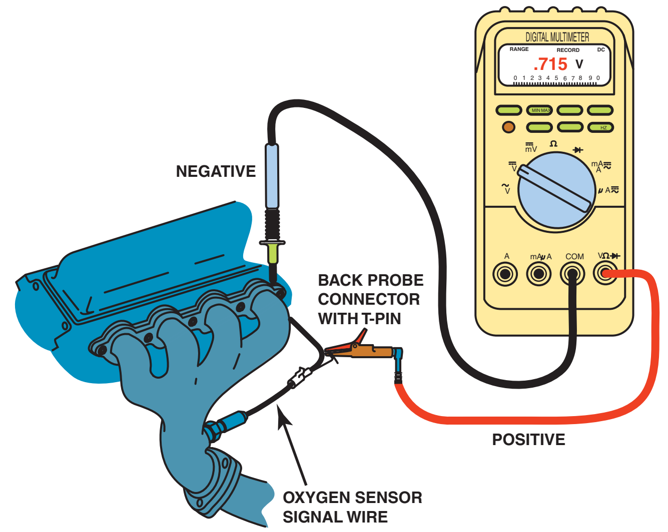


FIGURE 32–8 Testing an oxygen sensor using a DMM set on DC volts. With the engine operating in closed loop, the oxygen voltage should read over 800 mV and lower than 200 mV and be constantly fluctuating.

1. With the engine off, connect the red lead of the meter to the oxygen sensor signal wire and the black meter lead to a good engine ground. ● **SEE FIGURE 32–8.**
2. Start the engine and allow it to reach closed-loop operation.
3. In closed-loop operation, the oxygen sensor voltage should be constantly changing as the fuel mixture is being controlled.

The results should be interpreted as follows:

- If the oxygen sensor fails to respond, and its voltage remains at about 450 mV, the sensor may be defective and require replacement. Before replacing the oxygen sensor, check the manufacturer's recommended procedures.
- If the oxygen sensor reads high all the time (above 550 mV), the fuel system could be supplying too rich a fuel mixture or the oxygen sensor may be contaminated. An oxygen sensor reading that is high could be due to other things besides a rich air-fuel mixture. When the O2S reads high as a result of other factors besides a rich mixture, it is often called a **false rich** indication.

False rich indications (high O2S readings) can be attributed to the following:

- Contaminated O2S due to additives in the engine coolant or due to silicon poisoning
- A stuck open EGR valve (especially at idle)
- A spark plug wire too close to the oxygen sensor signal wire, which can induce a higher than normal voltage in the signal wire, thereby indicating to the PCM a false rich condition
- A loose oxygen sensor ground connection, which can cause a higher than normal voltage and a false rich signal
- A break or contamination of the wiring and its connectors, which could prevent reference oxygen from reaching the oxygen sensor, resulting in a false rich indication (All oxygen sensors require an oxygen supply inside the sensor itself for reference to be able to sense exhaust gas oxygen.)

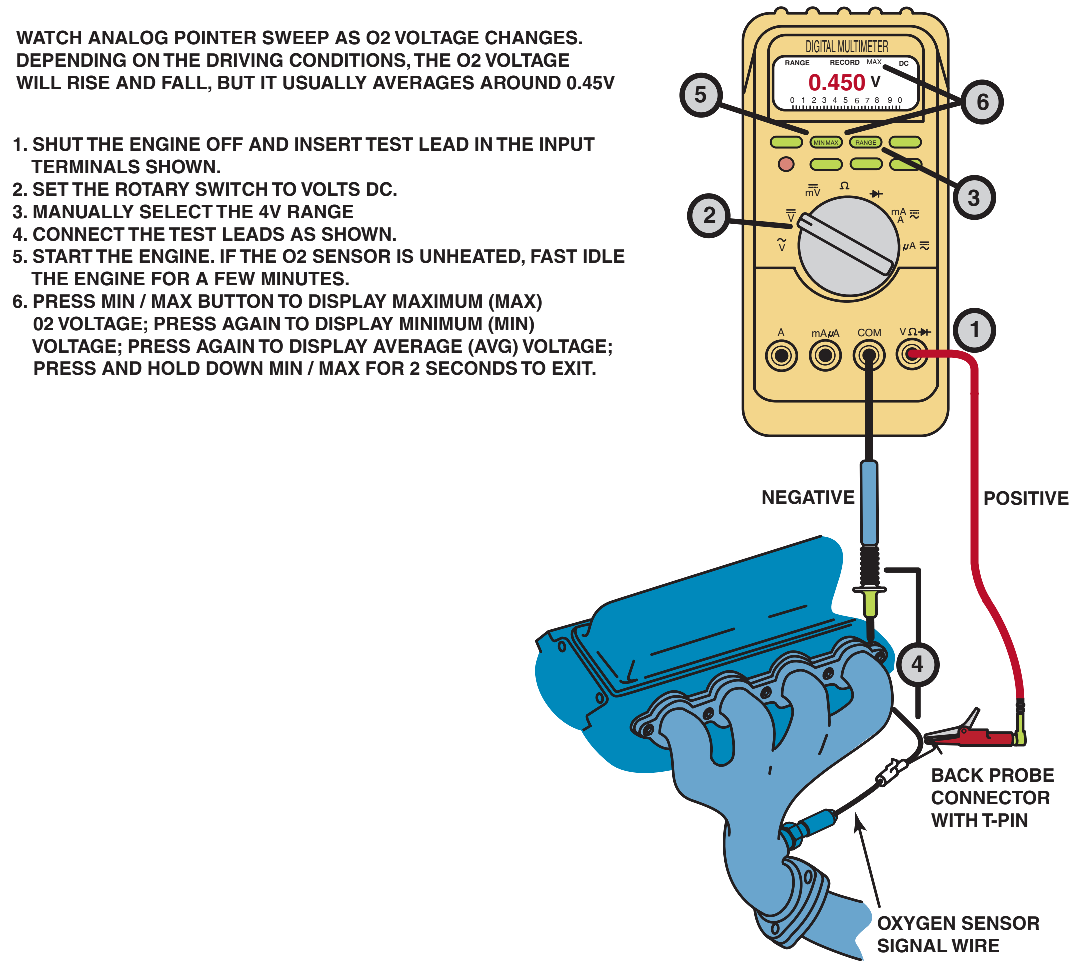


FIGURE 32–9 Using a digital multimeter to test an oxygen sensor using the MIN/MAX record function of the meter.

If the oxygen sensor voltage remains low (below 350 mV), the oxygen sensor itself could be bad or the fuel system could be supplying too lean a fuel mixture. Check for a vacuum leak or partially clogged fuel injector(s). Before replacing the oxygen sensor, check the manufacturer's recommended procedures. If an oxygen sensor reads low as a result of a factor besides a lean mixture, it is often called a **false lean** indication.

False lean indications (low O2S readings) can be attributed to the following:

1. **Ignition misfires.** An ignition misfire due to a defective spark plug wire, fouled spark plug, and so forth, causes no burned air and fuel to be exhausted past the O2S. The O2S "sees" the oxygen (not the unburned gasoline) and the O2S voltage is low.
2. **Exhaust leak in front of the O2S.** An exhaust leak between the engine and the oxygen sensor causes outside oxygen to be drawn into the exhaust and past the O2S. This oxygen is "read" by the O2S and produces a lower than normal voltage. The PCM interprets the lower than normal voltage signal from the O2S as meaning that the air-fuel mixture is lean. The PCM will cause the fuel system to deliver a richer air-fuel mixture.
3. **Spark plug misfire.** The PCM does not know that the extra oxygen going past the oxygen sensor is not due to a lean air-fuel mixture. The PCM commands a richer mixture, which could cause the spark plugs to foul, increasing the rate of misfiring.

TECH TIP

Do Not Solder Oxygen Sensor Wires

Oxygen sensors must have outside oxygen to compare with the oxygen content in the exhaust. Most oxygen sensors breathe through the signal wire and, if soldered, would block the flow of outside air to the sensor. If a replacement oxygen sensor is used, always use the factory replacement, using the original connectors or a crimp-and-seal connector that will seal out any moisture and still allow air to flow through the connector.

MIN/MAX TESTING A digital meter set on DC volts can be used to record the minimum and maximum voltage with the engine running. A good oxygen sensor should be able to produce a value of less than 300 mV and a maximum voltage above 800 mV. ● **SEE FIGURE 32–9.**

Replace any oxygen sensor that fails to go above 700 mV or lower than 300 mV. ● **SEE CHART 32–1.**

MIN/MAX OXYGEN SENSOR TEST CHART			
MINIMUM VOLTAGE	**MAXIMUM VOLTAGE**	**AVERAGE VOLTAGE**	**TEST RESULTS**
Below 200 mV	Above 800 mV	400 to 500 mV	Oxygen sensor is okay.
Above 200 mV	Any reading	400 to 500 mV	Oxygen sensor is defective.
Any reading	Below 800 mV	400 to 500 mV	Oxygen sensor is defective.
Below 200 mV	Above 800 mV	Below 400 mV	System is operating lean.*
Below 200 mV	Below 800 mV	Below 400 mV	System is operating lean. (Add propane to the intake air to see if the oxygen sensor reacts. If not, the sensor is defective.)
Below 200 mV	Above 800 mV	Above 500 mV	System is operating rich.
Above 200 mV	Above 800 mV	Above 500 mV	System is operating rich. (Remove a vacuum hose to see if the oxygen sensor reacts. If not, the sensor is defective.)

CHART 32–1

The test results of using a digital meter set to read minimum and maximum values while testing a narrow-band oxygen sensor.

* Check for an exhaust leak upstream from the O2S or ignition misfire that can cause a false lean indication before further diagnosis.

FREQUENTLY ASKED QUESTION

Why Does the Oxygen Sensor Voltage Read 5 Volts on Many Chrysler Vehicles?

Many Chrysler vehicles apply a 5 volt reference to the signal wire of the oxygen sensor. The purpose of this voltage is to allow the PCM to detect if the oxygen sensor signal circuit is open or grounded.

- If the voltage on the signal wire is 4.5 volts or more, the PCM assumes that the sensor is open.
- If the voltage on the signal wire is zero, the PCM assumes that the sensor is shorted-to-ground.

If either condition exists, the PCM can set a diagnostic trouble code (DTC).

SCAN TOOL TESTING A good oxygen sensor should sense the oxygen content and change voltage outputs rapidly. How fast an oxygen sensor switches from high (above 450 mV) to low (below 350 mV) is measured as frequency, or the number of times the voltage switches per second.

NOTE: On a fuel-injected engine at 2000 engine RPM, 1 to 5 Hz (one to five switches per second) is normal.

Using a scan tool, observe the oxygen sensor voltages with the engine running at 2000 RPM. Look for numbers higher than 800 mV and lower than 200 mV.

If the frequency of switching is low, the oxygen sensor may be contaminated, or the fuel delivery system is delivering a constant rich or lean air-fuel mixture. If the frequency of switching is higher than 5 Hz, look for misfire conditions.

1. Connect the scan tool and start the engine.

TECH TIP

The Key On, Engine Off Oxygen Sensor Test

This test works on General Motors vehicles and may work on others if the PCM applies a bias voltage to the oxygen sensors. Zirconia oxygen sensors become more electrically conductive as they get hot. To perform this test, be sure that the vehicle has not run for several hours.

STEP 1 Connect a scan tool and get the display ready to show oxygen sensor data.

STEP 2 Key the engine on *without* starting the engine. The heater in the oxygen sensor will start heating the sensor.

STEP 3 Observe the voltage of the oxygen sensor. The applied bias voltage of 450 mV should slowly decrease for all oxygen sensors as they become more electrically conductive as the bias voltage is flowing to ground.

STEP 4 A good oxygen sensor should indicate a voltage of less than 100 mV after three minutes. Any sensor that displays a higher than usual voltage or seems to stay higher longer than the others could be defective or skewed high.

2. Operate the engine at a fast idle (2,500 RPM) for two minutes to allow time for the oxygen sensor to warm to operating temperature.
3. Observe the oxygen sensor activity on the scan tool to verify closed-loop operation. Select the "snapshot" mode, hold the engine speed steady, and start recording.

4. Play back snapshot and place a mark beside each range of oxygen sensor voltage for each frame of the snapshot.

A good oxygen sensor and PCM should result in the most snapshot values at both ends (0 to 300 mV and 600 to 1,000 mV). If most of the readings are in the middle, the oxygen sensor is not working correctly.

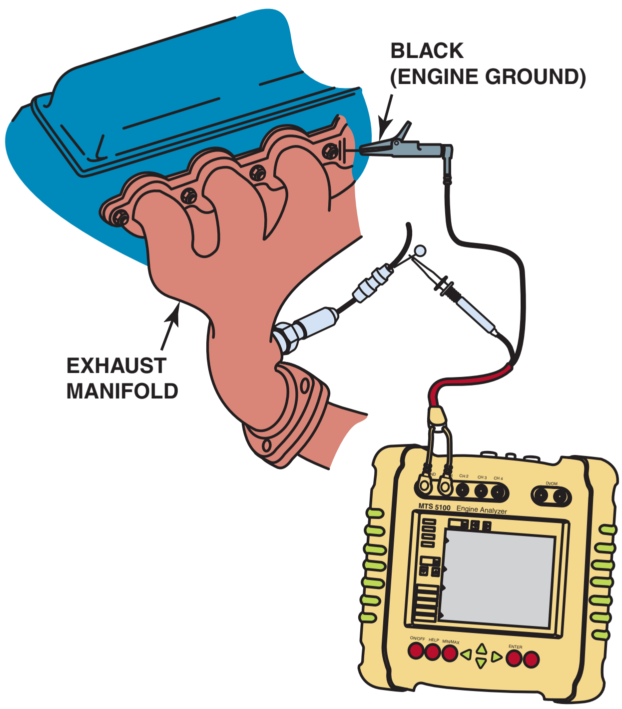


FIGURE 32–10 Connecting a handheld digital storage oscilloscope to an oxygen sensor signal wire. Check the instructions for the scope as some require the use of a filter to be installed in the test lead to reduce electromagnetic interference that can affect the oxygen sensor waveform.

SCOPE TESTING A scope can also be used to test an oxygen sensor. Connect the scope to the signal wire and ground for the sensor (if it is so equipped). ● **SEE FIGURE 32–10.**

With the engine operating in closed loop, the voltage signal of the sensor should be constantly changing. ● **SEE FIGURE 32–11.**

Check for rapid switching from rich to lean and lean to rich and change between once every two seconds and five times per second (0.5 to 5.0 Hz).

NOTE: General Motors warns not to base the diagnosis of an oxygen sensor problem solely on its scope pattern. The varying voltage output of an oxygen sensor can easily be mistaken for a fault in the sensor itself, rather than a fault in the fuel delivery system.

POST CATALYTIC CONVERTER OXYGEN SENSOR TESTING

The oxygen sensor located behind the catalytic converter is used on OBD-II vehicles to monitor converter efficiency. A changing air-fuel mixture is required for the most efficient operation of the converter. If the converter is working correctly, the oxygen content after the converter should be fairly constant. ● **SEE FIGURE 32–12.**

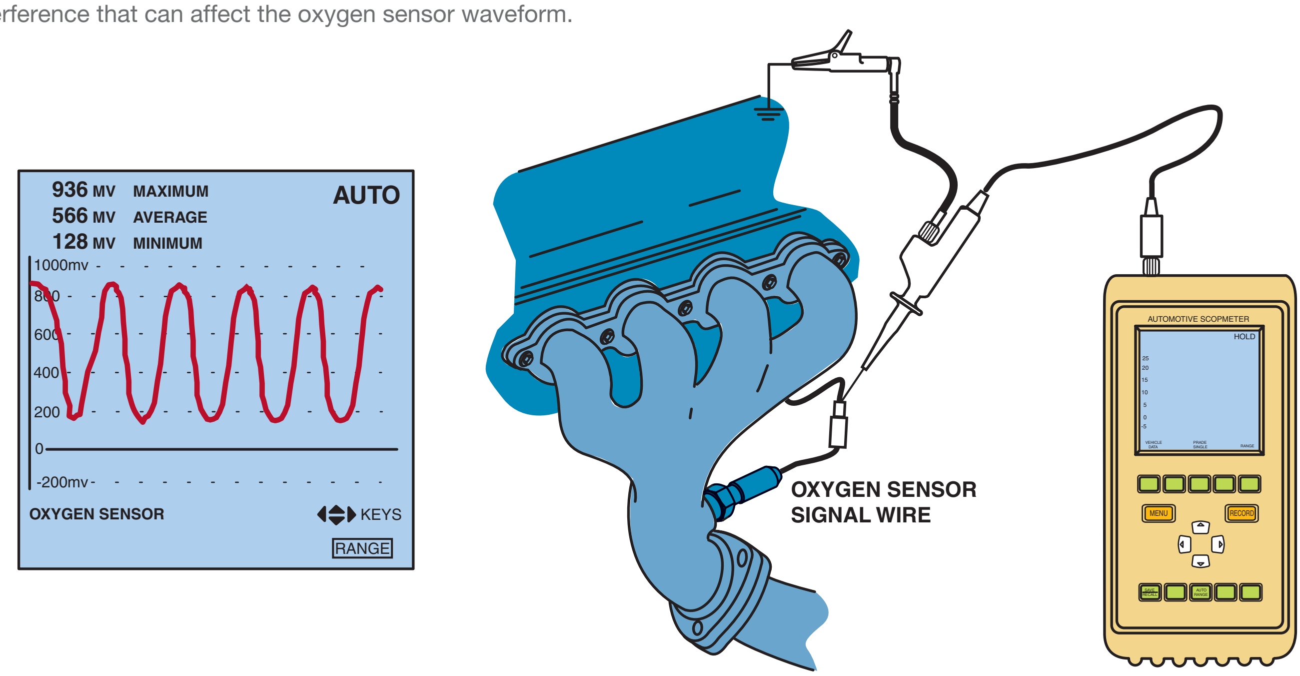


FIGURE 32–11 The waveform of a good oxygen sensor as displayed on a digital storage oscilloscope (DSO). Note that the maximum reading is above 800 mV and the minimum reading is less than 200 mV.

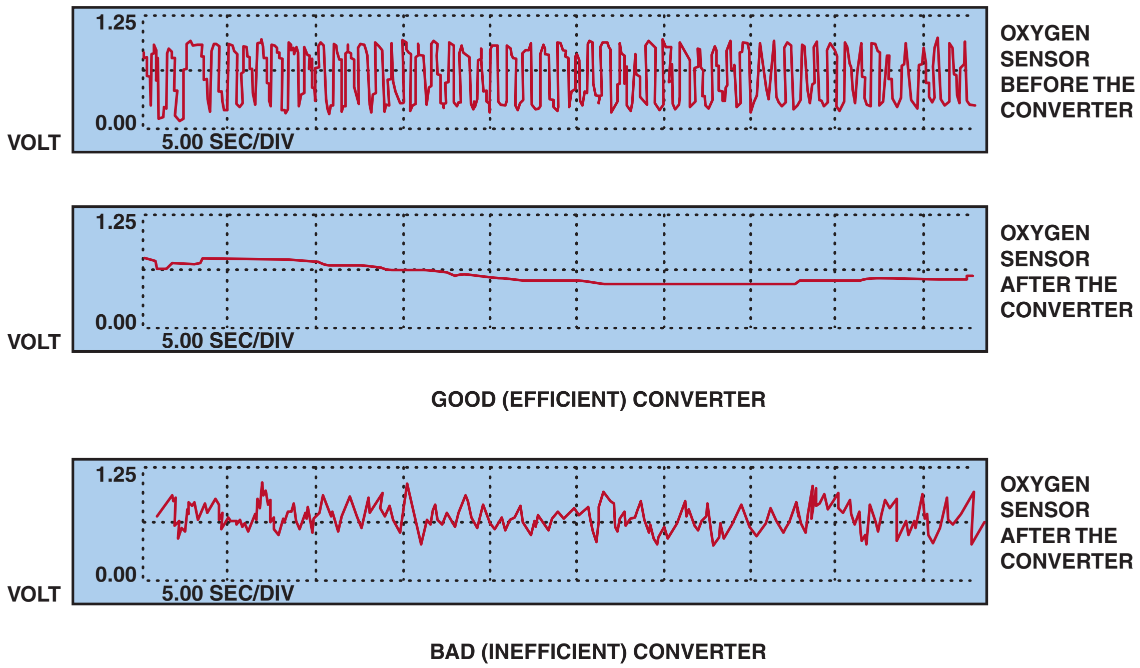


FIGURE 32–12 The post catalytic converter oxygen sensor should display very little activity if the catalytic converter is efficient.

TECH TIP

The Propane Oxygen Sensor Test

Adding propane to the air inlet of a running engine is an excellent way to check if the oxygen sensor is able to react to changes in air-fuel mixture. Follow these steps in performing the propane trick.

1. Connect a digital storage oscilloscope to the oxygen sensor signal wire.
2. Start and operate the engine until it reaches operating temperature and is in closed-loop fuel control.
3. While watching the scope display, add some propane to the air inlet. The scope display should read full rich (over 800 mV).
4. Shut off the propane. The waveform should drop to less than 200 mV (0.2 V).
5. Quickly add some propane while the oxygen sensor is reading low and watch for a rapid transition to rich. The transition should occur in less than 100 milliseconds (ms).

REAL WORLD FIX

How Could Using Silicone Sealer on a Valve Cover Gasket Affect the Oxygen Sensor?

The wrong type of silicone **room temperature vulcanization (RTV)** sealer on a valve cover gasket gives off harmful silica fumes during the curing process. These fumes enter the crankcase area by way of the oil drainback holes in the cylinder head as well as through pushrod openings and other passages in the engine. During engine operation, these fumes are drawn into the intake manifold through the positive crankcase ventilation (PCV) system and are burned in the engine. The harmful silica then exits through the exhaust system, where the contamination affects the oxygen sensor.

NOTE: Be careful not to spray any silicone lubricant near the engine vacuum, which might draw the fumes into the engine and cause silica damage to the oxygen sensor.

The post catalytic converter oxygen sensor also is used to modify the amount of fuel delivered to the engine to allow the converter to work efficiently. If, for example, the rear oxygen sensor voltage stayed high, the PCM will try to increase the amount of oxygen entering the converter by leaning the air-fuel mixture to the engine. This process is often called the target upstream fuel trim. Therefore, instead of the PCM commanding a target air-fuel mixture of 14.7:1, the new target may specify an air-fuel ratio of 14.9:1 or slightly leaner than normal to help provide a little extra oxygen for use by the catalytic converter. This target air-fuel ratio or fuel trim is displayed on scan tools.

WIDE-BAND OXYGEN SENSORS

TERMINOLOGY Honda was the first manufacturer to use **wide-band oxygen sensors** beginning in 1992. Today, they are used by most vehicle manufacturers to ensure that the exhaust emissions can meet the current standard. Wide-band oxygen sensors have various names, depending on the vehicle and/or oxygen sensor manufacturer, including:

- Wide-band oxygen sensor
- Broadband oxygen sensor
- Wide-range oxygen sensor
- Air-fuel ratio (AFR) sensor
- Wide-range air-fuel (WRAF) sensor
- Lean-air fuel (LAF) sensor
- Air-fuel (AF) sensor

Wide-band oxygen sensors are also manufactured in dual cell and single cell designs.

INTRODUCTION A conventional zirconia oxygen sensor reacts to an air-fuel mixture that is either richer or leaner than 14.7:1. This means that the sensor cannot be used to detect the exact air-fuel mixture. ● **SEE FIGURE 32–13.**

The need for more stringent exhaust emission standards such as the natural low emission vehicle (NLEV), plus the ultra low emission vehicle (ULEV) and the super ultra low emission vehicle (SULEV) require more accurate fuel control than can be provided by a traditional oxygen sensor.

PURPOSE AND FUNCTION A wide-band oxygen sensor is capable of supplying air-fuel ratio information to the PCM over a much broader range. Compared with a conventional zirconia oxygen sensor, the wide-band oxygen sensor has the following features.

1. The ability to detect exhaust air-fuel ratio from as rich as 10:1 to as lean as 23:1 in some cases
2. Cold start activity within as little as 10 seconds

PLANAR DESIGN In 1998, Bosch introduced a wide-band oxygen sensor that is flat and thin (1.5 mm or 0.006 in.) 0, known as a planar design and not in the shape of a thimble as previously constructed. Now several manufacturers produce a similar **planar** design wide-band oxygen sensor. Its thin design makes it easier to heat than older styles of oxygen sensors and, as a result, it can achieve closed loop in less than 10 seconds. This fast heating, called **light-off time (LOT),** helps improve fuel economy and reduces cold-start exhaust emissions. The type of construction is not noticed by the technician, nor does it affect the testing procedures.

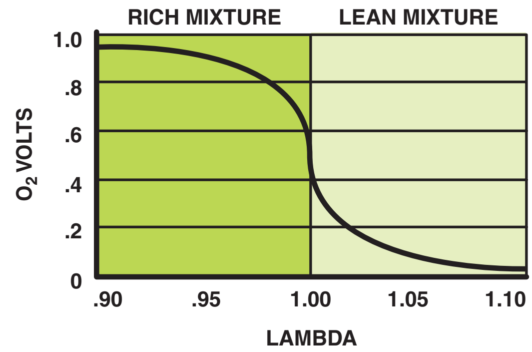


FIGURE 32–13 A conventional zirconia oxygen sensor can only reset to exhaust mixtures that are richer or leaner than 14.7:1 (lambda 1.00).

? FREQUENTLY ASKED QUESTION

How Quickly Can a Wide-Band Oxygen Sensor Achieve Closed Loop?

In a Toyota Highlander hybrid electric vehicle, the operation of the gasoline engine is delayed for a short time when the vehicle is first driven. During this time of electric operation, the oxygen sensor heaters are turned on in readiness for the gasoline engine starting. The gasoline engine often achieves closed-loop operation during *cranking* because the oxygen sensors are fully warm and ready to go at the same time the engine is started. Having the gasoline engine achieve closed loop quickly, allows it to meet the stringent SULEV standards.

A conventional oxygen sensor can also be constructed using a planar design instead of the thimble-type design. A planar design has the following features.

- The elements including the zirconia electrolyte and the two electrodes and heater are stacked together in a flat-type design.
- It allows faster warm-up because the heater is in direct contact with the other elements.
- Planar oxygen sensors are the most commonly used. Some planar designs are used as a conventional narrow-band oxygen sensor.

The sandwich-type designs of the planar style of oxygen sensor have the same elements and operate the same, but are stacked in the following way from the exhaust side to the ambient air side.

Exhaust stream
Outer electrode
Zirconia (Zr_2) (electrolyte)
Inner electrode (reference or signal)
Outside (ambient) air
Heater
● **SEE FIGURE 32–14**

NOTE: Another name for a conventional oxygen sensor is a Nernst cell, named for Walther Nernst, 1864–1941, a German physicist known for his work in electrochemistry.

DUAL CELL PLANAR WIDE-BAND SENSOR OPERATION

CONSTRUCTION In a conventional zirconia oxygen sensor, a bias or reference voltage can be applied to the two platinum electrodes, and then oxygen ions can be forced (pumped) from the ambient reference air side to the exhaust side of the sensor. If the polarity is reversed, the oxygen ion can be forced to travel in the opposite direction.

A **dual cell** planar-type wide-band oxygen sensor is made like a conventional planar O2S, or Nernst cell. Above the Nernst cell is another zirconia layer with two electrodes, called the **pump cell.** The two cells share a common ground, called the **reference.**

There are two internal chambers:

- The air reference chamber is exposed to ambient air.
- The diffusion chamber is exposed to the exhaust gases.

Platinum electrodes are on both sides of the zirconia electrolyte elements, which separate the air reference chamber and the exhaust exposed diffusion chamber.

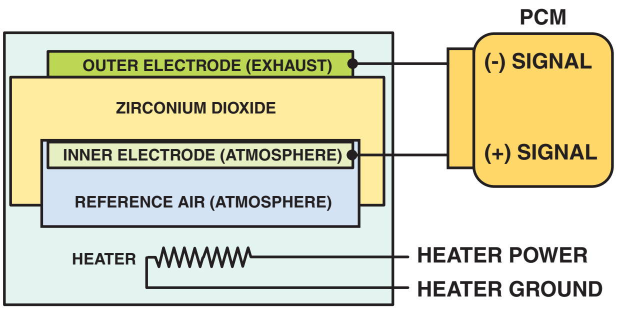


FIGURE 32–14 A planar design zirconia oxygen sensor places all of the elements together, which allows the sensor to reach operating temperature quickly.

OPERATION The basic principle of operation of a typical wide-band oxygen sensor is that it uses a positive or negative voltage signal to keep a balance between two sensors. Oxygen sensors do not measure the quantity of free oxygen in the exhaust. Instead, oxygen sensors produce a voltage that is based on the ion flow between the platinum electrodes of the sensor to maintain a stoichiometric balance.

For example:

- If there is a lean exhaust, there is oxygen in the exhaust and the ion flow from the ambient side to the exhaust side is low.
- If there is rich exhaust, the ion flow is increased to help maintain balance between the ambient air side and the exhaust side of the sensor.

The PCM can apply a small current to the pump cell electrodes, which causes oxygen ions through the zirconia into or out of the diffusion chamber. The PCM pumps O_2 ions in and out of the diffusion chamber to bring the voltage back to 0.45 V, using the pump cell.

The operation of a wide-band oxygen sensor is best described by looking at what occurs when the exhaust is stoichiometric, rich, and lean. ● **SEE FIGURE 32–15.**

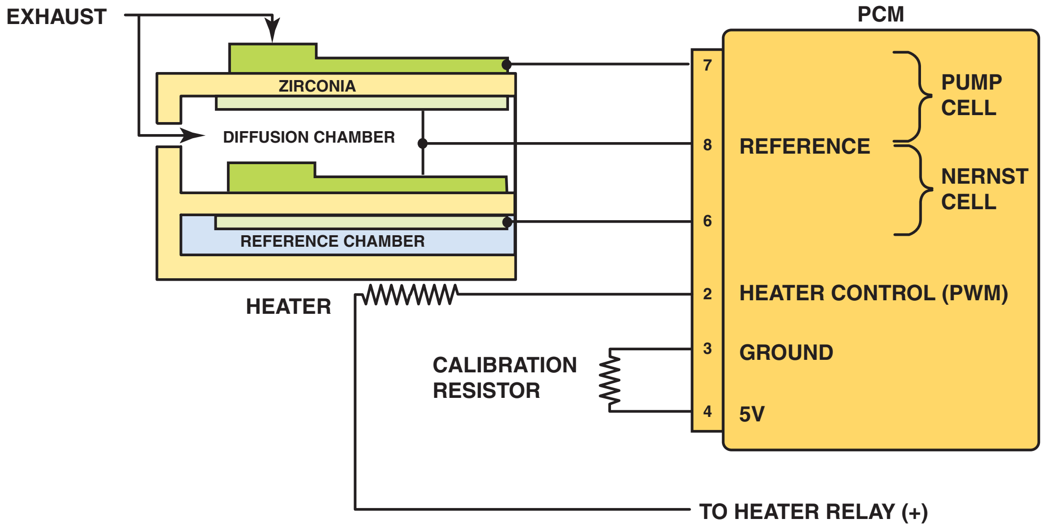


FIGURE 32–15 The reference electrodes are shared by the Nernst cell and the pump cell.

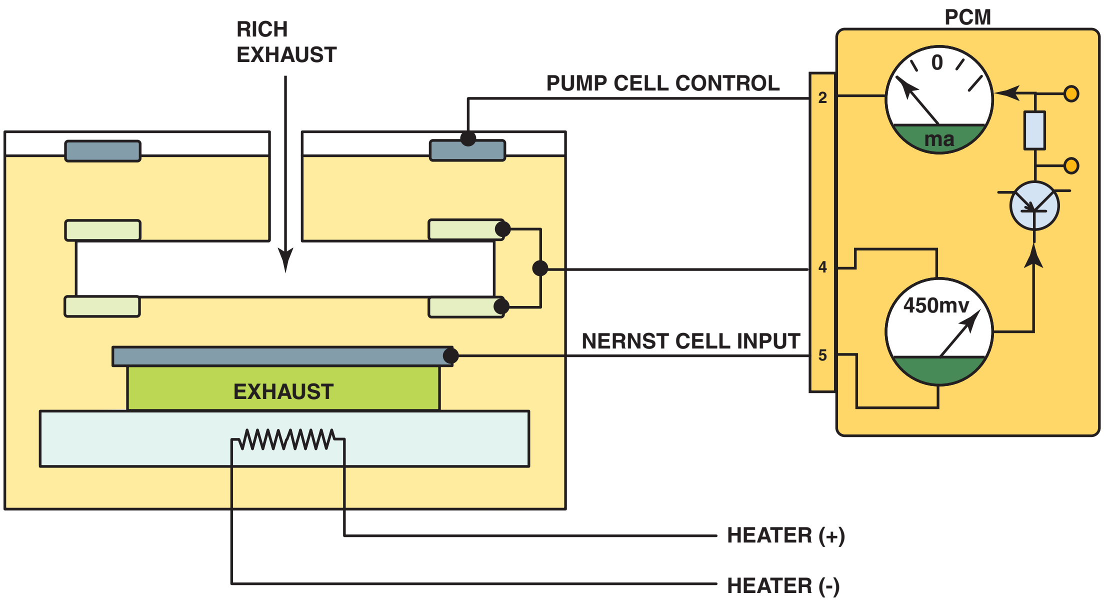


FIGURE 32–16 When the exhaust is rich, the PCM applies a negative current into the pump cell.

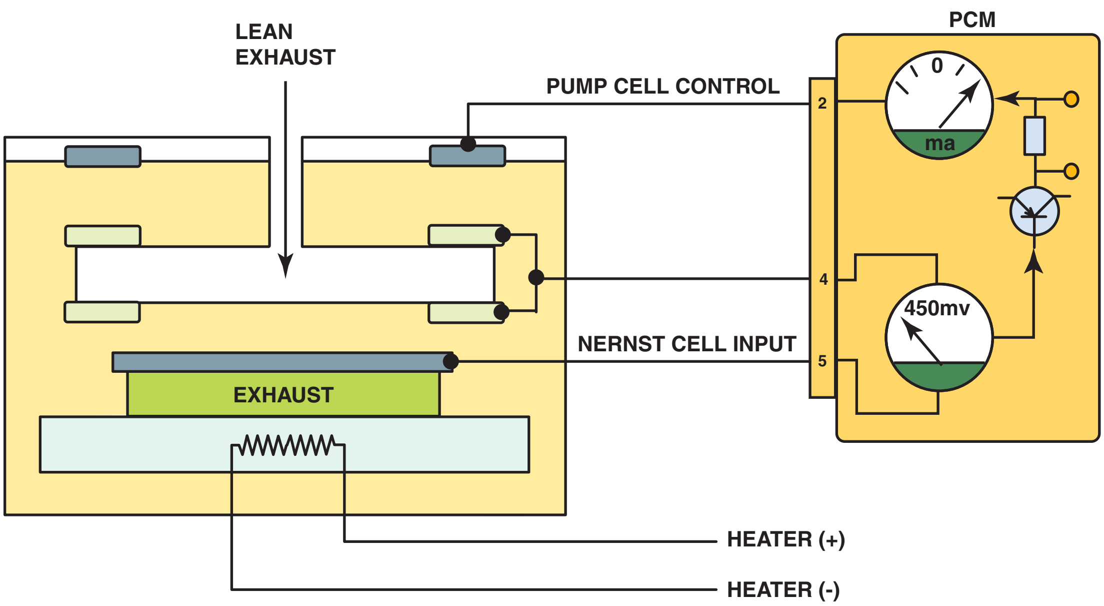


FIGURE 32–17 When the exhaust is lean, the PCM applies a positive current into the pump cell.

STOICHIOMETRIC

- When the exhaust is at stoichiometric (14.7:1 air-fuel ratio), the voltage of the Nernst cell is 450 mV (0.45 V).
- The voltage between the diffusion chamber and the air reference chamber changes from 0.45 V. This voltage will be:
  - Higher if the exhaust is rich
  - Lower if the exhaust is lean

The reference voltage remains constant, usually at 2.5 V, but can vary depending on the year, make, and model of vehicle and the type of sensor. Typical reference voltages include:

- 2.2 V
- 2.5 V
- 2.7 V
- 3.3 V
- 3.6 V

RICH EXHAUST. When the exhaust is rich, the voltage between the common (reference) electrode and the Nernst cell electrode that is exposed to ambient air is higher than 0.45 V. The PCM applies a negative current in milliamperes to the pump cell electrode to bring the circuit back into balance. **SEE FIGURE 32–16.**

LEAN EXHAUST. When the exhaust is lean, the voltage between the common (reference) electrode and the Nernst cell electrode is lower than 0.45 V. The PCM applies a positive current in milliamperes to the pump cell to bring the circuit back into balance. **SEE FIGURE 32–17.**

FACTORY SCAN TOOL	OBD II SCAN TOOL	AIR-FUEL RATIO
2.50 V	0.50 V	12.5:1
3.00 V	0.60 V	14.0:1
3.30 V	0.66 V	14.7:1
3.50 V	0.70 V	15.5:1
4.00 V	0.80 V	18.5:1

CHART 32–2

A comparison showing what a factory scan tool and a generic OBD-II scan tool might display at various air-fuel ratios.

DUAL CELL DIAGNOSIS

SCAN TOOL DIAGNOSIS Most service information specifies that a scan tool be used to check the wide-band oxygen sensor, because the PCM performs tests of the unit and can identify faults. However, even wide-band oxygen sensors can be fooled if there is an exhaust manifold leak or other fault which could lead to false or inaccurate readings. If the oxygen sensor reading is false, the PCM will command an incorrect amount of fuel. The scan data shown on a generic (global) OBD-II scan tool will often be different than the reading on the factory scan tool. ● **SEE CHART 32–2** for an example of a Toyota wide-band oxygen sensor being tested using a factory scan tool and a generic OBD-II scan tool.

SCAN TOOL DATA (PID) The following information will be displayed as a scan tool when looking at data for a wide-band oxygen sensor.

H02S1 = ________ mA ÷	If the current is positive, this means that the PCM is pumping current in the diffusion gap due to a rich exhaust. If the current is negative, the PCM is pumping current out of the diffusion gap due to a lean exhaust.
Air-fuel ratio = ________	Usually expressed in lambda. One means that the exhaust is at stoichiometric (14.7:1 air-fuel ratio) and numbers higher than one indicate a lean exhaust and numbers lower than one indicate a rich exhaust.

DIGITAL METER TESTING When testing a wide-band oxygen sensor for proper operation, perform the following steps.

STEP 1 Check service information and determine the circuit and connector terminal identification.

STEP 2 Measure the calibration resistor. While the value of this resistor can vary widely, depending on the type of sensor, the calibrating resistor should still be checked for opens and shorts.

NOTE: The calibration resistor is usually located within the connector itself.

- If open, the ohmmeter will read OL (infinity ohms).
- If shorted, the ohmmeter will read zero or close to zero.

STEP 3 Measure the heater circuit for proper resistance or current flow.

STEP 4 Measure the reference voltage relative to ground. This can vary but is generally 2.4 to 2.6 V.

STEP 5 Using jumper wires, connect an ammeter and measure the current in the pump cell control wire.

RICH EXHAUST When the exhaust is rich (lambda less than 1.00), the Nernst cell voltage will move higher than 0.45 V. The PCM will pump oxygen from the exhaust into the diffusion gap by applying a negative voltage to the pump cell.

LEAN EXHAUST When the exhaust is lean (lambda higher than 1.00), the Nernst cell voltage will move lower than 0.45 V. The PCM will pump oxygen out of the diffusion gap by applying a positive voltage to the pump cell.

Pump cell is used to pump oxygen into the diffusion gap when the exhaust is rich. The pump cell applies a negative voltage to do this.

- Positive current = lean exhaust
- Negative current = rich exhaust

● **SEE FIGURE 32–18.**

SINGLE CELL WIDE-BAND OXYGEN SENSORS

CONSTRUCTION A typical **single cell** wide-band oxygen sensor looks similar to a conventional four-wire zirconia oxygen sensor. The typical single cell wide-band oxygen sensor, usually called an **air-fuel ratio sensor,** has the following construction features.

- It can be made using the cup or planar design.
- Oxygen (O_2) is pumped into the diffusion layer similar to the operation of a dual cell wide-band oxygen sensor. ● **SEE FIGURE 32–19.**
- Current flow reverses positive and negative.
- There are two cell wires and two heater wires (power and ground).
- The heater usually requires 6 amperes and the ground side is pulse-width modulated.

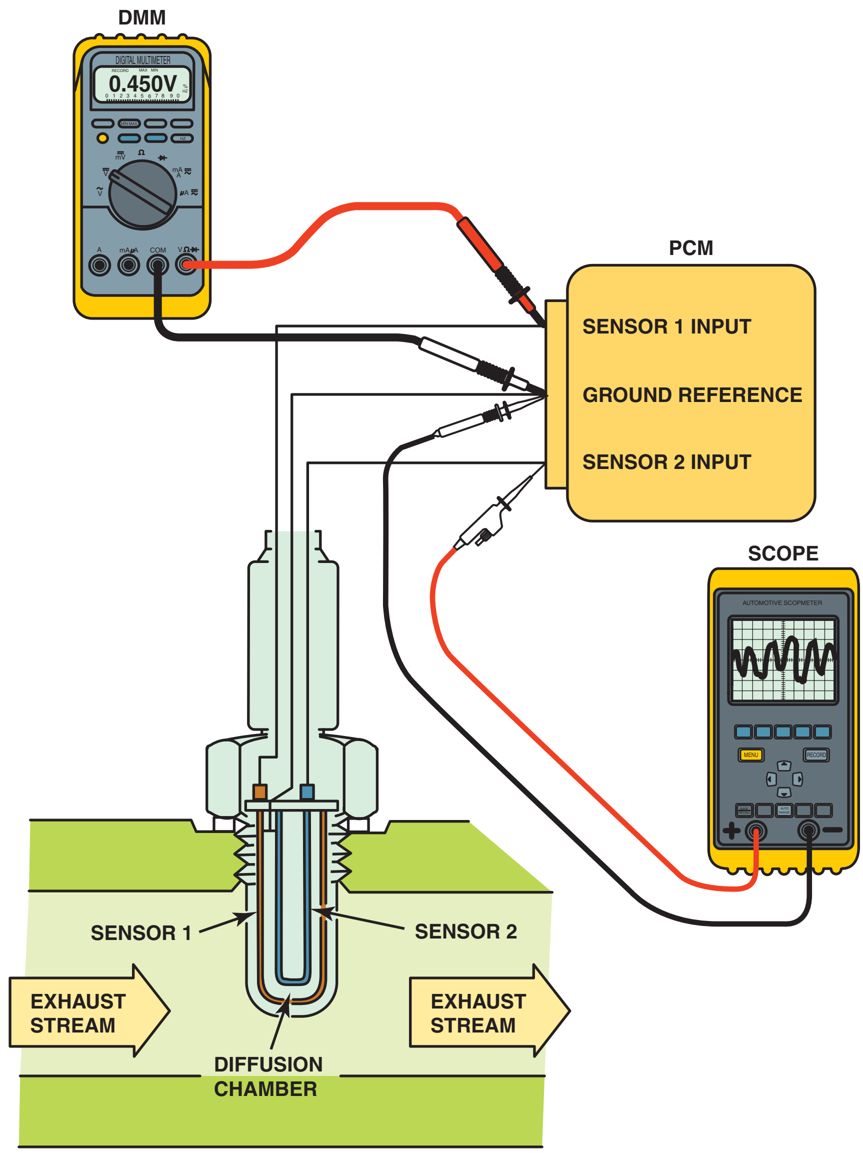


FIGURE 32–18 Testing a dual cell wide-band oxygen sensor can be done using a voltmeter or a scope. The meter reading is attached to the Nernst cell and should read stoichiometric (450 mV) at all times. The scope is showing activity to the pump cell with commands from the PCM to keep the Nernst cell at 14.7:1 air-fuel ratio.

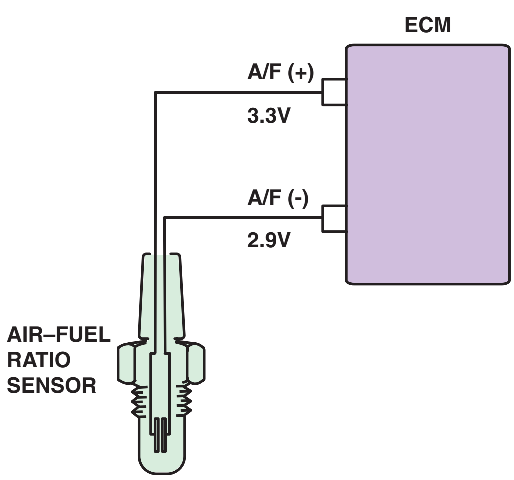


FIGURE 32–19 A single cell wide-band oxygen sensor has four wires with two for the heater and two for the sensor itself. The voltage applied to the sensor is 0.4 V (3.3 − 2.9 = 0.4) across the two leads of the sensor.

MILLIAMMETER TESTING The PCM controls the single cell wide-band oxygen sensor by maintaining a voltage difference of 300 mV (0.3 V) between the two sensor leads. The PCM keeps the voltage difference constant under all operating conditions by increasing or decreasing current between the element of the cell.

- Zero (0 mA) represents lambda or stoichiometric air-fuel ratio of 14.7:1
- +10 mA indicates a lean condition
- −10 mA indicates a rich condition

SCAN TOOL TESTING A scan tool will display a voltage reading but can vary depending on the type and maker of scan tool. ● **SEE FIGURE 32–20.**

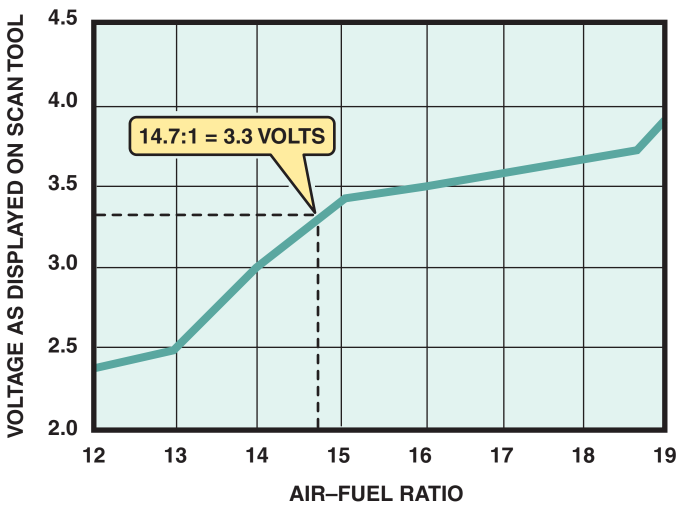


FIGURE 32–20 The scan can display various voltages but will often show 3.3 V because the PCM is controlling the sensor through applying a low current to the sensor to achieve balance.

WIDE-BAND OXYGEN PATTERN FAILURES

Wide-band oxygen sensors have a long life, but they can fail. Most of the failures will cause a diagnostic trouble code (DTC) to set, usually causing the malfunction indicator (check engine) lamp to light.

However, one type of failure may not set a DTC, such as when the following occurs.

1. Voltage from the heater circuit bleeds into the Nernst cell.
2. This voltage will cause the engine to operate extremely lean and may or may not set a diagnostic trouble code.
3. When testing indicates an extremely lean condition, unplug the connector to the oxygen sensor. If the engine starts to operate correctly with the sensor unplugged, this is confirmation that the wide-band oxygen sensor has failed and requires replacement.

OXYGEN SENSOR–RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic trouble codes (DTCs) associated with the oxygen sensor include the following:

Diagnostic Trouble Codes	Description	Possible Causes
P0131	Upstream HO2S grounded	• Exhaust leak upstream of HO2S (bank 1) • Extremely lean air-fuel mixture • HO2S defective or contaminated • HO2S signal wire shorted-to-ground
P0132	Upstream HO2S shorted	• Upstream HO2S (bank 1) shorted • Defective HO2S • Fuel-contaminated HO2S
P0133	Upstream HO2S slow response	• Open or short in heater circuit • Defective or fuel-contaminated HO2S • EGR or fuel system fault

SUMMARY

1. An oxygen sensor produces a voltage output signal based on the oxygen content of the exhaust stream.
2. If the exhaust has little oxygen, the voltage of the oxygen sensor will be close to 1 volt (1,000 mV) and close to zero if there is high oxygen content in the exhaust.
3. Oxygen sensors can have one, two, three, four, or more wires, depending on the style and design.
4. A wide-band oxygen sensor, also called a lean air-fuel (LAF) or linear air-fuel ratio sensor, can detect air-fuel ratios from as rich as 12:1 to as lean as 22:1.
5. The oxygen sensor signal determines fuel trim, which is used to tailor the air-fuel mixture for the catalytic converter.
6. Conditions can occur that cause the oxygen sensor to be fooled and give a false lean or false rich signal to the PCM.
7. Oxygen sensors can be tested using a digital meter, scope, or scan tool.

REVIEW QUESTIONS

1. How does an oxygen sensor detect oxygen levels in the exhaust?
2. What are three basic designs of oxygen sensors and how many wires may be used for each?
3. What is the difference between open-loop and closed-loop engine operation?
4. What are three ways oxygen sensors can be tested?
5. How can the oxygen sensor be fooled and provide the wrong information to the PCM?
6. What is the purpose of a wide-band oxygen sensor?

CHAPTER QUIZ

1. The voltage output of a zirconia oxygen sensor when the exhaust stream is lean (excess oxygen) is ______________.
   - **a.** Relatively high (close to 1 volt)
   - **b.** About in the middle of the voltage range
   - **c.** Relatively low (close to 0 volt)
   - **d.** Either a or b, depending on atmospheric pressure
2. A high O2S voltage could be due to a ______________.
   - **a.** Rich exhaust
   - **b.** Lean exhaust
   - **c.** Defective spark plug wire
   - **d.** Both a and c
3. A low O2S voltage could be due to a ______________.
   - **a.** Rich exhaust
   - **b.** Lean exhaust
   - **c.** Defective spark plug wire
   - **d.** Both b and c
4. An oxygen sensor is being tested with a digital multimeter (DMM), using the MIN/MAX function. The readings are: minimum = 78 mV; maximum = 932 mV; average = 442 mV. Technician A says that the engine is operating correctly. Technician B says that the oxygen sensor is skewed too rich. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. An oxygen sensor is being tested using a digital storage oscilloscope (DSO). A good oxygen sensor should display how many transitions (switches) per second?
   - **a.** 1 to 5
   - **b.** 5 to 10
   - **c.** 10 to 15
   - **d.** 15 to 20
6. A wide-band oxygen sensor was first used on a Honda in what model year?
   - **a.** 1992
   - **b.** 1996
   - **c.** 2000
   - **d.** 2006
7. A wide-band oxygen sensor is capable of detecting the air-fuel mixture in the exhaust from ______________ (rich) to ______________ (lean).
   - **a.** 12:1; 15:1
   - **b.** 13:1; 16.7:1
   - **c.** 10:1; 23:1
   - **d.** 8:1; 18:1
8. A wide-band oxygen sensor needs to be heated to what operating temperature?
   - **a.** 600°F (315°C)
   - **b.** 800°F (427°C)
   - **c.** 1,400°F (760°C)
   - **d.** 2,000°F (1,093°C)
9. A wide-band oxygen sensor heater could draw how much current (amperes)?
   - **a.** 0.8 to 2 A
   - **b.** 2 to 4 A
   - **c.** 6 to 8 A
   - **d.** 8 to 10 A
10. A P0133 DTC is being discussed. Technician A says that a defective heater circuit could be the cause. Technician B says that a contaminated sensor could be the cause. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

chapter 33 IGNITION SYSTEM OPERATION AND DIAGNOSIS

OBJECTIVES: **After studying Chapter 33, the reader should be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "B" (Ignition System Diagnosis and Repair). • Explain how ignition coils create 40,000 volts or more. • Discuss crankshaft position sensor and pickup coil operation. • Describe the operation of waste-spark and coil-on-plug ignition systems. • Describe the test procedure for the diagnosis and repair of electronic ignition (EI) systems. • Explain how to inspect and replace spark plugs. • Discuss what to inspect and look for during a visual inspection of the ignition system. • List the steps necessary to check and/or adjust ignition timing on engines equipped with a distributor-type ignition system.

KEY TERMS: Coil-on-plug (COP) ignition 460 • Companion cylinders 466 • Detonation 470 • Distributor ignition (DI) 460 • Electronic ignition (EI) 460 • EMI 460 • Firing order 465 • Hall effect 462 • ICM 461 • Ignition coil 460 • Ignition timing 480 • Ion-sensing ignition 470 • Iridium spark plugs 477 • Knock sensors 470 • Magnetic pulse generator 462 • Pickup coil 462 • Ping 470 • Platinum spark plugs 477 • Primary ignition circuit 461 • Primary winding 460 • Schmitt trigger 463 • Secondary ignition circuit 461 • Secondary winding 460 • Spark knock 470 • Spark plugs 477 • Spark tester 472 • Switching 461 • Track 475 • Transistor 462 • Trigger 462 • Turns ratio 460 • Waste-spark system 460

IGNITION SYSTEM

PURPOSE AND FUNCTION The ignition system includes components and wiring necessary to create and distribute a high voltage (up to 40,000 volts or more) and send to the spark plug. A high-voltage arc occurs across the gap of a spark plug inside the combustion chamber. The spark raises the temperature of the air-fuel mixture and starts the combustion process inside the cylinder.

BACKGROUND All ignition systems apply battery voltage (close to 12 volts) to the positive side of the ignition coil(s) and pulse the negative side to ground.

- **Early ignition systems.** Before the mid-1970s, ignition systems used a mechanically opened set of contact points to make and break the electrical connection to ground. A cam lobe, located in and driven by the distributor, opened the points. There was one lobe for each cylinder. The points used a rubbing block that was lubricated by applying a thin layer of grease on the cam lobe at each service interval. Each time the points opened, a spark was created in the ignition coil. The high-voltage spark then traveled to each spark plug through the distributor cap and rotor. The distributor was used twice in the creation of the spark, as follows:

  1. It was connected to the camshaft which rotated the distributor cam, causing the points to open and close.

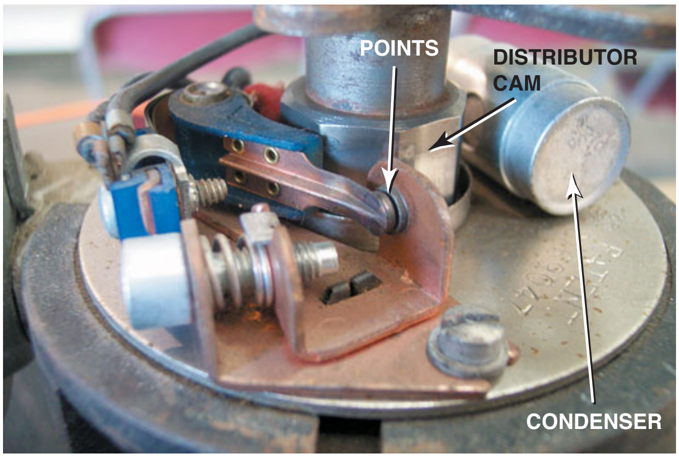


FIGURE 33–1 A point-type distributor from a hot rod.

  2. It used a rotor to send the high-voltage spark from the coil entering the center of the distributor cap to inserts connected to spark plug wires to each cylinder.

  ● **SEE FIGURE 33–1.**

- **Electronic ignition.** Since the mid-1970s, ignition systems have used sensors, such as a pickup coil and reluctor (trigger wheel), to trigger or signal an electronic module that switches the primary ground circuit of the ignition coil. **Distributor ignition (DI)** is the term specified by the Society of Automotive Engineers (SAE) for an ignition system that uses a distributor. **Electronic ignition (EI)** is the term specified by the SAE for an ignition system that does not use a distributor. Electronic ignition system types include:

1. **Waste-spark system.** This type of system uses one ignition coil to fire the spark plugs for two cylinders at the same time.
2. **Coil-on-plug (COP) system.** This type of system uses a single ignition coil for each cylinder with the coil placed above or near the spark plug.

IGNITION COIL CONSTRUCTION The heart of any ignition system is the **ignition coil.** When the coil negative lead is grounded, the primary (low-voltage) circuit of the coil is complete and a magnetic field is created around the coil windings. When the circuit is opened, the magnetic field collapses and induces a high voltage in the secondary winding of the ignition coil.

The coil creates a high-voltage spark by electromagnetic induction. Many ignition coils contain two separate but electrically connected windings of copper wire. Other coils are true transformers in which the primary and secondary windings are not electrically connected. ● **SEE FIGURE 33–2.**

The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil.

- **Secondary coil winding.** Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge). The winding is called the **secondary winding.**
- **Primary coil winding.** Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge). The winding is called the **primary winding.** The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio** (approximately 100:1).

In older coils, these windings are surrounded with a thin metal shield and insulating paper and placed into a metal container filled with transformer oil to help cool the coil windings. Other coil designs use an air-cooled, epoxy-sealed E coil. The *E coil* is so named because the laminated, soft iron core is E shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. ● **SEE FIGURES 33–3 AND 33–4.**

IGNITION COIL OPERATION All ignition systems use electromagnetic induction to produce a high-voltage spark from the ignition coil. **Electromagnetic induction (EMI)** means that a current can be created in a conductor (coil winding) by a moving magnetic field. The magnetic field in an ignition coil is produced by current flowing through the primary winding of

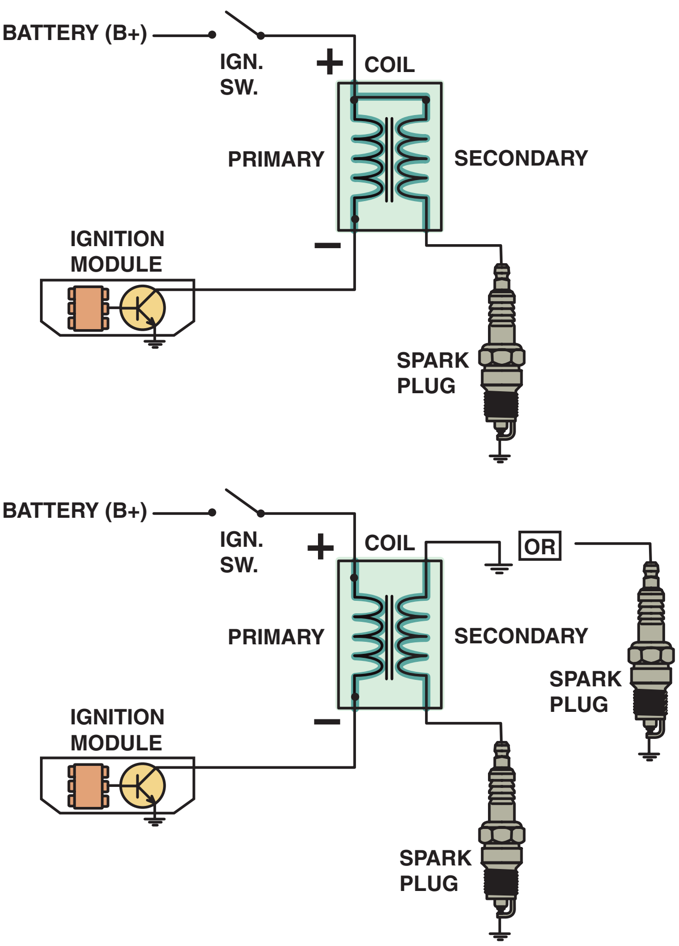


FIGURE 33–2 Some ignition coils are electrically connected, called married (top figure), whereas others use separate primary and secondary windings, called divorced (lower figure). The polarity (positive or negative) of a coil is determined by the direction in which the coil is wound.

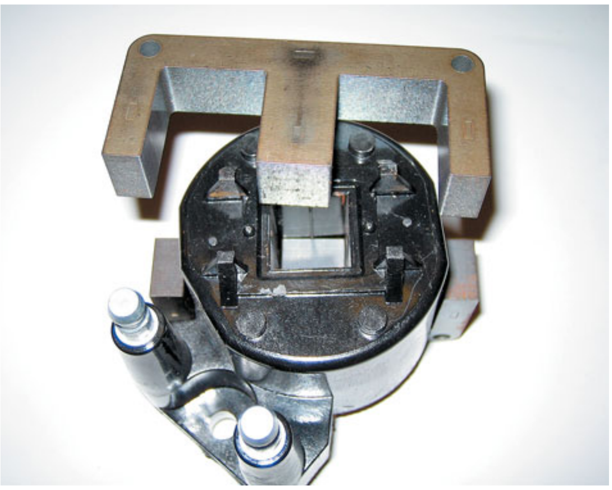


FIGURE 33–3 The steel lamination used in an E coil helps increase the magnetic field strength, which helps the coil produce higher energy output for a more complete combustion in the cylinders.

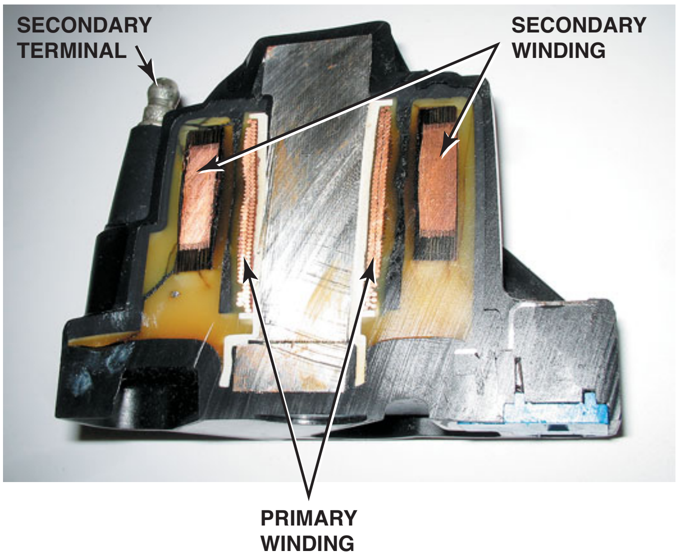


FIGURE 33–4 The primary windings are inside the secondary windings on this General Motors coil.

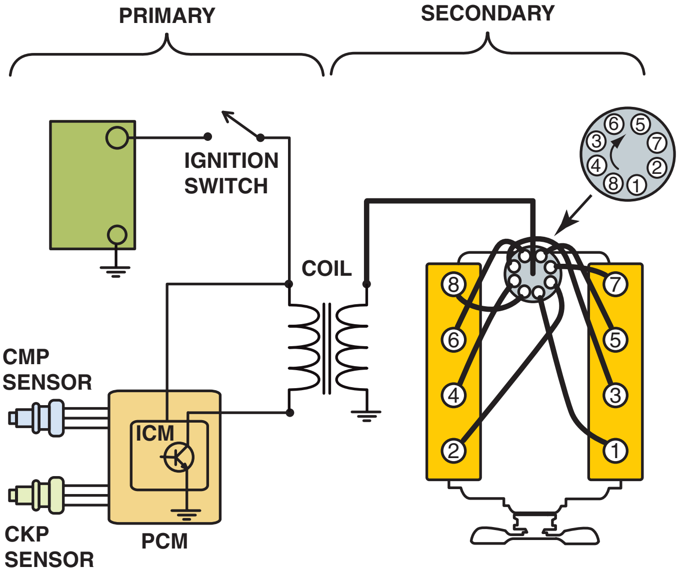


FIGURE 33–5 The primary ignition system is used to trigger and therefore create the secondary (high-voltage) spark from the ignition coil.

the coil. An ignition coil is able to increase battery voltage to 40,000 volts or more in the following way.

- Battery voltage is applied to the primary winding.
- A ground is provided to the primary winding by the **ignition control module (ICM),** igniter, or PCM.
- Current (approximately 2 to 6 amperes) flows in the primary coil creating a magnetic field.
- When the ground is opened by the ICM, the built-up magnetic field collapses.
- The movement of the collapsing magnetic field induces a voltage of 250 to 400 volts in the primary winding and 20,000 to 40,000 volts or more in the secondary winding with a current of 0.020 to 0.080 ampere.
- The high voltage created in the secondary winding is high enough to jump the air gap at the spark plug.
- The electrical arc at the spark plug ignites the air-fuel mixture in the combustion chamber of the engine.
- For each spark that occurs, the coil must be charged with a magnetic field and then discharged.

WARNING

The spark from an ignition coil is strong enough to cause physical injury. Always follow the exact service procedure and avoid placing hands near the secondary ignition components when the engine is running.

The ignition components that regulate the current in the coil primary winding by turning it on and off are known collectively as the **primary ignition circuit.** When the primary circuit is carrying current, the secondary circuit is off. When the primary circuit is turned off, the secondary circuit has high voltage. The components necessary to create and distribute the high voltage produced in the secondary windings of the coil are called the **secondary ignition circuit.** ● **SEE FIGURE 33–5.**

These circuits include the following components.

- Primary ignition circuit
  1. Battery
  2. Ignition switch
  3. Primary windings of coil
  4. Pickup coil (crankshaft position sensor)
  5. Ignition control module (igniter)
- Secondary ignition circuit
  1. Secondary windings of coil
  2. Distributor cap and rotor (if the vehicle is so equipped)
  3. Spark plug wires
  4. Spark plugs

IGNITION SWITCHING AND TRIGGERING

SWITCHING For any ignition system to function, the primary current must be turned on to charge the coil and off to allow the coil to discharge, creating a high-voltage spark. This turning on and off of the primary circuit is called **switching.** The unit that does

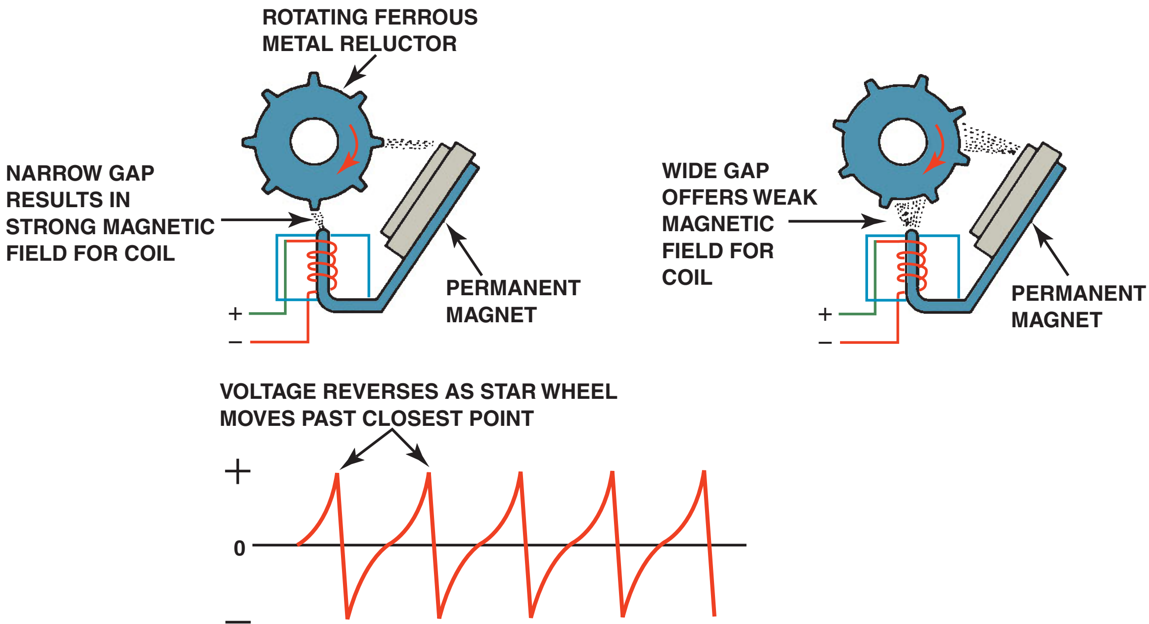


FIGURE 33–6 Operation of a typical pulse generator (pickup coil). At the bottom is a line drawing of a typical scope pattern of the output voltage of a pickup coil. The module receives this voltage from the pickup coil and opens the ground circuit to the ignition coil when the voltage starts down from its peak (just as the reluctor teeth start moving away from the pickup coil).

the switching is an electronic switch, such as a power transistor. This power transistor can be found in the following locations.

- Ignition control module (ICM) or igniter
- PCM (computer)

NOTE: On some coil-on-plug systems, the ICM is part of the ignition coil itself and is serviced as an assembly.

TRIGGERING The device that signals the switching of the coil on and off or just on in most instances is called the **trigger.** A trigger is typically a pickup coil in some distributor-type ignitions and a crankshaft position sensor (CKP) on electronic systems (waste spark and coil on plug). There are three types of devices used for triggering.

1. Magnetic sensor
2. Hall-effect switch
3. Optical sensor

PRIMARY CIRCUIT OPERATION To get a spark out of an ignition coil, the primary coil circuit must be turned on and off. The primary circuit current switching is controlled by a **transistor** (electronic switch) inside the ignition module (or igniter) and is controlled by one of several devices, including:

- **Magnetic sensor.** A simple and common ignition electronic switching device is the magnetic pulse generator system. This is a type of magnetic sensor, often called a **magnetic pulse generator** or **pickup coil,** and is installed in the distributor housing. The pulse generator consists of a trigger wheel (reluctor) and a pickup coil. The pickup coil consists of an iron core wrapped with fine wire, in a coil at one end and attached to a permanent magnet at the other end. The center of the coil is called the pole piece. The pickup coil signal triggers the transistor inside the module and is also used by the PCM for piston position information and engine speed (RPM). The reluctor is shaped so that the magnetic strength changes enough to create a usable varying signal for use by the module to trigger the coil. ● **SEE FIGURE 33–6.**

  Magnetic crankshaft position sensors use the changing strength of the magnetic field surrounding a coil of wire to signal the module and computer. This signal is used by the electronics in the module and computer to determine piston position and engine speed (RPM). This sensor operates similarly to the distributor magnetic pickup coil. The crankshaft position sensor uses the strength of the magnetic field surrounding a coil of wire to signal the ICM. The rotating crankshaft has notches cut into it that trigger the magnetic position sensor, which change the strength of the magnetic field as the notches pass by the position sensor. ● **SEE FIGURE 33–7.**
- **Hall-effect switch.** This switch also uses a stationary sensor and rotating trigger wheel (shutter). Unlike the magnetic pulse generator, the Hall-effect switch requires a small input voltage to generate an output or signal voltage. **Hall effect** has the ability to generate a voltage signal in semiconductor material (gallium arsenate crystal) by passing current through it in one direction and applying a magnetic field to it at a right angle to its surface. If the input current is held steady and the magnetic field fluctuates, an output voltage is produced that changes in proportion to field strength. Most Hall-effect switches in distributors have the following:

  1. Hall element or device
  2. Permanent magnet
  3. Rotating ring of metal blades (shutters) similar to a trigger wheel (Another method uses a stationary sensor with a rotating magnet.) ● **SEE FIGURE 33–8.**

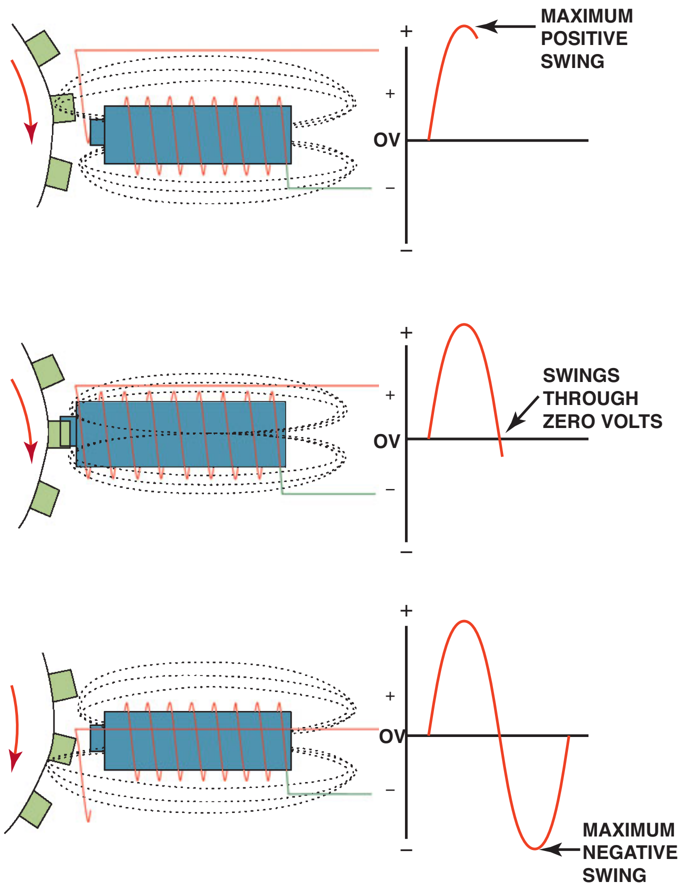


FIGURE 33–7 A magnetic sensor uses a permanent magnet surrounded by a coil of wire. The notches of the crankshaft (or camshaft) create a variable magnetic field strength around the coil. When a metallic section is close to the sensor, the magnetic field is stronger because metal is a better conductor of magnetic lines of force than air.

Some blades are designed to hang down, typically found in Bosch and Chrysler systems, while others may be on a separate ring on the distributor shaft, typically found in General Motors and Ford Hall-effect distributors. There are two types of Hall effect sensors used including:

1. When the shutter blade enters the gap between the magnet and the Hall element, it creates a magnetic shunt that changes the field strength through the Hall element.
2. This analog signal is sent to a **Schmitt trigger** inside the sensor itself, which converts the analog signal into a digital signal. A digital (on or off) voltage signal is created at a varying frequency to the ignition module or onboard computer. ● **SEE FIGURE 33–9.**

- **Optical sensors.** These use light from an LED and a phototransistor to signal the computer. An interrupter disc between the LED and the phototransistor has slits that allow the light from the LED to trigger the phototransistor on the other side of the disc. Most optical sensors (usually located inside the distributor) use two rows of slits to provide individual cylinder recognition (low resolution) and precise distributor angle recognition (high resolution) signals that are used for cylinder misfire detection. ● **SEE FIGURE 33–10.**

TECH TIP

Optical Distributors Do Not Like Light

Optical distributors use the light emitted from LEDs to trigger phototransistors. Most optical distributors use a shield between the distributor rotor and the optical interrupter ring. Sparks jump the gap from the rotor tip to the distributor cap inserts. This shield blocks the light from the electrical arc from interfering with the detection of the light from the LEDs.

If this shield is not replaced during service, the light signals are reduced and the engine may not operate correctly. ● **SEE FIGURE 33–11.**

This can be difficult to detect because nothing looks wrong during a visual inspection. Remember that all optical distributors must be shielded between the rotor and the interrupter ring.

TECH TIP

The Tachometer Trick

When diagnosing a no-start or intermediate missing condition, check the operation of the tachometer. If the tachometer does not indicate engine speed (no-start condition) or drops toward zero (engine missing), then the problem is due to a defect in the *primary* ignition circuit. The tachometer gets its signal from the pulsing of the primary winding of the ignition coil. The following components in the primary circuit could cause the tachometer to not work when the engine is cranking.

- Pickup coil
- Crankshaft position sensor
- Ignition module (igniter)
- Coil primary wiring

If the vehicle is not equipped with a tachometer, use a scan tool to look at engine RPM. The results are as follows:

- No or an unstable engine RPM reading means the problem is in the primary ignition circuit.
- A steady engine RPM reading means the problem is in the secondary ignition circuit or is a fuel-related problem.

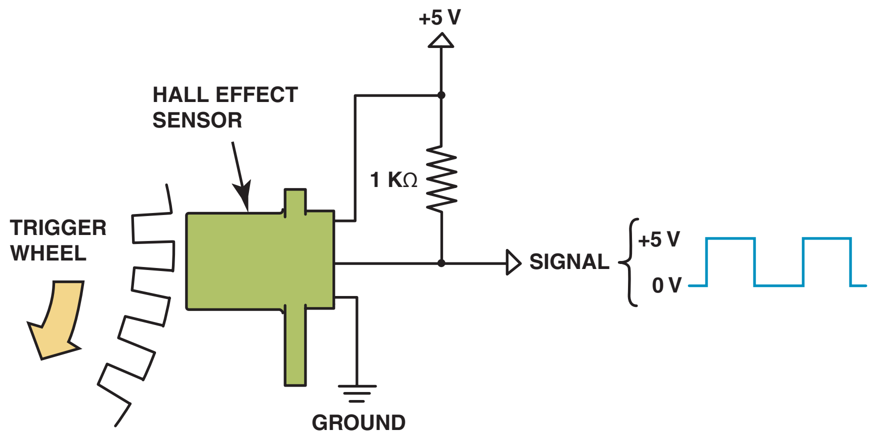


FIGURE 33–8 A Hall-effect sensor produces a digital on-off voltage signal whether it is used with a blade or a notched wheel.

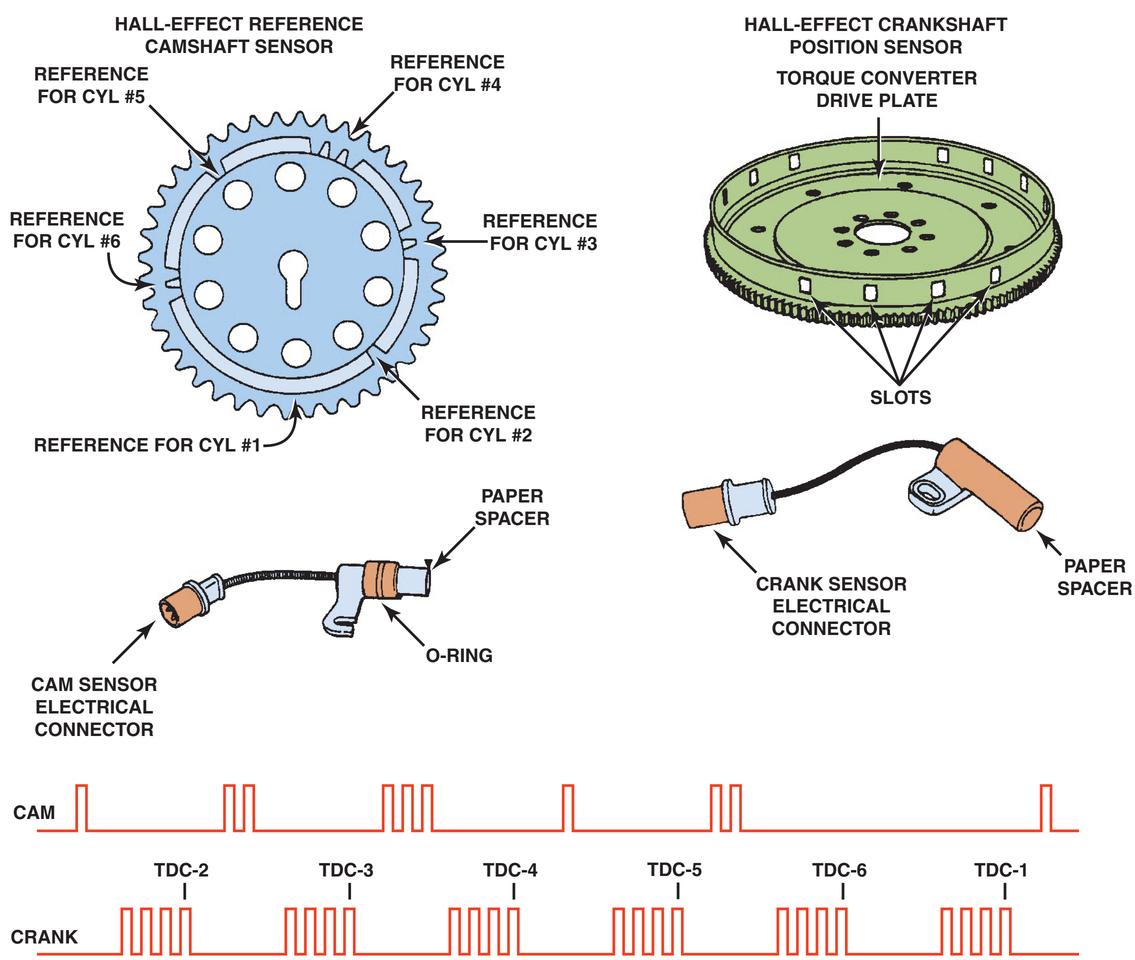


FIGURE 33–9 Some Hall-effect sensors look like magnetic sensors. This Hall-effect camshaft reference sensor and crankshaft position sensor have an electronic circuit built in that creates a 0 to 5 volt signal as shown at the bottom. These Hall-effect sensors have three wires: a power supply (8 volts) from the computer (controller), a signal (0 to 5 volts), and a signal ground.

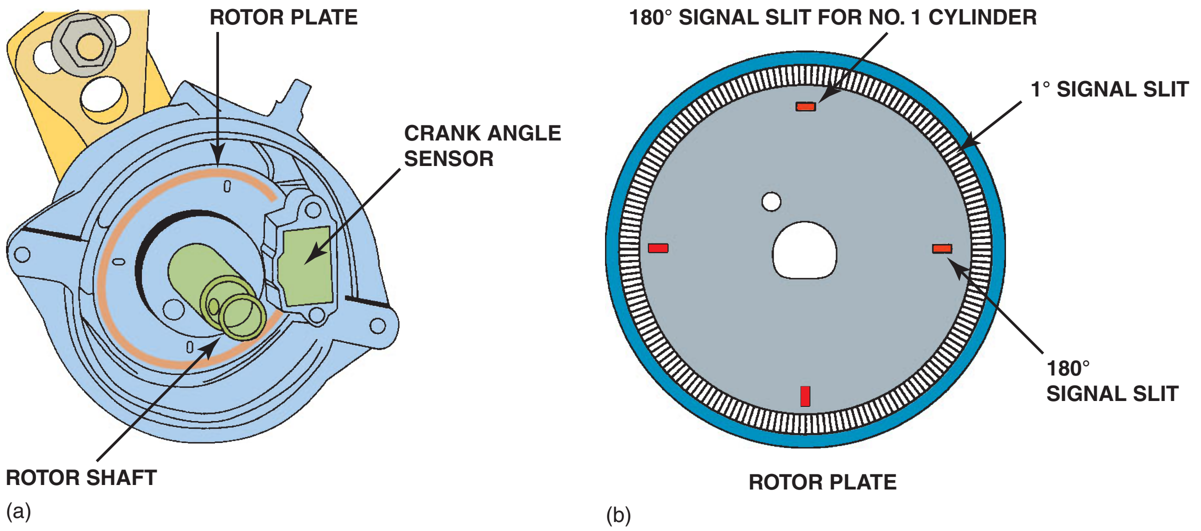


FIGURE 33–10 (a) Typical optical distributor. (b) Cylinder I slit signals the computer the piston position for cylinder I. The 1-degree slits provide accurate engine speed information to the PCM.

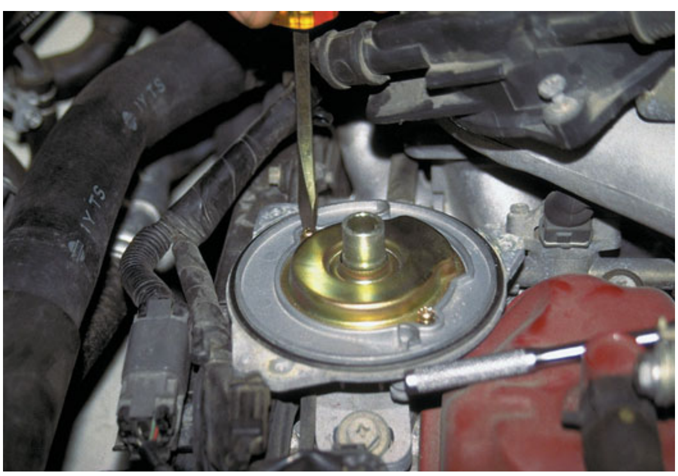


FIGURE 33–11 A light shield being installed before the rotor is attached.

FIGURE 33–12 The firing order is cast or stamped on the intake manifold on most engines that have a distributor ignition.

DISTRIBUTOR IGNITION (DI)

PURPOSE AND FUNCTION The purpose of a distributor is to distribute the high-voltage spark from the output terminal of the ignition coil to the spark plugs for each cylinder. A gear or shaft drives the distributor that is connected to the camshaft and is driven at camshaft speed. Most distributor ignition systems also use a sensor to trigger the ignition control module.

OPERATION OF DISTRIBUTOR IGNITION The distributor is used twice in most ignition systems that use a distributor.

- First, to trigger the ignition control module by the use of the rotating distributor shaft
- Second, by rotating the rotor to distribute the high-voltage spark to the individual spark plugs

FIRING ORDER **Firing order** means the order that the spark is distributed to the correct spark plug at the right time. The firing order of an engine is determined by crankshaft and camshaft design. The firing order is determined by the location of the spark plug wires in the distributor cap of an engine equipped with a distributor. The firing order is often cast into the intake manifold for easy reference. ● **SEE FIGURE 33–12.**

Service information also shows the firing order and the direction of the distributor rotor rotation, as well as the location of the spark plug wires on the distributor cap.

CAUTION: Ford V-8s use two different firing orders depending on whether the engine is high output (HO) or standard. Using the incorrect firing order can cause the engine to backfire and could cause engine damage or personal injury. General Motors V-6 engines use different firing orders and different locations for cylinder 1 between the 60-degree V-6 and the 90-degree V-6. Using the incorrect firing order or cylinder number location chart could result in poor engine operation or a no start. Firing order is also important for waste-spark-type ignition systems. The spark plug wire can often be installed on the wrong coil pack, which can create a no-start condition or poor engine operation.

WASTE-SPARK IGNITION SYSTEMS

PARTS INVOLVED Waste-spark ignition is another name for distributorless ignition system (DIS) or electronic ignition (EI). Waste-spark ignition was introduced in the mid-1980s and uses the ignition control module (ICM) and/or the powertrain control module (PCM) to fire the ignition coils. A 4-cylinder engine uses two ignition coils and a 6-cylinder engine uses three ignition coils. Each coil is a true transformer because the primary winding and secondary winding are not electrically connected. Each end of the secondary winding is connected to a cylinder exactly opposite the other in the firing order, which is called a **companion** (paired) **cylinder.** ● **SEE FIGURE 33–13.**

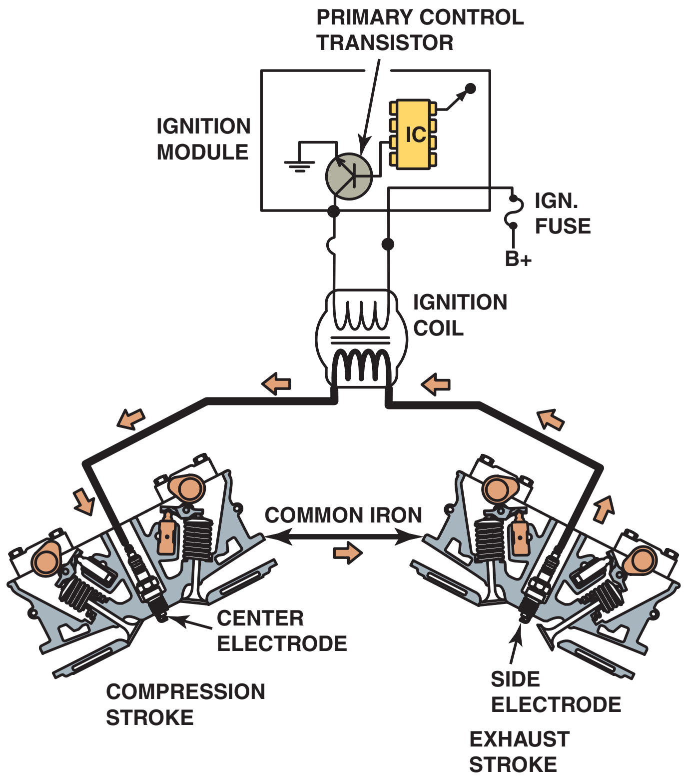


FIGURE 33–13 A waste-spark system fires one cylinder while its piston is on the compression stroke and into paired or companion cylinders while it is on the exhaust stroke. In a typical engine, it requires only about 2 to 3 kV to fire the cylinder on the exhaust stroke. The remaining coil energy is available to fire the spark plug under compression (typically about 8 to 12 kV).

FREQUENTLY ASKED QUESTION

How Can You Determine the Companion Cylinder?

Companion cylinders are two cylinders in the same engine that both reach top dead center (TDC) at the same time.

- One cylinder is on the compression stroke.
- The other cylinder is on the exhaust stroke.

To determine which two cylinders are companion cylinders in the engine, follow these steps.

STEP 1 Determine the firing order (such as 165432 for a typical V-6 engine).

STEP 2 Write the firing order and then place the second half under the first half.

$$\frac{165}{432}$$

STEP 3 The cylinder numbers above and below each other are companion or paired cylinders.

In this case 1 and 4, 6 and 3, and 5 and 2 are companion cylinders.

TECH TIP

Odds Fire Straight

Waste-spark ignition systems fire two spark plugs at the same time. Most vehicle manufacturers use a waste-spark system that fires the odd number cylinders (1, 3, and 5) by straight polarity (current flow from the top of the spark plug through the gap and to the ground electrode). The even number cylinders (2, 4, and 6) are fired reverse polarity, meaning that the spark jumps from the side electrode to the center electrode. Some vehicle manufacturers equip their vehicles with platinum plugs that have the expensive platinum alloy on only one electrode, as follows:

- On odd number cylinders (1, 3, 5), the platinum is on the center electrode.
- On even number cylinders (2, 4, 6), the platinum is on the ground electrode.

Replacement spark plugs use platinum on both electrodes (double platinum) and, therefore, can be placed in any cylinder location.

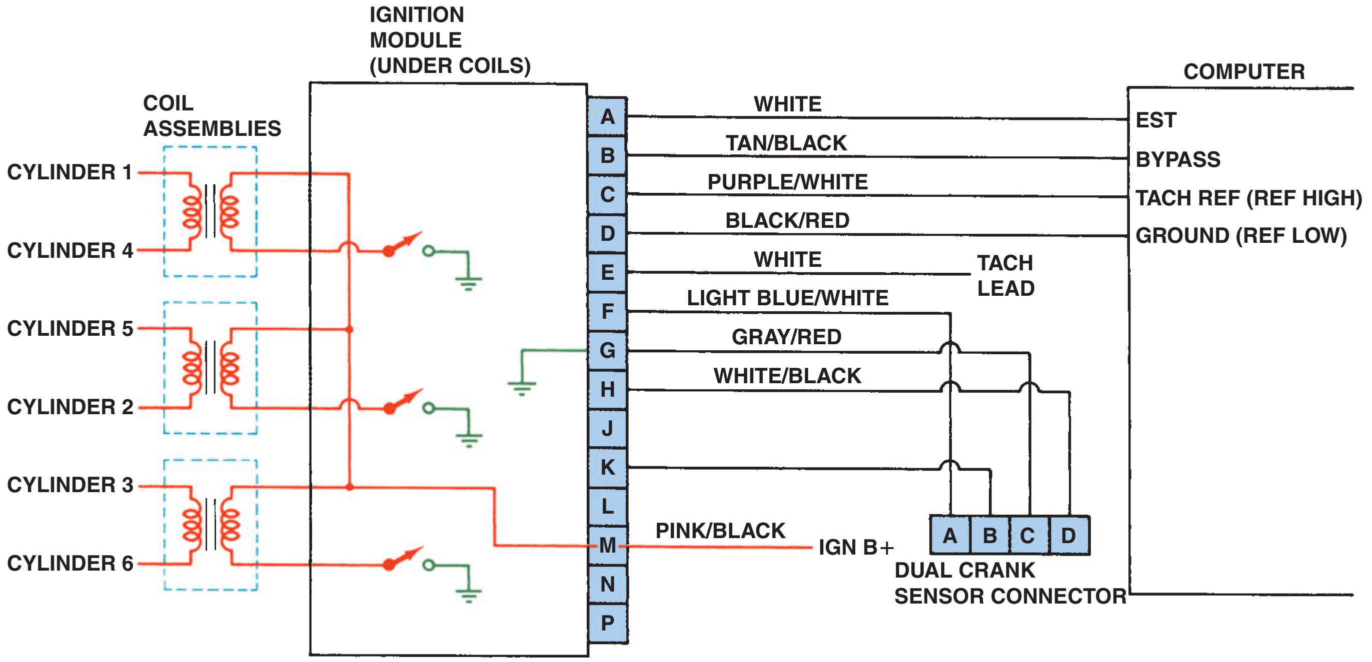


FIGURE 33–14 Typical wiring diagram of a GM V-6 waste-spark ignition system.

WASTE-SPARK SYSTEM OPERATION *Both* spark plugs fire at the same time (within nanoseconds of each other).

- When one cylinder (for example, cylinder number 6) is on the compression stroke, the other cylinder (number 3) is on the exhaust stroke.
- The spark that occurs on the exhaust stroke is called the *waste spark,* because it does no useful work and is only used as a ground path for the secondary winding of the ignition coil. The voltage required to jump the spark plug gap on cylinder 3 (the exhaust stroke) is only 2 to 3 kV.
- The cylinder on the compression stroke uses the remaining coil energy.
- One spark plug of each pair always fires straight polarity and the other cylinder always fires reverse polarity. Spark plug life is not greatly affected by the reverse polarity. If there is only one defective spark plug wire or spark plug, two cylinders may be affected.

The coil polarity is determined by the direction the coil is wound (left-hand rule for conventional current flow) and cannot be changed.

Each spark plug for a particular cylinder always will be fired either with straight or reversed polarity, depending on its location in the engine and how the coils are wired. However, the compression and waste-spark condition flip-flops. When one cylinder is on compression, such as cylinder 1, then the paired cylinder (number 4) is on the exhaust stroke. During the next rotation of the crankshaft, cylinder 4 is on the compression stroke and cylinder 1 is on the exhaust stroke.

Cylinder 1 Always fires straight polarity (from the center electrode to the ground electrode), one time, requiring 10 to 12 kV, and one time, requiring 3 to 4 kV.

Cylinder 4 Always fires reverse polarity (from the ground electrode to the center electrode), one time, requiring 10 to 12 kV, and one time, requiring 3 to 4 kV.

Waste-spark ignitions require a sensor (usually a crankshaft sensor) to trigger the coils at the correct time. ● **SEE FIGURE 33–14.**

The crankshaft sensor cannot be moved to adjust ignition timing, because ignition timing is not adjustable. The slight adjustment of the crankshaft sensor is designed to position the sensor exactly in the middle of the rotating metal disc for maximum clearance.

COMPRESSION-SENSING WASTE-SPARK IGNITION

Some waste-spark ignition systems, such as those used on Saturns and others, use the voltage required to fire the cylinders to determine cylinder position. It requires a higher voltage to fire a spark plug under compression than it does when the spark plug is being fired on the exhaust stroke. The electronics in the coil and the PCM can detect which of the two companion (paired) cylinders that are fired at the same time requires the higher voltage, and therefore indicates the cylinder that is on the compression stroke. For example, a typical 4-cylinder engine equipped with a waste-spark ignition system will fire both cylinders 1 and 4. If cylinder 4 requires a higher voltage to fire, as determined by the electronics connected to the coil,

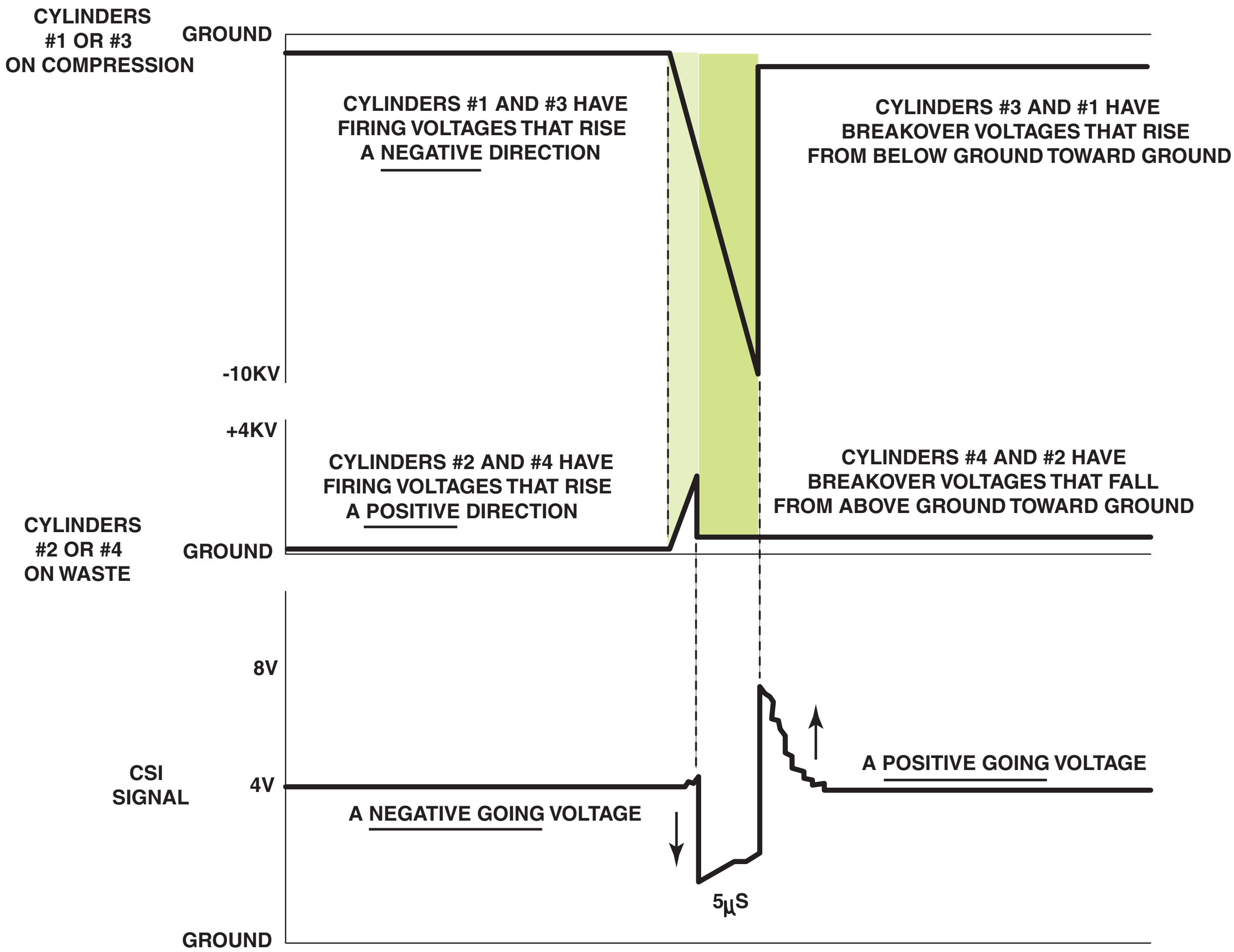


FIGURE 33–15 The slight (5 microsecond) difference in the firing of the companion cylinders is enough time to allow the PCM to determine which cylinder is firing on the compression stroke.

then the PCM assumes that cylinder 4 is on the compression stroke. Engines equipped with compression-sensing ignition systems do not require the use of a camshaft position sensor to determine specific cylinder numbers. ● **SEE FIGURE 33–15.**

COIL-ON-PLUG IGNITION

TERMINOLOGY Coil-on-plug (COP) ignition uses one ignition coil for each spark plug. This system is also called *coil-by-plug, coil-near-plug,* or *coil-over-plug ignition.* ● **SEE FIGURES 33–16 AND 33–17.**

ADVANTAGES The coil-on-plug system eliminates the spark plug wires that are often the source of electromagnetic interference (EMI) that can cause problems to some computer signals. The vehicle computer controls the timing of the spark. Ignition timing also can be changed (retarded or advanced) on a cylinder-by-cylinder basis for maximum performance and to respond to knock sensor signals.

TYPES OF COP SYSTEMS There are two basic types of coil-on-plug ignition systems.

- **Two primary wires.** This design uses the vehicle computer to control the firing of the ignition coil. The two wires include the ignition voltage feed and the pulse ground wire, which is controlled by the computer. The ignition control module is located in the PCM, which handles all ignition timing and coil on-time control.
- **Three primary wires.** This design includes an ignition module at each coil. The three wires include:
  - Ignition voltage
  - Ground
  - Pulse from the computer to the built-in ignition module

Vehicles use a variety of coil-on-plug-type ignition systems, including:

- Many General Motors V-8 engines use a coil-near-plug system with individual coils and modules for each individual cylinder that are placed on the valve covers. Short secondary ignition spark plug wires are used to connect the output terminal of the ignition coil to the

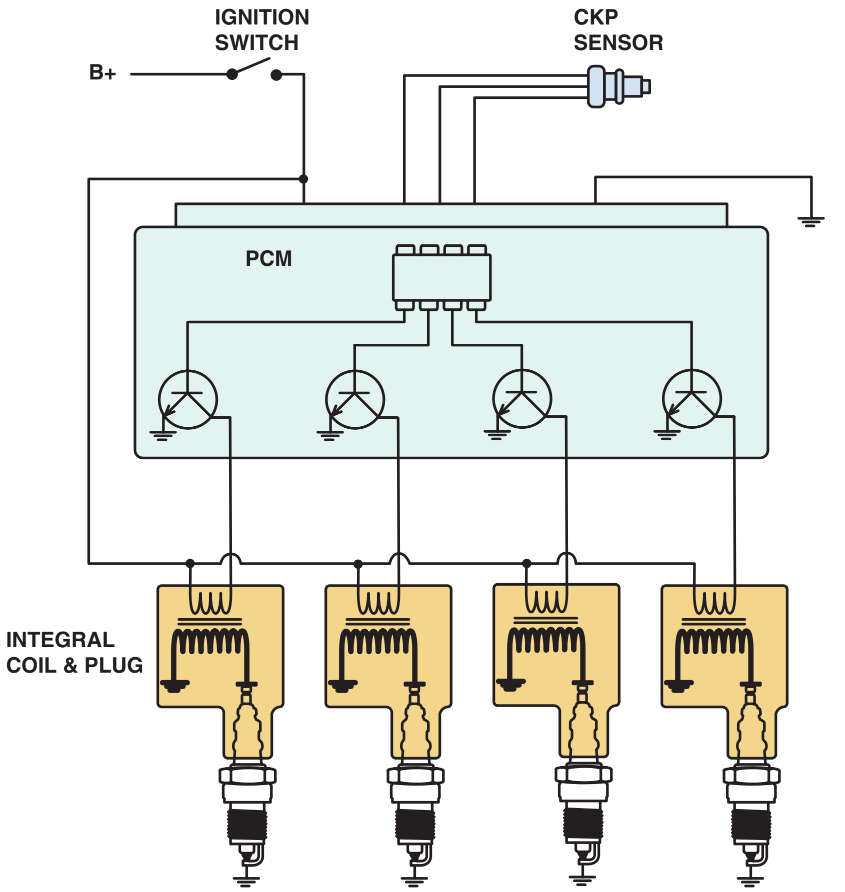


FIGURE 33–16 A typical two wire coil-on-plug ignition system showing the triggering and the switching being performed by the PCM from input from the crankshaft position sensor.

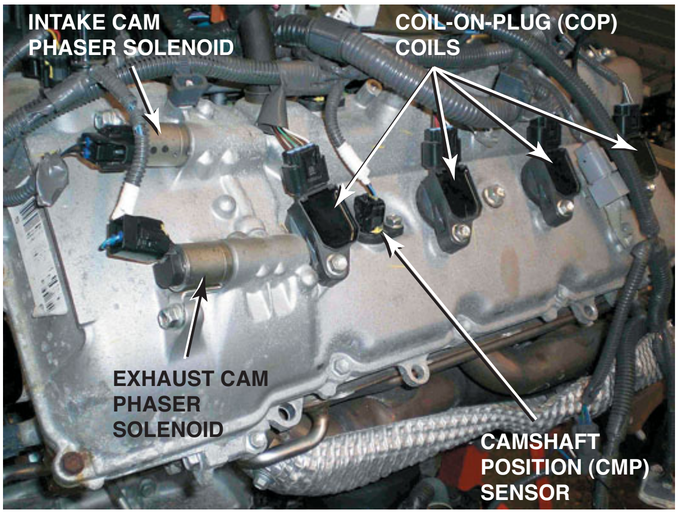


FIGURE 33–17 An overhead camshaft engine equipped with variable valve timing on both the intake and exhaust camshafts and coil-on-plug ignition.

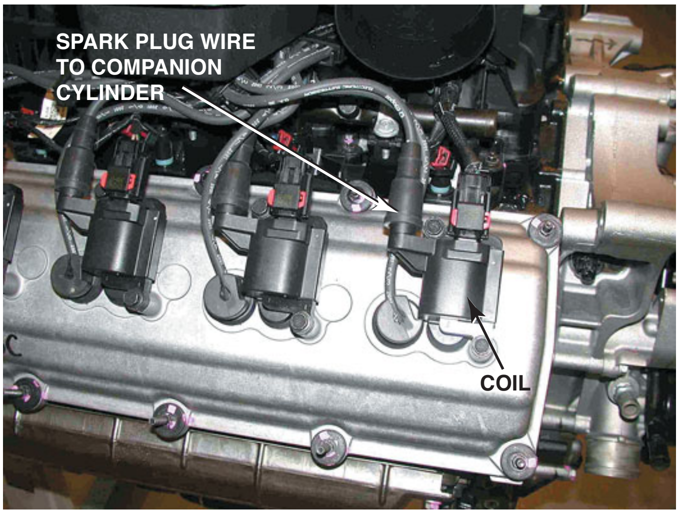


FIGURE 33–18 A Chrysler Hemi V-8 that has two spark plugs per cylinder. The coil on top of one spark fires that plug plus, through a spark plug wire, fires a plug in the companion cylinder.

spark plug; and therefore this system is called a *coil-near-plug* system.

- In a combination of coil-on-plug and waste-spark systems, the systems fire a spark plug attached to the coil plus use a spark plug wire attached to the other secondary terminal of the coil to fire another spark plug of the companion cylinder. This type of system is used in some Chrysler Hemi V-8 and Toyota V-6 engines. ● **SEE FIGURE 33–18.**

Most new engines use coil-over-plug-type ignition systems. Each coil is controlled by the PCM, which can vary the

SAFETY TIP

Never Disconnect a Spark Plug Wire When the Engine Is Running!

Ignition systems produce a high-voltage pulse necessary to ignite a lean air-fuel mixture. If you disconnect a spark plug wire when the engine is running, this high-voltage spark could cause personal injury or damage to the ignition coil and/or ignition module.

ignition timing separately for each cylinder based on signals the PCM receives from the knock sensor(s). For example, if the knock sensor detects that a spark knock has occurred after firing cylinder 3, then the PCM will continue to monitor cylinder 3 and retard timing on just this one cylinder if necessary to prevent engine-damaging detonation.

ION-SENSING IGNITION In an **ion-sensing ignition** system, the spark plug itself becomes a sensor. An ion-sensing ignition uses a coil-on-plug design where the ignition control module (ICM) applies a DC voltage across the spark plug gap *after* the ignition event to sense the ionized gases (called plasma) inside the cylinder. Ion-sensing ignition is used in the General Motors EcoTec 4-cylinder engines. ● **SEE FIGURE 33–19.**

The secondary coil discharge voltage (10 to 15 kV) is electrically isolated from the ion-sensing circuit. The combustion flame is ionized and will conduct some electricity, which can be accurately measured at the spark plug gap. The purpose of this circuit includes:

- Misfire detection (required by OBD-II regulations)
- Knock detection (eliminates the need for a knock sensor)
- Ignition timing control (to achieve the best spark timing for maximum power with lowest exhaust emissions)
- Exhaust gas recirculation (EGR) control
- Air-fuel ratio control on an individual cylinder basis

Ion-sensing ignition systems still function the same as conventional coil-on-plug designs, but the engine does not need to be equipped with a camshaft position sensor for misfire detection, or a knock sensor, because both of these faults are achieved using the electronics inside the ignition control circuits.

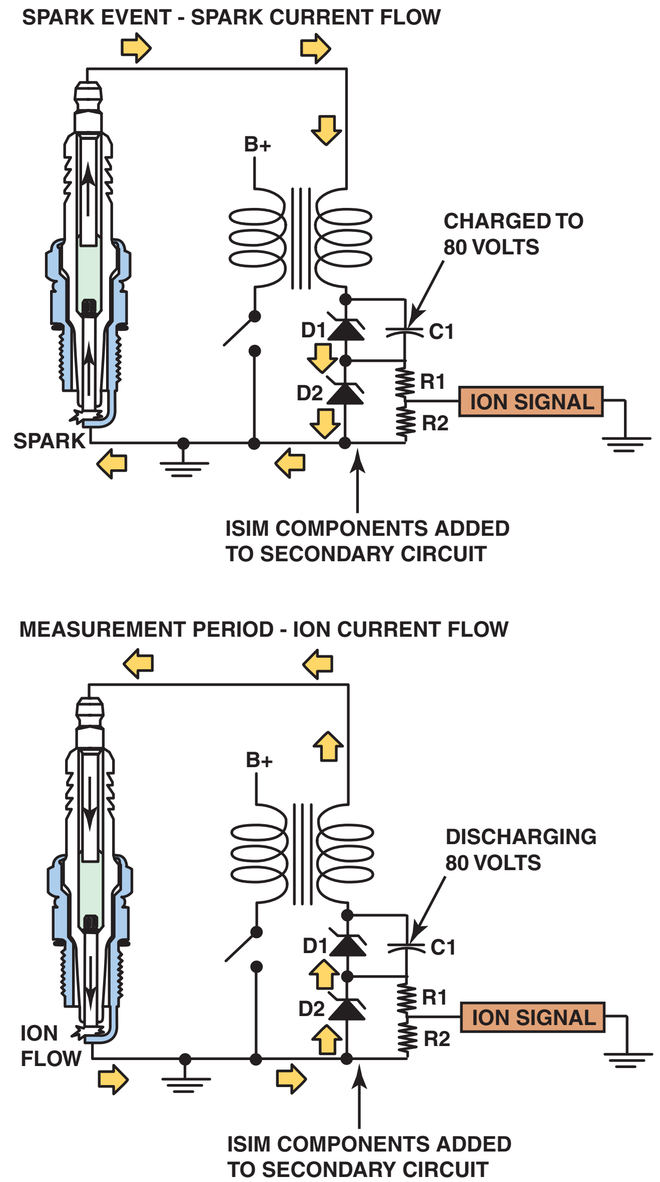


FIGURE 33–19 A DC voltage is applied across the spark plug gap after the plug fires and the circuit can determine if the correct air-fuel ratio was present in the cylinder and if knock occurred. The applied voltage for ion-sensing does not jump the spark plug gap, but determines the conductivity of the ionized gases left over from the combustion process.

KNOCK SENSORS

PURPOSE AND FUNCTION **Knock sensors** are used to detect abnormal combustion, often called **ping, spark knock,** or **detonation.** Whenever abnormal combustion occurs, a rapid pressure increase occurs in the cylinder, creating a vibration in the engine block. It is this vibration that is detected by the knock sensor. The signal from the knock sensor is used by the PCM to retard the ignition timing until the knock is eliminated, thereby reducing the damaging effects of the abnormal combustion on pistons and other engine parts.

Inside the knock sensor is a piezoelectric element that is a type of crystal that produces a voltage when pressure or a vibration is applied to the unit. The knock sensor is tuned to the engine knock frequency, which is a range from

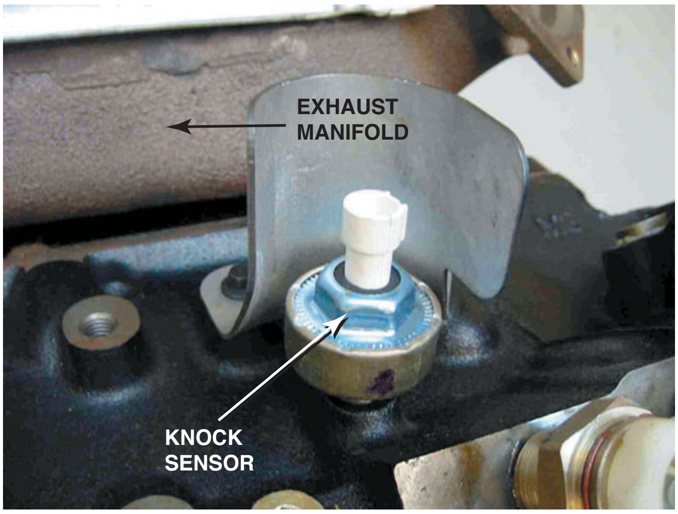


FIGURE 33–20 A typical knock sensor on the side of the block. Some are located in the "V" of a V-type engine and are not noticeable until the intake manifold has been removed.

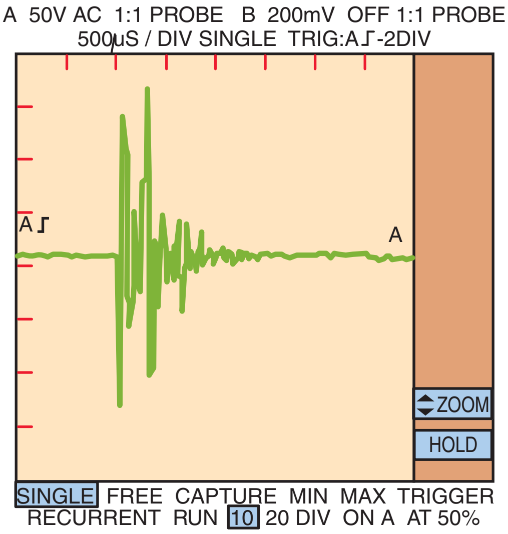


FIGURE 33–21 A typical waveform from a knock sensor during a spark knock event. This signal is sent to the computer which in turn retards the ignition timing. This timing retard is accomplished by an output command from the computer to either a spark advance control unit or directly to the ignition module.

5 to 10 kHz, depending on the engine design. The voltage signal from the knock sensor is sent to the PCM. The PCM retards the ignition timing until the knocking stops. ● **SEE FIGURE 33–20.**

DIAGNOSING THE KNOCK SENSOR If a knock sensor diagnostic trouble code (DTC) is present, follow the specified testing procedure in the service information. A scan tool can be used to check the operation of the knock sensor, using the following procedure.

STEP 1 Start the engine and connect a scan tool to monitor ignition timing and/or knock sensor activity.

STEP 2 Create a simulated engine knocking sound by tapping on the engine block or cylinder head with a soft faced mallet.

STEP 3 Observe the scan tool display. The vibration from the tapping should have been interpreted by the knock sensor as a knock, resulting in a knock sensor signal and a reduction in the spark advance.

A knock sensor also can be tested using a digital storage oscilloscope. ● **SEE FIGURE 33–21.**

NOTE: Some engine computers are programmed to ignore knock sensor signals when the engine is at idle speed to avoid having the noise from a loose accessory drive belt, or other accessory, interpreted as engine knock. Always follow the vehicle manufacturer's recommended testing procedure.

REPLACING A KNOCK SENSOR If replacing a knock sensor, be sure to purchase the exact replacement needed, because they often look the same, but the frequency range can vary according to engine design and location on the engine. Always tighten the knock sensor using a torque wrench and tighten to the specified torque to avoid causing damage to the piezoelectric element inside the sensor.

REAL WORLD FIX

The Low Power Toyota

A technician talked about the driver of a Toyota who complained about poor performance and low fuel economy. The technician checked everything, and even replaced all secondary ignition components. Then the technician connected a scan tool and noticed that the knock sensor was commanding the timing to be retarded. Careful visual inspection revealed a "chunk" missing from the serpentine belt which caused a "noise" similar to a spark knock. Apparently the knock sensor was "hearing" the accessory drive belt noise and kept retarding the ignition timing. After replacing the accessory drive belt, a test drive confirmed that normal engine power was restored.

Other items that can fool the knock sensor to retard the ignition timing include:

- Loose valve lifter adjustment
- Engine knocks
- Loose accessory brackets such as air-conditioning compressor, power steering pumps, or alternator

FIGURE 33–22 A spark tester looks like a regular spark plug with an alligator clip attached to the shell. This tester has a specified gap that requires at least 25,000 volts (25 kV) to fire.

FIGURE 33–23 A close-up showing the recessed center electrode on a spark tester. It is recessed 3/8 in. into the shell and the spark must then jump another 3/8 in. to the shell for a total gap of 3/4 in.

IGNITION SYSTEM DIAGNOSIS

CHECKING FOR SPARK In the event of a no-start condition, the first step should be to check for secondary voltage out of the ignition coil or to the spark plugs. If the engine is equipped with a separate ignition coil, remove the coil wire from the center of the distributor cap, install a **spark tester,** and crank the engine. See the Tech Tip, "Always Use a Spark Tester." A good coil and ignition system should produce a blue spark at the spark tester. ● **SEE FIGURES 33–22 AND 33–23.**

If the ignition system being tested does not have a separate ignition coil, disconnect any spark plug wire from a spark plug and, while cranking the engine, test for spark available at the spark plug wire, again using a spark tester.

NOTE: An intermittent spark should be considered a no-spark condition.

Typical causes of a no-spark (intermittent spark) condition include the following:

1. Weak ignition coil
2. Low or no voltage to the primary (positive) side of the coil
3. High resistances, open coil wire, or spark plug wire
4. Negative side of the coil not being pulsed by the ignition module
5. Defective pickup coil or crankshaft position sensor
6. Defective ignition control module (ICM)
7. Defective main relay (can be labeled Main, EFI, ASD on Chrysler products; EEC on Ford vehicle relays)

The triggering sensor has to work to create a spark from the ignition coil(s). If there is a no-spark condition, check for triggering by using a scan tool and check for engine RPM while cranking the engine.

- If the engine speed (RPM) shows zero or almost zero while cranking, the most likely cause is a defective triggering sensor or sensor circuit fault.
- If the engine speed (RPM) is shown on the scan tool while cranking the engine, then the triggering sensor is working (in most cases).

Check service information for the exact procedure to follow for testing triggering sensors.

IGNITION COIL TESTING USING AN OHMMETER If an ignition coil is suspected of being defective, a simple ohmmeter check can be performed to test the resistance of the primary and secondary windings inside the coil. For accurate resistance measurements, the wiring to the coil should be removed before testing. To test the primary coil winding resistance, take the following steps. ● **SEE FIGURE 33–24.**

STEP 1 Set the meter to read low ohms.

STEP 2 Measure the resistance between the positive terminal and the negative terminal of the ignition coil. Most coils will give a reading between less than 1 ohm and 3 ohms. Check the manufacturer's specifications for the exact resistance values.

To test the secondary coil winding resistance, follow these steps.

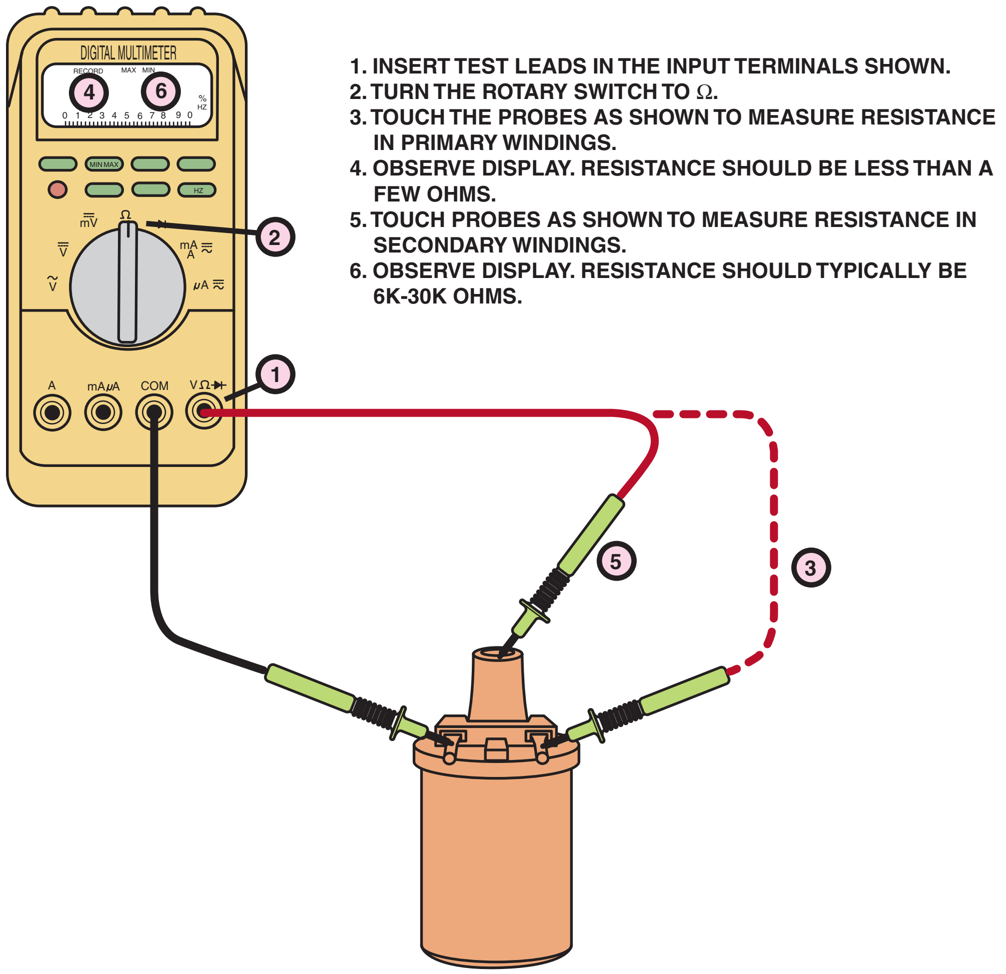


FIGURE 33–24 Checking an ignition coil using a multimeter set to read ohms.

TECH TIP

Always Use a Spark Tester

A spark tester looks like a spark plug except it has a recessed center electrode and no side electrode. The tester commonly has an alligator clip attached to the shell so that it can be clamped on a good ground connection on the engine. A good ignition system should be able to cause a spark to jump this wide gap at atmospheric pressure. Without a spark tester, a technician might assume that the ignition system is okay, because it can spark across a normal, grounded spark plug. The voltage required to fire a standard spark plug when it is out of the engine and not under pressure is about 3,000 volts or less. An electronic ignition spark tester requires a minimum of 25,000 volts to jump the 3/4 in. gap. Therefore, never assume that the ignition system is okay because it fires a spark plug—always use a spark tester. *Remember that an intermittent spark across a spark tester should be interpreted as a no-spark condition.*

STEP 1 Set the meter to read kilohms (kΩ).

STEP 2 Measure the resistance between either the primary terminal and the secondary coil tower or between the secondary towers. The normal resistance of most coils ranges between 6,000 and 30,000 ohms. Check the manufacturer's specifications for the exact resistance values.

MAGNETIC SENSOR TESTING Magnetic Sensor such as the pickup coil, located under the distributor cap on many electronic ignition engines, can cause a no-spark condition if defective. The sensor must generate an AC voltage pulse to the ignition module so that the module can pulse the ignition coil.

The sensor contains a coil of wire, and the resistance of this coil should be within the range specified by the manufacturer.

Some common tests for pickup coils and magnetic crankshaft position sensors include:

- **Resistance.** Usually between 150 and 1,500 ohms, but check service information for the exact specifications. ● **SEE FIGURE 33–25.**
- **Coil shorted to ground.** Check that the coil windings are insulated from ground by checking for continuity

FIGURE 33–25 Measuring the resistance of an HEI pickup coil using a digital multimeter set to the ohms position. The reading on the face of the meter is 0.796 kΩ or 796 ohms in the middle of the 500 to 1,500 ohm specifications.

using an ohmmeter. With one ohmmeter lead attached to ground, touch the other lead of the ohmmeter to the pickup coil terminal. The ohmmeter should read OL (over limit) with the ohmmeter set on the high scale. If the sensor resistance is not within the specified range or if it has continuity to ground, replace the pickup coil assembly.

- **AC voltage output.** The sensor also can be tested for proper voltage output. During cranking, most sensors should produce a minimum of 0.25 volt AC.

TESTING HALL-EFFECT SENSORS As with any other sensor, the output of the Hall-effect sensor should be tested first. Using a digital voltmeter, check for:

- Power and ground to the sensor
- Changing voltage (pulsed on and off or digital DC voltage) when the engine is being cranked
- Waveform, using an oscilloscope ● **SEE FIGURE 33–26.**

TESTING OPTICAL SENSORS Optical sensors will not operate if they are dirty or covered in oil. Perform a thorough visual inspection and look for an oil leak that could cause dirty oil to get on the LED or phototransistor. Also be sure that the light shield is securely fastened and that the seal is lightproof. An optical sensor also can be checked using an oscilloscope. ● **SEE FIGURE 33–27.**

Because of the speed of the engine and the number of slits in the optical sensor disk, a scope is one of the only tools that can capture useful information. For example, a Nissan has 360 slits and if it is running at 2000 RPM, a signal is generated 720,000 times per minute or 12,000 times per second.

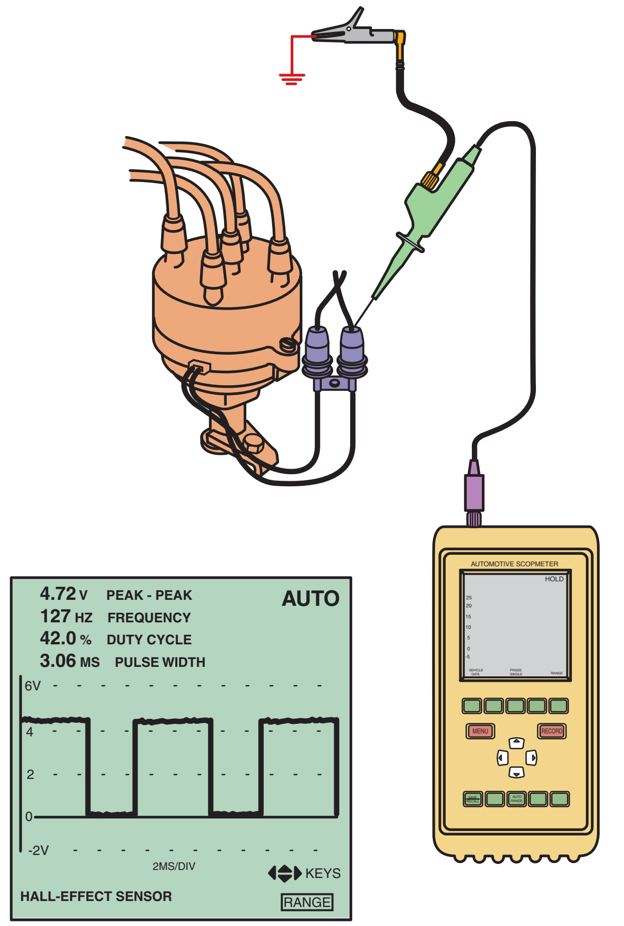


FIGURE 33–26 The connection required to test a Hall-effect sensor. A typical waveform from a Hall-effect sensor.

SPARK PLUG WIRE INSPECTION

Spark plug wires should be visually inspected for cuts or defective insulation. Faulty spark plug wire insulation can cause hard starting or no starting in rainy or damp weather conditions. When removing a spark plug wire, be sure to rotate the boot of the wire at the plug before pulling it off the spark plug. This will help prevent damaging the wire as many wires are stuck to the spark plug and are often difficult to remove.

VISUAL INSPECTION A thorough visual inspection should include a look at the following items.

- Check all spark plug wires for proper routing. All plug wires should be in the factory wiring separators and be clear of any metallic object that could damage the insulation and cause a short-to-ground fault.
- Check that all spark plug wires are securely attached to the spark plugs and to the distributor cap or ignition coil(s).

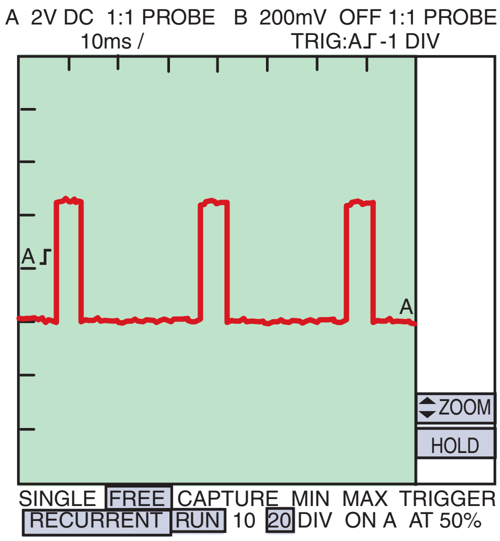


FIGURE 33–27 (a) The low-resolution signal has the same number of pulses as the engine has cylinders. (b) A dual-trace pattern showing both the low-resolution signal and the high-resolution signals that usually represent 1 degree of rotation.

TECH TIP

Bad Wire? Replace the Coil!

When performing engine testing (such as a compression test), always ground the coil wire. Never allow the coil to discharge without a path to ground for the spark. High-energy ignition systems can produce 40,000 volts or more of electrical pressure. If the spark cannot spark to ground, the coil energy can (and usually does) arc inside the coil itself, creating a low-resistance path to the primary windings or the steel laminations of the coil. ● **SEE FIGURE 33–28.**

This low-resistance path is called a **track,** and could cause an engine miss under load even though all of the remaining component parts of the ignition system are functioning correctly. Often these tracks do not show up on any coil test, including most scopes. Because the track is a lower resistance path to ground than normal, it requires that the ignition system be put under a load for it to be detected, and even then, the misfire may be intermittent. If a misfire was the result of an open circuit in the secondary circuit, the coil is ruined and must be replaced.

When disabling an ignition system, perform one of the following procedures to prevent possible ignition coil damage.

1. Remove the power source wire from the ignition system to prevent any ignition operation.
2. On distributor-equipped engines, remove the secondary coil wire from the center of the distributor cap and connect a jumper wire between the disconnected coil wire and a good engine ground. This ensures that the secondary coil energy will be safely grounded and prevents high-voltage coil damage.

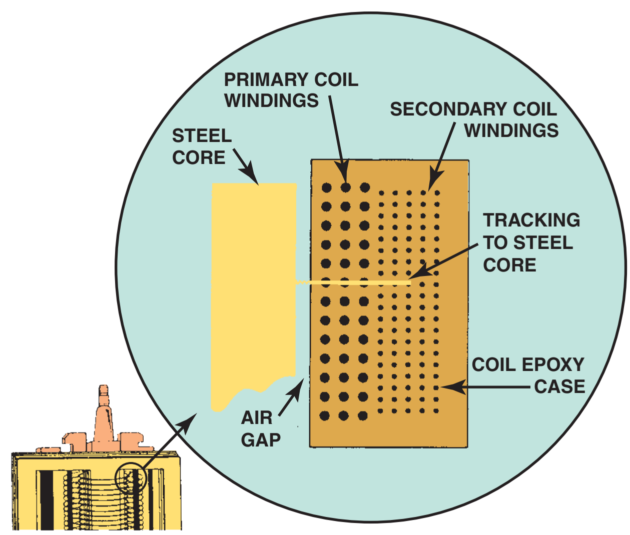


FIGURE 33–28 A track inside an ignition coil is not a short, but a low-resistance path or hole that has been burned through from the secondary wiring to the steel core.

- Check that all spark plug wires are clean and free from excessive dirt or oil. Check that all protective covers normally covering the coil and/or distributor cap are in place and not damaged.
- Carefully check the cap and distributor rotor for faults or coil secondary terminal on waste spark coils. ● **SEE FIGURE 33–29.**

Visually check the wires and boots for damage. ● **SEE FIGURE 33–30.**

Check all spark plug wires with an ohmmeter for proper resistance. Good spark plug wires should measure less than 10,000 ohms per foot of length. ● **SEE FIGURE 33–31.**

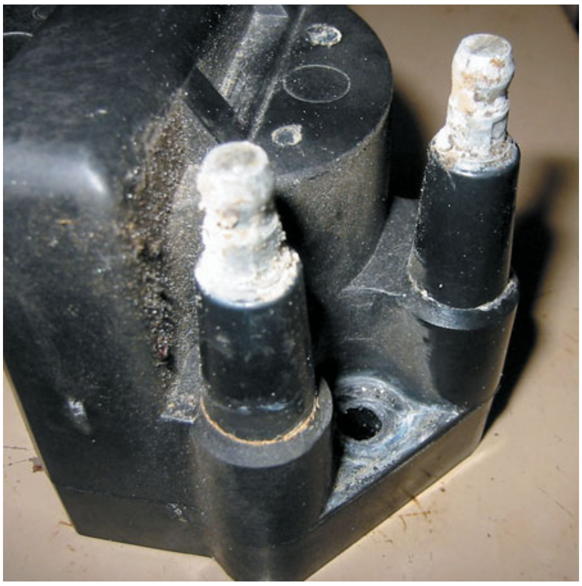


FIGURE 33–29 Corroded terminals on a waste-spark coil can cause misfire diagnostic trouble codes to be set.

FIGURE 33–30 This spark plug boot on an overhead camshaft engine has been arcing to the valve cover causing a misfire to occur.

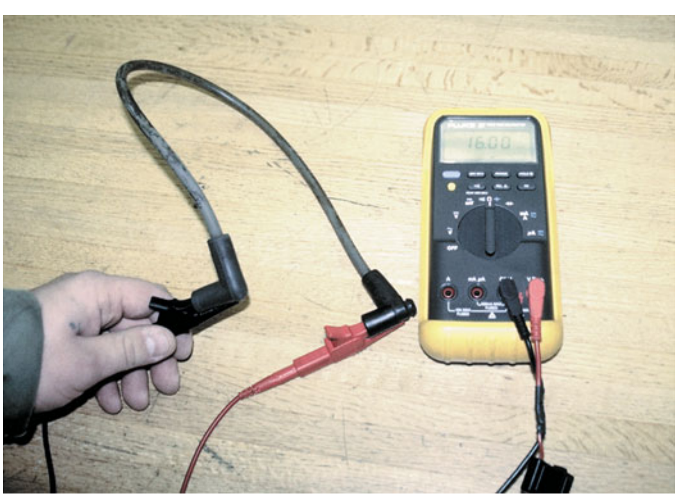


FIGURE 33–31 Measuring the resistance of a spark plug wire with a multimeter set to the ohms position. The reading of 16.03 kΩ (16,030 ohms) is okay because the wire is about 2 ft long. Maximum allowable resistance for a spark plug wire this long would be 20 kΩ (20,000 ohms).

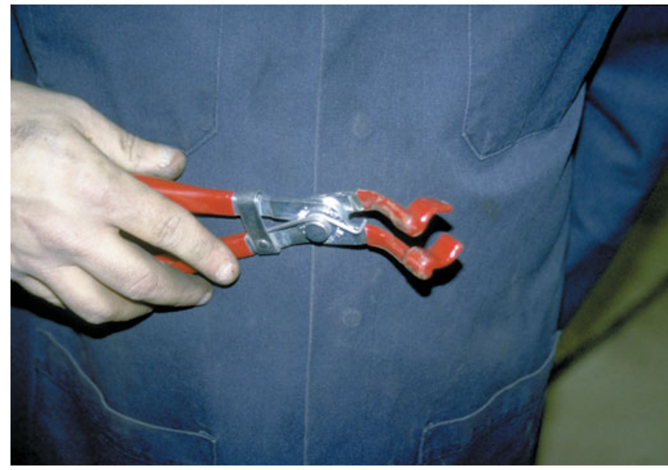


FIGURE 33–32 This spark plug wire boot pliers is a handy addition to any tool box.

TECH TIP

Spark Plug Wire Pliers Are a Good Investment

Spark plug wires are often difficult to remove. Using good-quality spark plug wire pliers, as shown in ● **FIGURE 33–32,** saves time and reduces the chance of harming the wire during removal.

TECH TIP

Route the Wires Right!

High voltage is present through spark plug wires when the engine is running. Surrounding the spark plug wires is a magnetic field that can affect other circuits or components of the vehicle. For example, if a spark plug wire is routed too closely to the signal wire from a mass airflow (MAF) sensor, the induced signal from the ignition wire could create a false MAF signal to the computer. The computer, not able to detect that the signal was false, would act on the MAF signal and command the appropriate amount of fuel based on the false MAF signal.

To prevent any problems associated with high-voltage spark plug wires, be sure to route them using all of the factory holding brackets and wiring combs. ● **SEE FIGURE 33–33.**

If the factory method is unknown, most factory service information shows the correct routing.

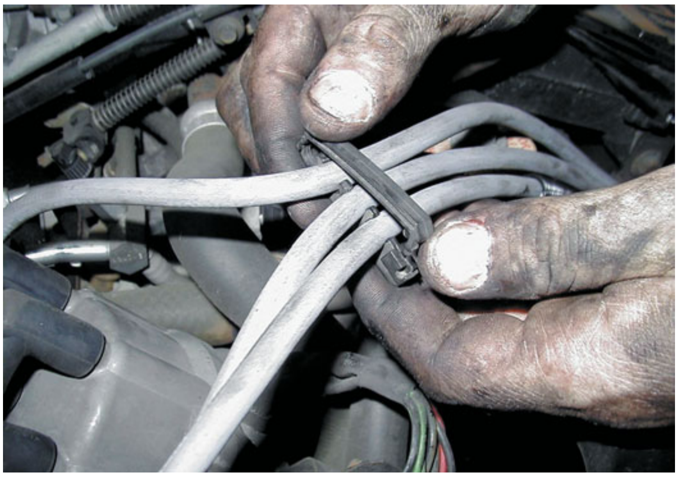


FIGURE 33–33 Always take the time to install spark plug wires back into the original holding brackets (wiring combs).

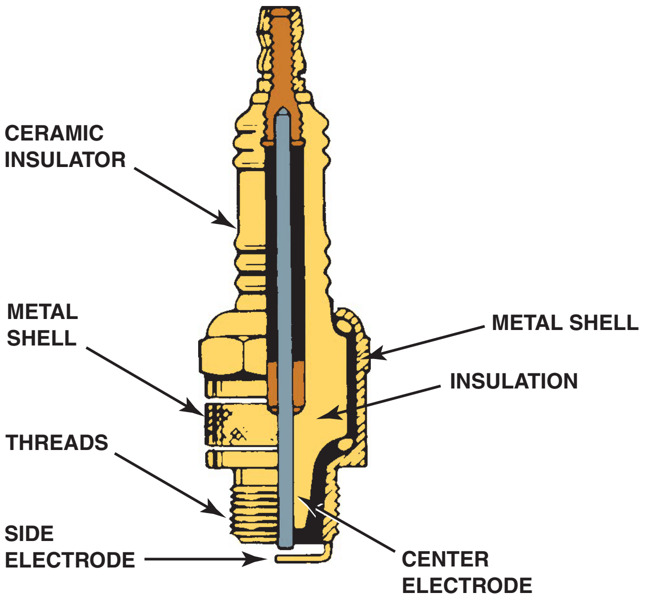


FIGURE 33–34 Parts of a spark plug.

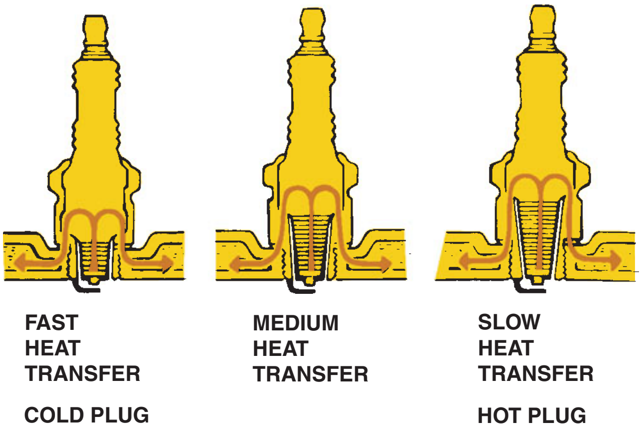


FIGURE 33–35 The heat range of a spark plug is determined by distance the heat flows from the tip to the cylinder head.

SPARK PLUGS

SPARK PLUG CONSTRUCTION **Spark plugs** are manufactured from ceramic insulators inside a steel shell. The threads of the shell are rolled and a seat is formed to create a gas-tight seal with the cylinder head. ● **SEE FIGURE 33–34.**

The physical differences in spark plugs include:

- **Reach.** This is the length of the threaded part of the plug.
- **Heat range.** This refers to how rapidly the heat created at the tip is transferred to the cylinder head. A spark plug with a long ceramic insulator path will run hotter at the tip than one that has a shorter path, because the heat must travel farther. ● **SEE FIGURE 33–35.**
- **Type of seat.** Some spark plugs use a gasket and others rely on a tapered seat to seal.

RESISTOR SPARK PLUGS Most spark plugs include a resistor in the center electrode, which helps to reduce electromagnetic noise or radiation from the ignition system. The closer the resistor is to the actual spark or arc, the more effective it becomes. The value of the resistor is usually between 2,500 and 7,500 ohms.

PLATINUM SPARK PLUGS **Platinum spark plugs** have a small amount of the precious metal platinum included on the end of the center electrode, as well as on the ground or side electrode. Platinum is a gray-white metal that does not react with oxygen and, therefore, will not erode away as can occur with conventional nickel alloy spark plug electrodes. Platinum is also used as a catalyst in catalytic converters where it is able to start a chemical reaction without itself being consumed.

IRIDIUM SPARK PLUGS Iridium is a white precious metal and is the most corrosion-resistant metal known. Most **iridium spark plugs** use a small amount of iridium welded onto the tip of a small center electrode, 0.0015 to 0.002 in. (0.4 to 0.6 mm) in diameter. The small diameter reduces the voltage required to jump the gap between the center and the side electrode, thereby reducing possible misfires. The ground or side electrode is usually tipped with platinum to help reduce electrode gap wear.

Spark plugs should be inspected when an engine performance problem occurs and should be replaced at specified intervals to ensure proper ignition system performance.

- Nonplatinum spark plugs have a service life of over 20,000 miles (32,000 km).
- Platinum-tipped original equipment spark plugs have a typical service life of 60,000 to 100,000 miles (100,000 to 160,000 km) or longer.

Used spark plugs should *not* be cleaned and reused unless absolutely necessary. The labor required to remove and replace (R & R) spark plugs is the same whether the spark plugs are replaced or cleaned. Although cleaning spark plugs often restores proper engine operation, the service life of cleaned spark plugs is definitely shorter than that of new spark plugs.

FIGURE 33–36 When removing spark plugs, it is wise to arrange them so that they can be compared and any problem can be identified with a particular cylinder.

FIGURE 33–37 A spark plug thread chaser is a low-cost tool that hopefully will not be used often, but is necessary to use to clean the threads before new spark plugs are installed.

NOTE: Platinum-tipped spark plugs should not be regapped on one that has been used in an engine before. The engine heat makes the platinum brittle and the center electrode can be easily broken if re-gapping the plug is attempted. Using a gapping tool can break the platinum after it has been used in an engine. Check service information regarding the recommended type of spark plugs and the specified service procedures.

SPARK PLUG SERVICE When replacing spark plugs, perform the following steps.

STEP 1 **Check service information.** Check for the exact spark plug to use and the specified instructions and/or technical service bulletins that affect the number of plug to be used or a revised replacement procedure.

STEP 2 **Allow the engine to cool before removing spark plugs.** This is true especially on engines with aluminum cylinder heads.

STEP 3 **Use compressed air or a brush to remove dirt from around the spark plug before removal.** This step helps prevent dirt from getting into the cylinder of an engine while removing a spark.

STEP 4 **Check the spark plug gap and correct as needed.** Be careful not to damage the tip on the center electrode if adjusting a platinum or iridium type of spark plug.

STEP 5 **Install the spark plugs by hand.** After tightening by hand, then use a torque wrench and tighten the spark plugs to factory specifications. ● **SEE FIGURES 33–36 AND 33–37.**

Spark plugs are the windows to the inside of the combustion chamber. A thorough visual inspection of the spark plugs often can lead to the root cause of an engine performance problem. Two indications on spark plugs and their possible root causes in engine performance include the following:

1. **Carbon fouling.** If the spark plug(s) has *dry black carbon* (soot), the usual causes include:
   - Excessive idling
   - Overly rich air-fuel mixture due to a fuel system fault
   - Weak ignition system output
2. **Oil fouling.** If the spark plug has wet, oily deposits with little electrode wear, oil may be getting into the combustion chamber from the following:
   - Worn or broken piston rings
   - Worn valve guides
   - Defective or missing valve stem seals

When removing spark plugs, place them in order so that they can be inspected to check for engine problems that might affect one or more cylinders. All spark plugs should be in the same condition, and the color of the center insulator should be light tan or gray. If all the spark plugs are black or dark, the engine should be checked for conditions that could cause an overly rich air-fuel mixture or possible oil burning. If only one or a few spark plugs are black, check those cylinders for proper firing (possible defective spark plug wire) or an engine condition affecting only those particular cylinders. ● **SEE FIGURES 33–38 THROUGH 33–41.**

If all spark plugs are white, check for possible overadvanced ignition timing or a vacuum leak causing a lean air-fuel mixture. If only one or a few spark plugs are white, check for a vacuum leak or injector fault affecting the air-fuel mixture only to those particular cylinders.

NOTE: The engine computer "senses" rich or lean air-fuel ratios by means of input from the oxygen sensor(s). If one cylinder is lean, the PCM may make all other cylinders richer to compensate.

Inspect all spark plugs for wear by first checking the condition of the center electrode. As a spark plug wears, the center electrode becomes rounded. If the center electrode is rounded, higher ignition system voltage is required to fire the spark plug.

When installing spark plugs, always use the correct tightening torque to ensure proper heat transfer from the spark plug shell to the cylinder head. ● **SEE CHART 33–1.**

NOTE: General Motors does not recommend the use of antiseize compound on the threads of spark plugs being installed in an aluminum cylinder head, because the spark plug will be overtightened. This excessive tightening torque places the threaded portion of the spark plug too far into the combustion chamber where carbon can accumulate and result in the spark plugs being difficult to remove. If antiseize compound is used on spark plug threads, reduce the tightening torque by 40%. Always follow the vehicle manufacturer's recommendations.

FIGURE 33–38 A normally worn spark plug that uses a tapered platinum-tipped center electrode.

FIGURE 33–39 A worn spark plug showing fuel and/or oil deposits.

FIGURE 33–40 A spark plug from an engine that had a blown head gasket. The white deposits could be from the aluminum of the position or from the additives in the coolant.

FIGURE 33–41 A platinum tipped spark plug that is fuel soaked indicating a fault with the fuel system or the ignition system causing the spark plug to not fire.

SPARK PLUG TYPE	TORQUE WITH TORQUE WRENCH (LB-FT) CAST-IRON HEAD	ALUMINUM HEAD	TORQUE WITHOUT TORQUE WRENCH (TURNS AFTER SEATED) CAST-IRON HEAD	ALUMINUM HEAD
Gasket				
14 mm	26–30	18–22	1/4	1/4
18 mm	32–38	28–34	1/4	1/4
Tapered seat				
14 mm	7–15	7–15	1/16 (snug)	1/16 (snug)
18 mm	15–20	15–20	1/16 (snug)	1/16 (snug)

CHART 33–1

Typical spark plug installation torque.

TECH TIP

Two-Finger Trick

To help prevent overtightening a spark plug when a torque wrench is not available, simply use two fingers on the ratchet handle. Even the strongest service technician cannot overtighten a spark plug by using two fingers.

IGNITION TIMING

PURPOSE **Ignition timing** refers to when the spark plug fires in relation to piston position. The time when the spark occurs depends on engine speed and, therefore, must be advanced (spark plugs fire sooner) as the engine rotates faster. The ignition in the cylinder takes a certain amount of time, usually 30 ms (30/1,000 of a second) and remains constant regardless of engine speed. Therefore, to maintain the most efficient combustion, the ignition sequence has to occur sooner as the engine speed increases. For maximum efficiency from the expanding gases inside the combustion chamber, the burning of the air-fuel mixture should end by about 10 degrees after top dead center (ATDC). If the burning of the mixture is still occurring after that point, the expanding gases do not exert much force on the piston because the gases are "chasing" the piston as it moves downward.

Therefore, to achieve the goal of having the air-fuel mixture be completely burned by the time the piston reaches 10 degrees after top dead center, the spark must be advanced (occur sooner) as the engine speed increases. This timing advance is determined and controlled by the PCM on most vehicles. ● **SEE FIGURES 33–42 AND 33–43.**

If the engine is equipped with a distributor, it may be possible to adjust the base or the initial timing. The initial timing is usually set to fire the spark plug between zero degrees (TDC) or slightly before TDC (BTDC). Ignition timing changes as mechanical wear occurs to the following:

- Timing chain
- Distributor gear
- Camshaft drive gear

FIGURE 33–42 Ignition timing marks are found on the harmonic balancers on engines equipped with distributors that can be adjusted for timing.

CHECKING IGNITION TIMING To be assured of the proper ignition timing, follow exactly the timing procedure indicated on the underhood vehicle emission control information (VECI) decal. ● **SEE FIGURE 33–44.**

NOTE: The ignition timing for waste-spark and coil-on-plug ignition systems cannot be adjusted.

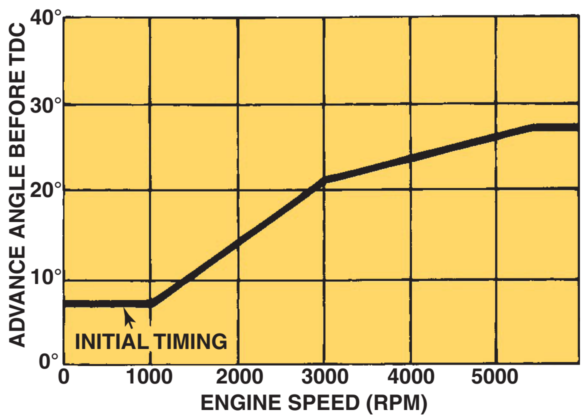
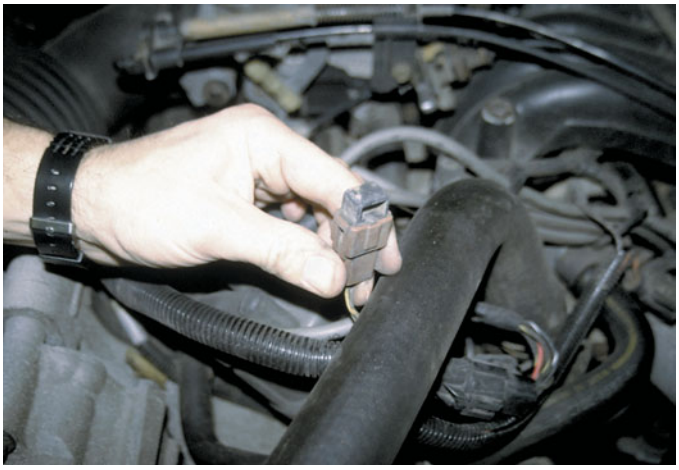


FIGURE 33–43 The initial (base) timing is where the spark plug fires at idle speed. The PCM then advances the timing based primarily on engine speed.



(a)

(b)

FIGURE 33–44 (a) Typical SPOUT connector as used on many Ford engines equipped with distributor ignition (DI). (b) The connector must be opened (disconnected) to check and/or adjust the ignition timing. On DIS/EDIS systems, the connector is called SPOUT/SAW (spark output/spark angle word).

TECH TIP

Two Marks Are the Key to Success

When a distributor is removed from an engine, always mark where the rotor is pointing to ensure that the distributor is reinstalled in the correct position. Because of the helical cut on the distributor drive gear, the rotor rotates as the distributor is being removed from the engine. To help reinstall a distributor without any problems, simply make another mark where the rotor is pointing just as the distributor is lifted out of the engine. Then to reinstall, simply line up the rotor to the second mark and lower the distributor into the engine. The rotor should then line up with the original mark as a double check.

IGNITION SYSTEM SYMPTOM GUIDE

Problem	Possible Causes and/or Solutions
No spark out of the coil	■ Open in the ignition switch circuit or theft deterrent system fault ■ Defective ignition control module ■ Defective triggering device (magnetic sensor, Hall-effect or optical sensor)
Weak spark out of the coil	■ High-resistance coil wire or spark plug wire ■ Poor ground between the distributor or ignition control module and the engine block
Engine misfire	■ Defective (open) spark plug wire ■ Worn or fouled spark plugs ■ Defective ignition control module (ICM)

SUMMARY

1. All inductive ignition systems supply battery voltage to the positive side of the ignition coil and pulse the negative side of the coil on and off to ground to create a high-voltage spark.
2. If an ignition system uses a distributor, it is a distributor ignition (DI) system.
3. If an ignition system does not use a distributor, it is an electronic ignition (EI) system.
4. A waste-spark ignition system fires two spark plugs at the same time.
5. A coil-on-plug ignition system uses an ignition coil for each spark plug.
6. A thorough visual inspection should be performed on all ignition components when diagnosing an engine performance problem.
7. Platinum spark plugs should not be regapped after use in an engine.

REVIEW QUESTIONS

1. How can 12 volts from a battery be changed to 40,000 volts for ignition?
2. How does a magnetic sensor work?
3. How does a Hall-effect sensor work?
4. How does a waste-spark ignition system work?
5. Why should a spark tester be used to check for spark rather than a standard spark plug?
6. How do you test a pickup coil for resistance and AC voltage output?
7. What harm can occur if the engine is cranked or run with an open (defective) spark plug wire?

CHAPTER QUIZ

1. The primary (low-voltage) ignition system must be working correctly before any spark occurs from a coil. Which component is not in the primary ignition circuit?
   - **a.** Spark plug wiring
   - **b.** Ignition module (igniter)
   - **c.** Pickup coil (pulse generator)
   - **d.** Ignition switch
2. The ignition module has direct control over the firing of the coil(s) of an ignition system. Which component(s) triggers (controls) the module?
   - **a.** Pickup coil
   - **b.** Computer
   - **c.** Crankshaft sensor
   - **d.** All of the above
3. Distributor ignition systems can be triggered by a ________.
   - **a.** Hall-effect sensor
   - **b.** Magnetic sensor
   - **c.** Spark sensor
   - **d.** Either a or b
4. Ignition coil primary resistance is usually ________ ohms.
   - **a.** 6,000 to 30,000
   - **b.** 150 to 1,500
   - **c.** Less than 1 to 3
   - **d.** Zero
5. Coil polarity is determined by the ________.
   - **a.** Direction of rotation of the coil windings
   - **b.** Turn ratio
   - **c.** Direction of laminations
   - **d.** Saturation direction
6. A compression-sensing ignition system uses a ________ type of ignition.
   - **a.** Distributor
   - **b.** Coil on plug
   - **c.** Waste spark
   - **d.** All of the above
7. The pulse generator ________.
   - **a.** Fires the spark plug directly
   - **b.** Signals the ignition control module (ICM)
   - **c.** Signals the computer that fires the spark plug directly
   - **d.** Is used as a tachometer reference signal by the computer and has no other function
8. Two technicians are discussing coil-on-plug ignition systems. Technician A says that they can be called coil-near-plug or coil-by-plug ignition systems. Technician B says that some can use ion sensing. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. A waste-spark-type ignition system fires ________.
   - **a.** Two spark plugs at the same time
   - **b.** One spark plug with reverse polarity
   - **c.** One spark plug with straight polarity
   - **d.** All of the above
10. Technician A says that a defective crankshaft position sensor can cause a no-spark condition. Technician B says that a faulty ignition control module can cause a no-spark condition. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

chapter 34

FUEL PUMPS, LINES, AND FILTERS

OBJECTIVES: After studying Chapter 34, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Discuss fuel tanks, lines and filters. • Describe how fuel pumps work. • Describe how to check an electric fuel pump for proper pressure and volume delivery. • Explain how to check a fuel-pressure regulator. • Describe how to test fuel injectors. • Explain how to diagnose electronic fuel-injection problems.

KEY TERMS: Accumulator 492 • Baffle 483 • Check valve 485 • Delivery system 483 • Filter basket 494 • Gerotor 489 • Hydrokinetic pump 489 • Inertia switch 485 • Onboard refueling vapor recovery (ORVR) 484 • Peripheral pump 489 • Residual or rest pressure 488 • Roller cell 488 • Rotary vane pump 488 • Side-channel pump 489 • Turbine pump 489 • Vacuum lock 485 • Vapor lock 485 • Volatile organic compound (VOC) 488

FUEL DELIVERY SYSTEM

Creating and maintaining a correct air–fuel mixture requires a properly functioning fuel and air **delivery system**. Fuel delivery (and return) systems use many if not all of the following components to make certain that fuel is available under the right conditions to the fuel-injection system:

- Fuel storage tank, filler neck, and gas cap
- Fuel tank pressure sensor
- Fuel pump
- Fuel filter(s)
- Fuel delivery lines and fuel rail
- Fuel-pressure regulator
- Fuel return line (if equipped with a return-type fuel delivery system)

FUEL TANKS

A vehicle fuel tank is made of corrosion-resistant steel or polyethylene plastic. Some models, such as sport utility vehicles (SUVs) and light trucks, may have an auxiliary fuel tank.

Tank design and capacity are a compromise between available space, filler location, fuel expansion room, and fuel movement. Some later-model tanks deliberately limit tank capacity by extending the filler tube neck into the tank low enough to prevent complete filling, or by providing for expansion room. **SEE FIGURE 34–1.** A vertical **baffle** in fuel tanks limits fuel sloshing as the vehicle moves.

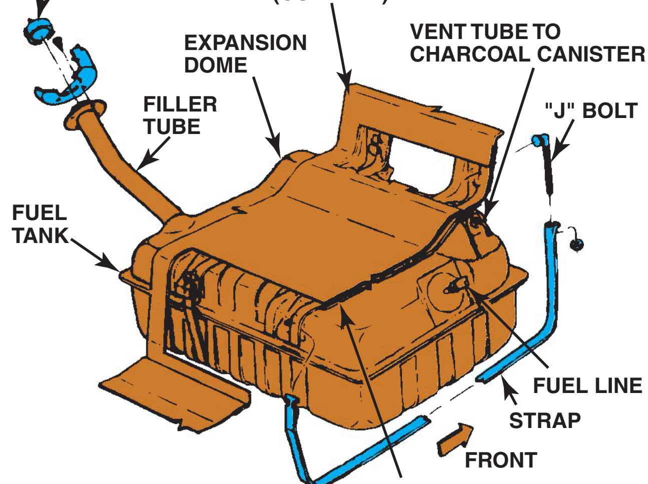


FIGURE 34–1 A typical fuel tank installation.

Regardless of size and shape, all fuel tanks incorporate most if not all of the following features:

- Inlet or filler tube through which fuel enters the tank
- Filler cap with pressure holding and relief features
- An outlet to the fuel line leading to the fuel pump or fuel injector
- Fuel pump mounted within the tank
- Tank vent system
- Fuel pickup tube and fuel level sending unit

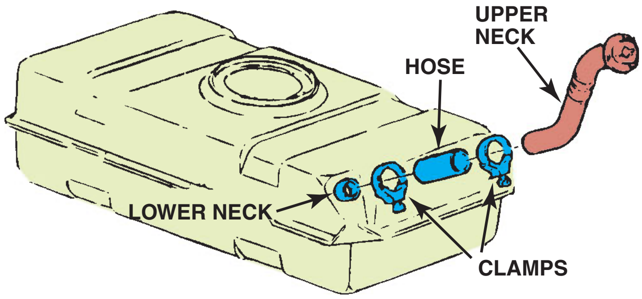


FIGURE 34–2 A three-piece filler tube assembly. The main three parts include the upper neck, hose and lower neck.

TANK LOCATION AND MOUNTING Most vehicles use a horizontally suspended fuel tank, usually mounted below the rear of the floor pan, just ahead of or behind the rear axle. Fuel tanks are located there so that frame rails and body components protect the tank in the event of a crash. To prevent squeaks, some models have insulated strips cemented on the top or sides of the tank wherever it contacts the underbody.

Fuel inlet location depends on the tank design and filler tube placement. It is located behind a filler cap and is often a hinged door in the outer side of either rear fender panel.

Generally, a pair of metal retaining straps holds a fuel tank in place. Underbody brackets or support panels hold the strap ends using bolts. The free ends are drawn underneath the tank to hold it in place, then bolted to other support brackets or to a frame member on the opposite side of the tank.

FILLER TUBES Fuel enters the tank through a large tube extending from the tank to an opening on the outside of the vehicle. ● **SEE FIGURE 34–2.**

Effective in 1993, federal regulations require manufacturers to install a device to prevent fuel from being siphoned through the filler neck. Federal authorities recognized methanol as a poison, and methanol used in gasoline is a definite health hazard. Additionally, gasoline is a suspected carcinogen (cancer-causing agent). To prevent siphoning, manufacturers welded a filler-neck check-ball tube in fuel tanks. To drain check-ball-equipped fuel tanks, a technician must disconnect the check-ball tube at the tank and attach a siphon directly to the tank. ● **SEE FIGURE 34–3.**

Onboard refueling vapor recovery (ORVR) systems have been developed to reduce evaporative emissions during refueling. ● **SEE FIGURE 34–4.** These systems add components to the filler neck and the tank. One ORVR system utilizes a tapered filler neck with a smaller diameter tube and a check valve. When fuel flows down the neck, it opens the normally closed check valve. The vapor passage to the charcoal canister is opened. The decreased size neck and the opened air passage allow fuel and vapor to flow rapidly into the tank and the canister respectively. When the fuel has reached a predetermined level, the check valve closes, and the fuel tank pressure increases. This forces the nozzle to shut off, thereby preventing the tank from being overfilled.

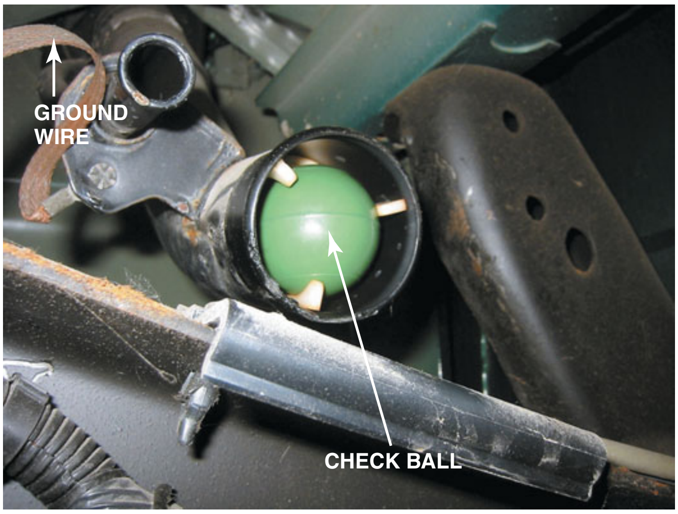


FIGURE 34–3 A view of a typical filler tube with the fuel tank removed. Notice the ground strap used to help prevent the buildup of static electricity as the fuel flows into the plastic tank. The check ball looks exactly like a ping-pong ball.

FIGURE 34–4 Vehicles equipped with onboard refueling vapor recovery usually have a reduced-size fill tube.

PRESSURE-VACUUM FILLER CAP Fuel and vapors are sealed in the tank by the safety filler cap. The safety cap must release excess pressure or excess vacuum. Either condition could cause fuel tank damage, fuel spills, and vapor escape. Typically, the cap will release if the pressure is over 1.5 to 2.0 PSI (10 to 14 kPa) or if the vacuum is 0.15 to 0.30 PSI (1 to 2 kPa).

FUEL PICKUP TUBE The fuel pickup tube is usually a part of the fuel sender assembly or the electric fuel pump assembly. Since dirt and sediment eventually gather on the bottom of a fuel tank, the fuel pickup tube is fitted with a filter sock or strainer to prevent contamination from entering the fuel lines. The woven plastic strainer also acts as a water separator by preventing water from being drawn up with the fuel. The filter sock usually is designed to filter out particles that are larger than 70 to 100 microns, or 30 microns if a gerotor-type fuel pump is used. One micron is 0.000039 in. ● **SEE FIGURE 34–5.**

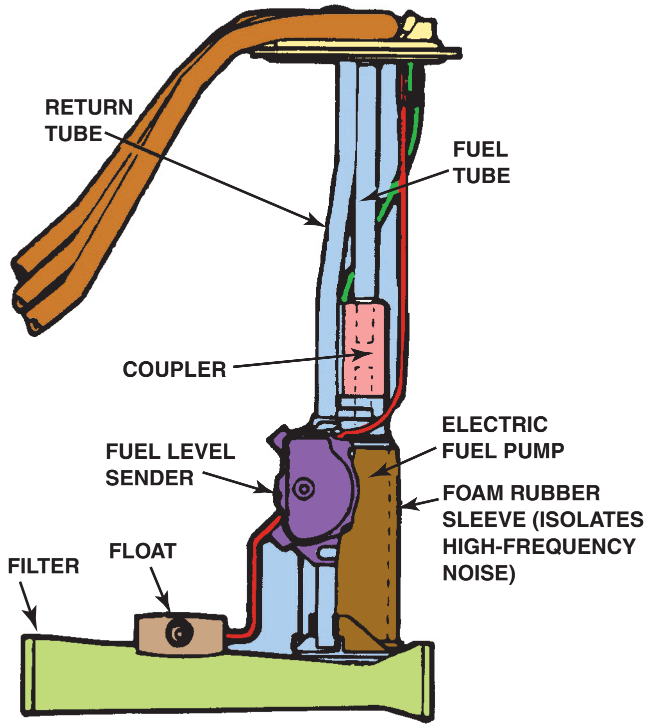


FIGURE 34–5 The fuel pickup tube is part of the fuel sender and pump assembly.

NOTE: The human eye cannot see anything smaller than about 40 microns.

The filter is made from woven Saran resin (copolymer of vinylidene chloride and vinyl chloride. The filter blocks any water that may be in the fuel tank, unless it is completely submerged in water. In that case, it will allow water through the filter. This filter should be replaced whenever the fuel pump is replaced.

TANK VENTING REQUIREMENTS Fuel tanks must be vented to prevent a **vacuum lock** as fuel is drawn from the tank. As fuel is used and its level drops in the tank, the space above the fuel increases. As the air in the tank expands to fill this greater space, its pressure drops. Without a vent, the air pressure inside the tank would drop below atmospheric pressure, developing a vacuum which prevents the flow of fuel. Under extreme pressure variance, the tank could collapse. Venting the tank allows outside air to enter as the fuel level drops, preventing a vacuum from developing.

An EVAP system vents gasoline vapors from the fuel tank directly to a charcoal-filled vapor storage canister, and uses an unvented filler cap. Many filler caps contain valves that open to relieve pressure or vacuum above specified safety levels. Systems that use completely sealed caps have separate pressure and vacuum relief valves for venting.

Because fuel tanks are not vented directly to the atmosphere, the tank must allow for fuel expansion, contraction, and overflow that can result from changes in temperature or overfilling. One way is to use a dome in the top of the tank. Many General Motors vehicles use a design that includes a vertical slosh baffle which reserves up to 12% of the total tank capacity for fuel expansion.

ROLLOVER LEAKAGE PROTECTION

All vehicles have one or more devices to prevent fuel leaks in case of vehicle rollover or a collision in which fuel may spill.

Variations of the basic one-way **check valve** may be installed in any number of places between the fuel tank and the engine. The valve may be installed in the fuel return line, vapor vent line, or fuel tank filler cap.

In addition to the rollover protection devices, some vehicles use devices to ensure that the fuel pump shuts off when an accident occurs. On some air vane sensors, a microswitch is built into the sensor to switch on the fuel pump as soon as intake airflow causes the vane to lift from its rest position. ● **SEE FIGURE 34–6.**

Ford vehicles use an **inertia switch**. ● **SEE FIGURE 34–7.** The inertia switch is installed in the rear of the vehicle between the electric fuel pump and its power supply. With any sudden impact, such as a jolt from another vehicle in a parking lot, the inertia switch opens and shuts off power to the fuel pump. The switch must be reset manually by pushing a button to restore current to the pump.

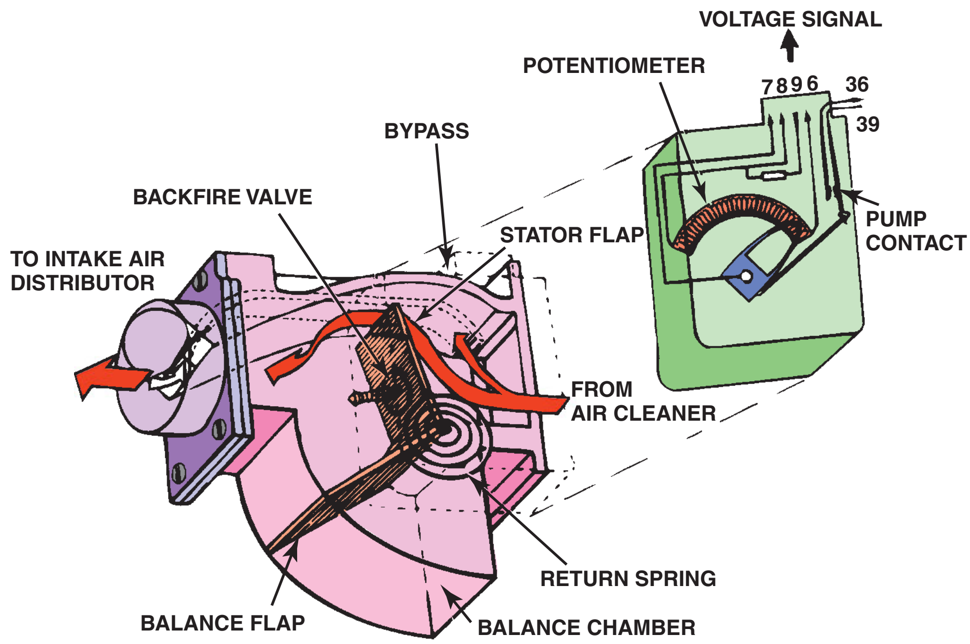
FUEL LINES

Fuel and vapor lines made of steel, nylon tubing, or fuel-resistant rubber hoses connect the parts of the fuel system. Fuel lines supply fuel to the throttle body or fuel rail. They also return excess fuel and vapors to the tank. Depending on their function, fuel and vapor lines may be either rigid or flexible.

Fuel lines must remain as cool as possible. If any part of the line is located near too much heat, the gasoline passing through it vaporizes and **vapor lock** occurs. When this happens, the fuel pump supplies only vapor that passes into the injectors. Without liquid gasoline, the engine stalls and a hot restart problem develops.

The fuel delivery system supplies 10 to 15 PSI (69 to 103 kPa) or up to 35 PSI (241 kPa) to many throttle-body injection units and up to 60 PSI (414 kPa) for multiport fuel-injection systems. Fuel-injection systems retain residual or rest pressure in the lines for a half hour or longer when the engine is turned off to prevent hot engine restart problems. Higher-pressure systems such as these require special fuel lines.

FIGURE 34–6 On some vehicles equipped with an airflow sensor, a switch is used to energize the fuel pump. In the event of a collision, the switch opens and the fuel flow stops.



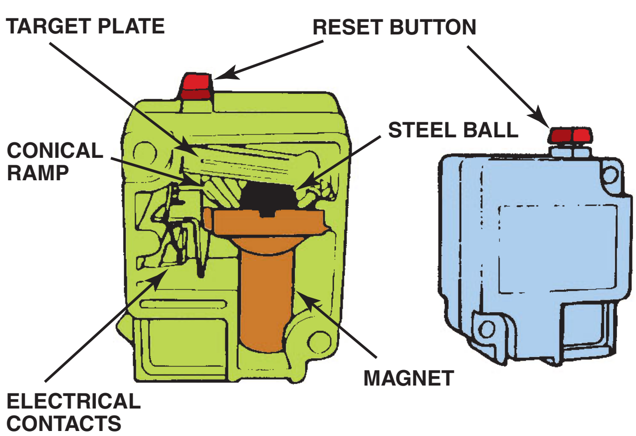


FIGURE 34–7 Ford uses an inertia switch to turn off the electric fuel pump in an accident.

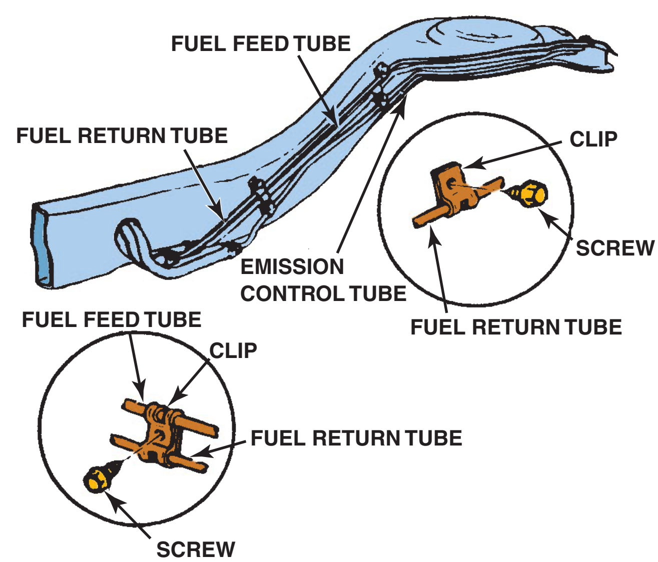


FIGURE 34–8 Fuel lines are routed along the frame or body and secured with clips.

RIGID LINES All fuel lines fastened to the body, frame, or engine are made from nylon reinforced plastic or seamless steel tubing. Steel springs may be wound around the tubing at certain points to protect against impact damage.

Only steel tubing, or that recommended by the manufacturer, should be used when replacing rigid fuel lines. *Never substitute copper or aluminum tubing for steel tubing.* These materials do not withstand normal vehicle vibration and could combine with the fuel to cause a chemical reaction.

FLEXIBLE LINES Most fuel systems use synthetic rubber hose sections where flexibility is needed. Short hose sections often connect steel fuel lines to other system components. The fuel delivery hose inside diameter (ID), is usually 3/16" or 3/8" (8 or 10 millimeters) and the return line ID is normally 1/4" (6 millimeters).

Fuel-injection systems require special-composition reinforced hoses specifically made for these higher-pressure systems. Similarly, vapor vent lines must be made of materials that resist fuel vapors. Replacement vent hoses are usually marked with the designation “EVAP” to indicate their intended use.

FUEL LINE MOUNTING Fuel supply lines from the tank to a throttle body or fuel rail are routed to follow the frame along the underbody of the vehicle. Vapor and return lines may be routed with the fuel supply line. All rigid lines are fastened to the frame rail or underbody with screws and clamps, or clips. ● **SEE FIGURE 34–8.**

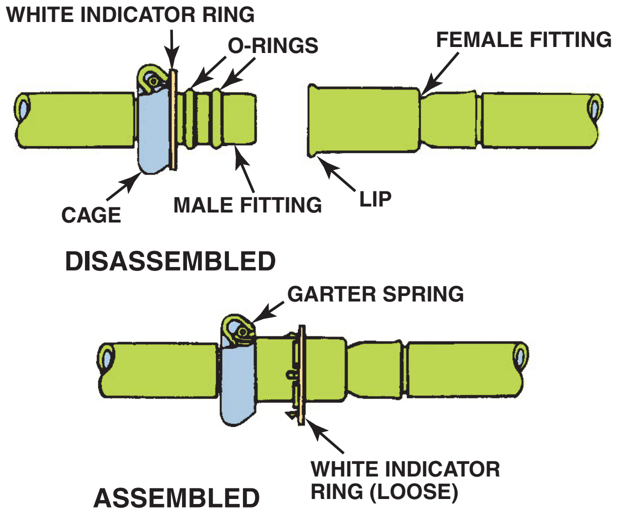


FIGURE 34–9 Some Ford metal line connections use spring-locks and O-rings.

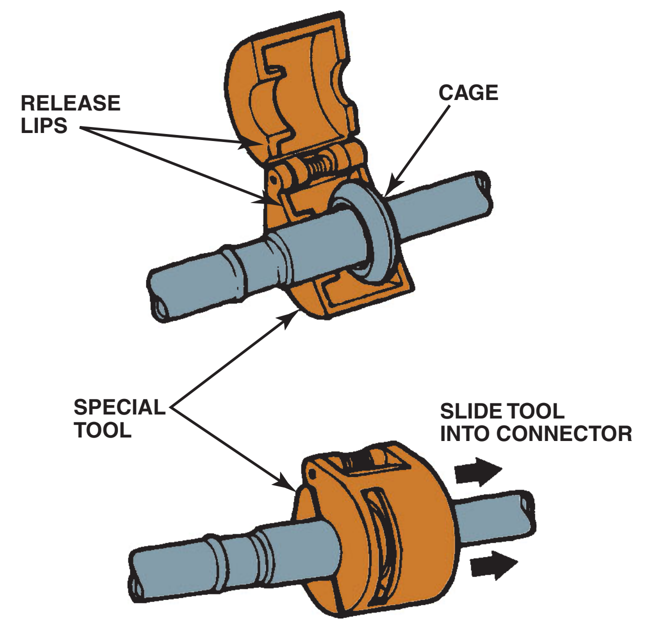


FIGURE 34–10 Ford spring-lock connectors require a special tool for disassembly.

FUEL-INJECTION LINES AND CLAMPS Hoses used for fuel-injection systems are made of materials with high resistance to oxidation and deterioration. Replacement hoses for injection systems should always be equivalent to original equipment manufacturer (OEM) hoses.

Screw-type clamps are essential on injected engines and should have rolled edges to prevent hose damage.

CAUTION: ***Do not use spring-type clamps on fuel-injected engines—they cannot withstand the fuel pressures involved.***

FUEL-INJECTION FITTINGS AND NYLON LINES Because of their operating pressures, fuel-injection systems often use special kinds of fittings to ensure leakproof connections. Some high-pressure fittings on GM vehicles with port fuel-injection systems use O-ring seals instead of the traditional flare connections. When disconnecting such a fitting, inspect the O-ring for damage and replace it if necessary. *Always* tighten O-ring fittings to the specified torque value to prevent damage.

Other manufacturers also use O-ring seals on fuel line connections. In all cases, the O-rings are made of special materials that withstand contact with gasoline and oxygenated fuel blends. Some manufacturers specify that the O-rings be replaced every time the fuel system connection is opened. When replacing one of these O-rings, a new part specifically designed for fuel system service must be used.

Ford also uses spring-lock connectors to join male and female ends of steel tubing. ● **SEE FIGURE 34–9.** The coupling is held together by a garter spring inside a circular cage. The flared end of the female fitting slips behind the spring to lock the coupling together.

General Motors has used nylon fuel lines with quick-connect fittings at the fuel tank and fuel filter since the early 1990s. Like the GM threaded couplings used with steel lines, nylon line couplings use internal O-ring seals. Unlocking the metal connectors requires a special quick-connector separator tool; plastic connectors can be released without the tool. ● **SEE FIGURES 34–10 AND 34–11.**

FUEL LINE LAYOUT Fuel pressures have tended to become higher to prevent vapor lock, and a major portion of the fuel routed to the fuel-injection system returns to the tank by way of a fuel return line or return-type systems. This allows better control, within limits, of heat absorbed by the gasoline as it is routed through the engine compartment. Throttle-body and multiport injection systems have typically used a pressure regulator to control fuel pressure in the throttle body or fuel rail, and also allow excess fuel not used by the injectors to return to the tank. However, the warmer fuel in the tank may create problems, such as an excessive rise in fuel vapor pressures in the tank.

? FREQUENTLY ASKED QUESTION

Just How Much Fuel Is Recirculated?

Approximately 80% of the available fuel-pump volume is released to the fuel tank through the fuel pressure regulator at idle speed. As an example, a passenger vehicle cruising down the road at 60 mph gets 30 mpg. With a typical return-style fuel system pumping about 30 gallons per hour from the tank, it would therefore burn 2 gallons per hour, and return about 28 gallons per hour to the tank!

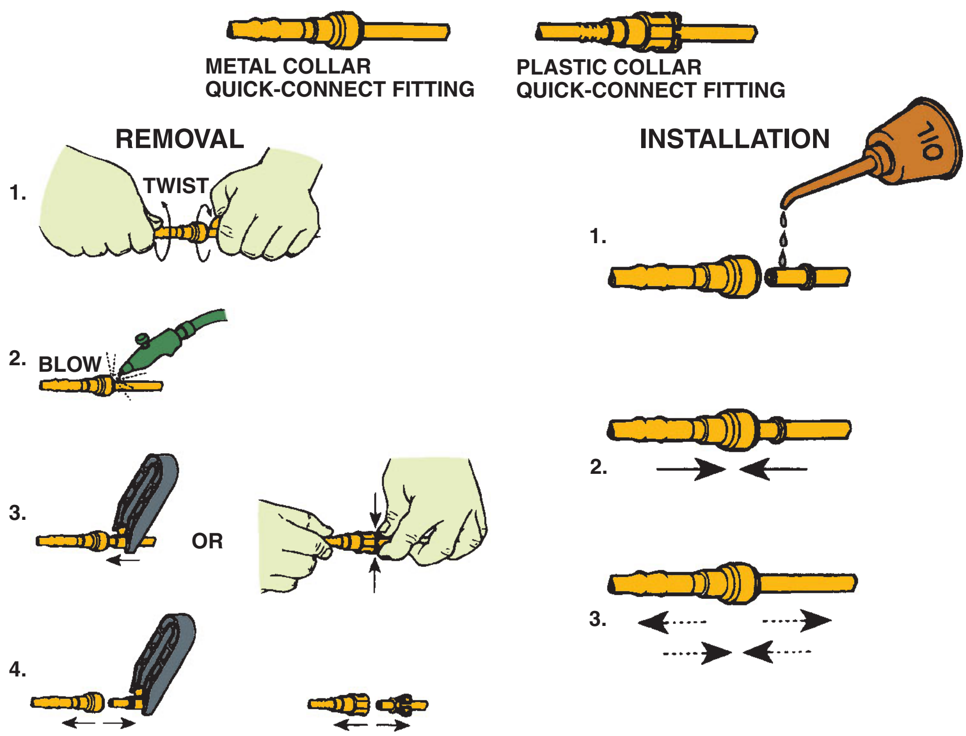


FIGURE 34–11 Typical quick-connect steps.

With late-model vehicles, there has been some concern about too much heat being sent back to the fuel tank, causing rising in-tank temperatures and increases in fuel vaporization and **volatile organic compound (VOC)** (hydrocarbon) emissions. To combat this problem, manufacturers have placed the pressure regulator back by the tank instead of under the hood on mechanical returnless systems. In this way, returned fuel is not subjected to the heat generated by the engine and the underhood environment. To prevent vapor lock in these systems, pressures have been raised in the fuel rail, and injectors tend to have smaller openings to maintain control of the fuel spray under pressure.

Not only must the fuel be filtered and supplied under adequate pressure, but there must also be a consistent *volume* of fuel to assure smooth engine performance even under the heaviest of loads.

ELECTRIC FUEL PUMPS

The electric fuel pump is a pusher unit. When the pump is mounted in the tank, the entire fuel supply line to the engine can be pressurized. Because the fuel, when pressurized, has a higher boiling point, it is unlikely that vapor will form to interfere with fuel flow.

Most vehicles use the impeller or turbine pumps. ● **SEE FIGURE 34–12.** All electrical pumps are driven by a small electric motor, but the turbine pump turns at higher speeds and is quieter than the others.

> ? **FREQUENTLY ASKED QUESTION**
>
> **How Can an Electric Pump Work Inside a Gas Tank and Not Cause a Fire?**
>
> Even though fuel fills the entire pump, no burnable mixture exists inside the pump because there is no air and no danger of commutator brush arcing, igniting the fuel.

POSITIVE DISPLACEMENT PUMP

A positive displacement pump is a design that forces everything that enters the pump to leave the pump.

In the **roller cell** or vane pump, the impeller draws fuel into the pump, and then pushes it out through the fuel line to the injection system. All designs of pumps use a variable-sized chamber to draw in fuel. When the maximum volume has been reached, the supply port closes and the discharge opens. Fuel is then forced out the discharge as this volume decreases. The chambers are formed by rollers or gears in a rotor plate. Because this type of pump uses no valves to move the fuel, the fuel flows steadily through the entire pump housing, including the electrical portion which keeps the pump cool. Usually, only when a vehicle runs out of fuel is there a risk of pump damage.

Most electric fuel pumps are equipped with a fuel outlet check valve that closes to maintain fuel pressure when the pump shuts off. **Residual or rest pressure** prevents vapor lock and hot-start problems on these systems.

● **FIGURE 34–13** shows the pumping action of a **rotary vane pump.** The pump consists of a central impeller disk,

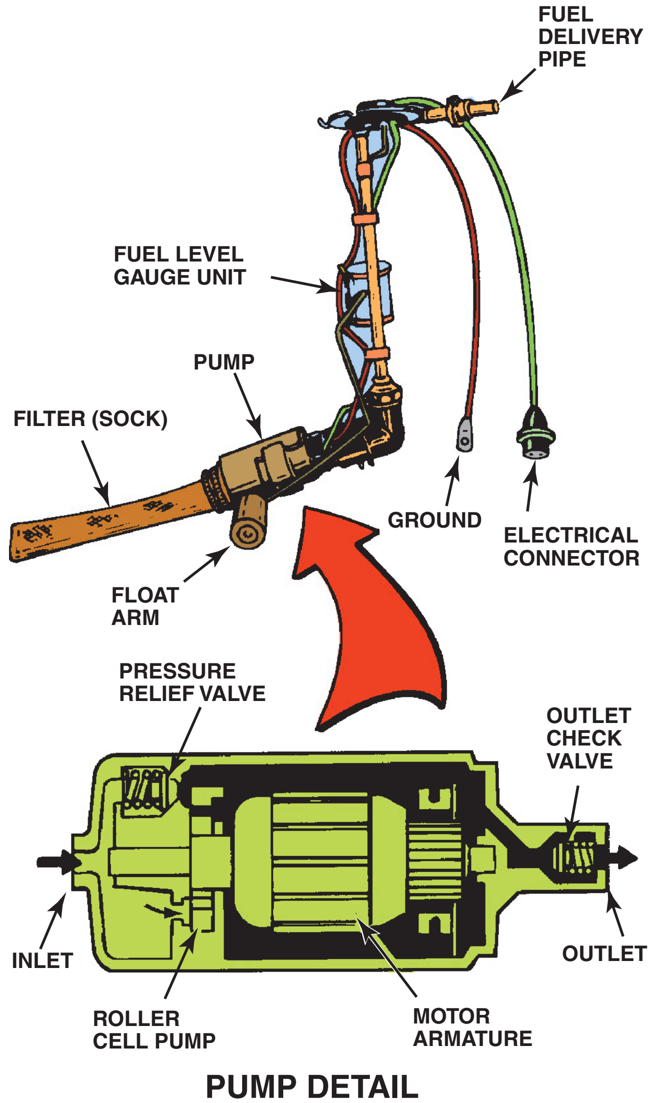


FIGURE 34–12 A roller cell-type electric fuel pump.

several rollers or vanes that ride in notches in the impeller, and a pump housing that is offset from the impeller centerline. The impeller is mounted on the end of the motor armature and spins whenever the motor is running. The rollers are free to slide in and out within the notches in the impeller to maintain sealing contact. Unpressurized fuel enters the pump, fills the spaces between the rollers, and is trapped between the impeller, the housing, and two rollers. An internal gear pump, called a **gerotor**, is another type of positive displacement pump that is often used in engine oil pumps. It uses the meshing of internal and external gear teeth to pressurize the fuel. ● **SEE FIGURE 34–14** for an example of a gerotor-type fuel pump that uses an impeller as the first stage and is used to move the fuel gerotor section where it is pressurized.

HYDROKINETIC FLOW PUMP DESIGN The word *hydro* means liquid and the term *kinetic* refers to motion, so the term **hydrokinetic pump** means that this design of pump rapidly

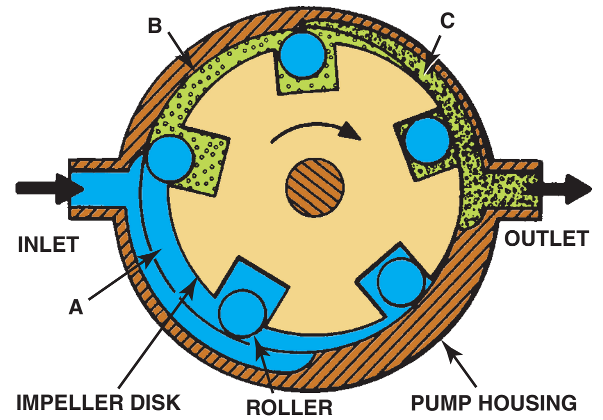


FIGURE 34–13 The pumping action of an impeller or rotary vane pump.

moves the fuel to create pressure. This design of pump is a nonpositive displacement pump design.

A **turbine pump** is the most common because it tends to be less noisy. Sometimes called **turbine, peripheral,** and **side-channel,** these units use an impeller that accelerates the fuel particles before actually discharging them into a tract where they generate pressure via pulse exchange. Actual pump volume is controlled by using a different number of impeller blades, and in some cases a higher number of impellers, or different shapes along the side discharge channels. These units are fitted more toward lower operating pressures of less than 60 PSI. ● **SEE FIGURE 34–15** for an example of a two-stage turbine pump. The turbine impeller has a staggered blade design to minimize pump harmonic noise and to separate vapor from the liquid fuel. The end cap assembly contains a pressure relief valve and a radio-frequency interference (RFI) suppression module. The check valve is usually located in the upper fuel pipe connector assembly.

After fuel passes the strainer, it is drawn into the lower housing inlet port by the impellers. It is pressurized and delivered to the convoluted fuel tube for transfer through a check valve into the fuel feed pipe. A typical electric fuel pump used on a fuel-injection system delivers about 40 to 50 gallons per hour or 0.6 to 0.8 gallons per minute at a pressure of 70 to 90 PSI.

MODULAR FUEL SENDER ASSEMBLY The modular fuel sender consists of a fuel level sensor, a turbine pump, and a jet pump. The reservoir housing is attached to the cover containing fuel pipes and the electrical connector. Fuel is transferred from the pump to the fuel pipe through a convoluted (flexible) fuel pipe. The convoluted fuel pipe eliminates the need for rubber hoses, nylon pipes, and clamps. The reservoir dampens fuel slosh to maintain a constant fuel level available to the roller vane pump; it also reduces noise.

Some of the flow, however, is returned to the jet pump for recirculation. Excess fuel is returned to the reservoir through one of the three hollow support pipes. The hot fuel quickly

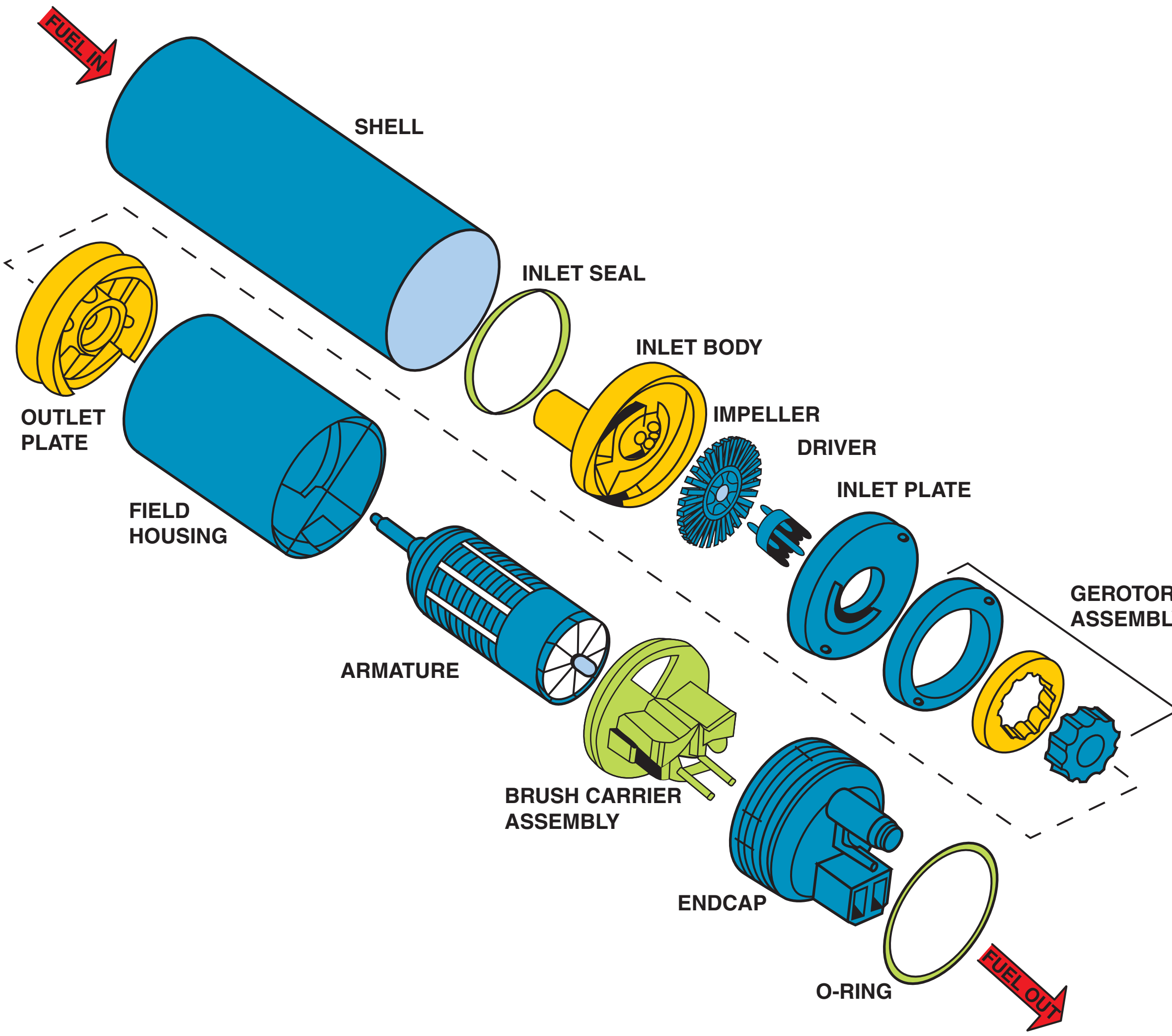


FIGURE 34–14 An exploded view of a gerotor electric fuel pump.

mixes with the cooler fuel in the reservoir; this minimizes the possibility of vapor lock. In these modules, the reservoir is filled by the jet pump. Some of the fuel from the pump is sent through the jet pump to lift fuel from the tank into the reservoir.

ELECTRIC PUMP CONTROL CIRCUITS Fuel-pump circuits are controlled by the fuel-pump relay. Fuel-pump relays are activated initially by turning the ignition key to on, which allows the pump to pressurize the fuel system. As a safety precaution, the relay de-energizes after a few seconds until the key is moved to the crank position. Once an ignition coil signal, or "tach" signal, is received by the engine control computer, indicating the engine is rotating, the relay remains energized even with the key released to the run position.

CHRYSLER. On Chrysler vehicles, the PCM must receive an engine speed (RPM) signal during cranking before it can energize a circuit driver inside the power module to activate an automatic shutdown (ASD) relay to power the fuel pump, ignition coil, and injectors. As a safety precaution, if the RPM signal to the logic module is interrupted, the logic module signals the power module to deactivate the ASD, turning off the pump, coil,

> **?** **FREQUENTLY ASKED QUESTION**
>
> **Why Are Many Fuel-Pump Modules Spring-Loaded?**
>
> Fuel modules that contain the fuel pickup sock, fuel pump, and fuel level sensor are often spring-loaded when fitted to a plastic fuel tank. The plastic material shrinks when cold and expands when hot, so having the fuel module spring-loaded ensures that the fuel pickup sock will always be the same distance from the bottom of the tank. ● **SEE FIGURE 34–16**.

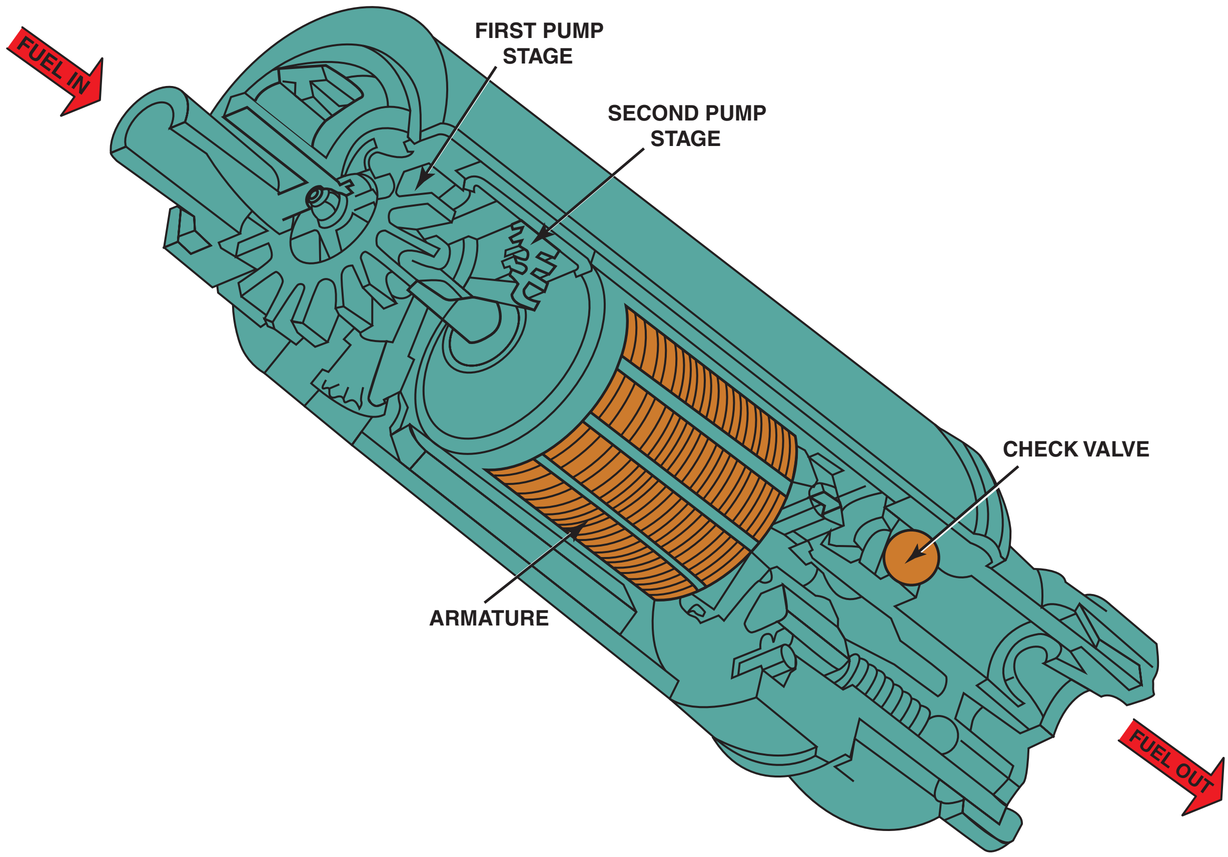


FIGURE 34–15 A cutaway view of a typical two-stage turbine electric fuel pump.

FIGURE 34–16 A typical fuel-pump module assembly, which includes the pickup strainer and fuel pump, as well as the fuel-pressure sensor and fuel level sensing unit.

and injectors. In some vehicles, the oil pressure switch circuit may be used as a safety circuit to activate the pump in the ignition switch run position.

GENERAL MOTORS. General Motors systems energize the pump with the ignition switch to initially pressurize the fuel lines, but then deactivate the pump if an RPM signal is not received within one or two seconds. The pump is reactivated as soon as engine cranking is detected. The oil pressure sending unit serves as a backup to the fuel-pump relay on some vehicles. In case of pump relay failure, the oil pressure switch will operate the fuel pump once oil pressure reaches about 4 PSI (28 kPa).

FORD. Most Ford vehicles with fuel injection have an inertia switch between the fuel-pump relay and fuel pump. When the ignition switch is turned to the On position, the electronic engine control (EEC) power relay energizes, providing current to the fuel-pump relay and a timing circuit in the EEC module. If the RPM signal is not received by the PCM within one second, within about one second, the timing circuit opens the ground circuit to de-energize the fuel-pump relay and shut down the pump. This circuit is designed to prepressurize the system. Once the key is turned to the start position, power to the pump is sent through the relay and inertia switch.

The inertia switch opens under a specified impact, such as a collision. When the switch opens, current to the pump shuts off

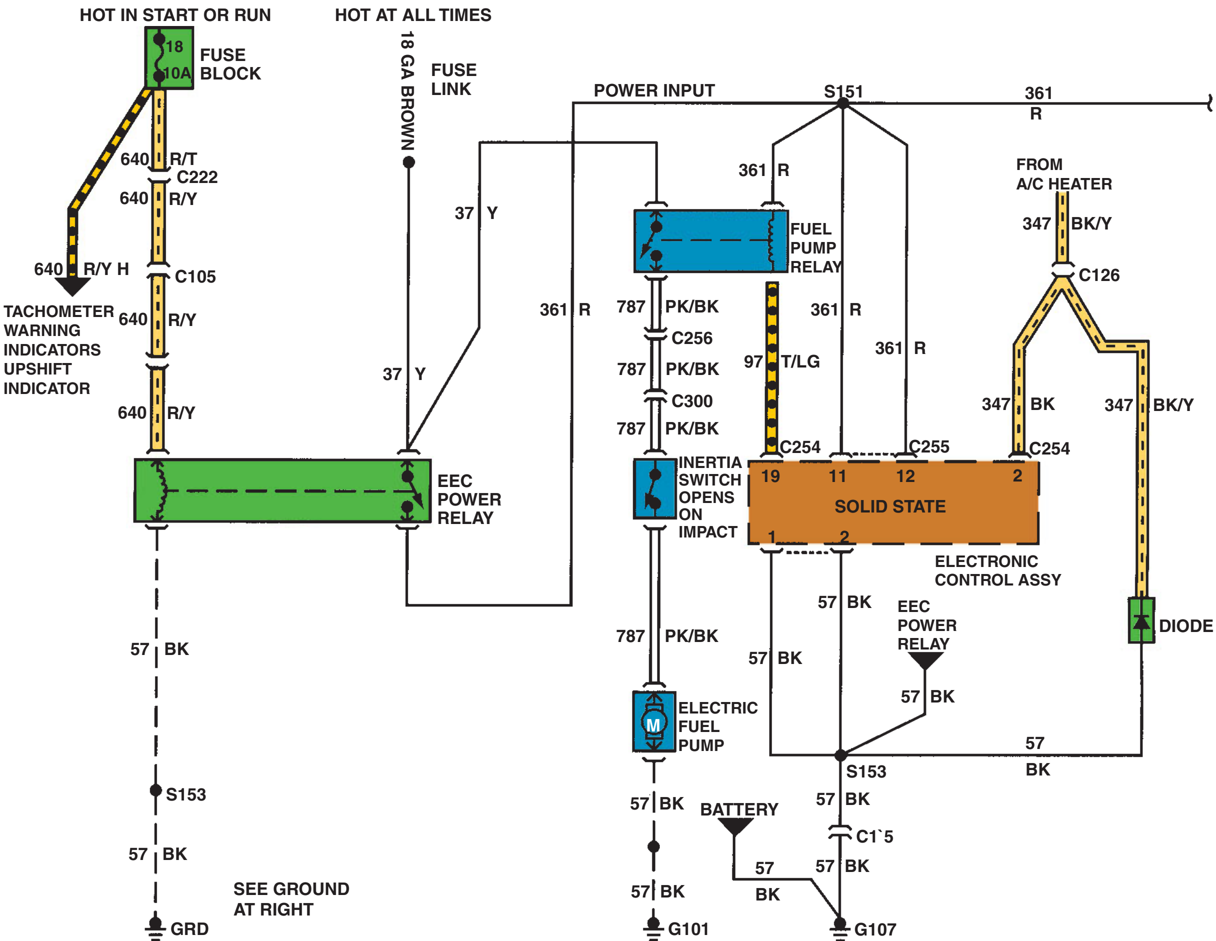


FIGURE 34–17 A schematic showing that an inertia switch is connected in series between the fuel-pump relay and the fuel pump.

because the fuel-pump relay will not energize. The switch must be reset manually by opening the trunk and depressing the reset button before current flow to the pump can be restored. ● **SEE FIGURE 34–17** for a schematic of a typical fuel system that uses an inertia switch in the power feed circuit to the electric fuel pump.

PUMP PULSATION DAMPENING Some manufacturers use an **accumulator** in the system to reduce pressure pulses and noise. Others use a pulsator located at the outlet of the fuel pump to absorb pressure pulsations that are created by the pump. These pulsators are usually used on roller vane pumps and are a source of many internal fuel leaks. ● **SEE FIGURE 34–18.**

NOTE: Some experts suggest that the pulsator be removed and replaced with a standard section of fuel line to prevent the loss of fuel pressure that results when the connections on the pulsator loosen and leak fuel back into the tank.

VARIABLE SPEED PUMPS Another way to help reduce noise, current draw, and pump wear is to reduce the speed of the pump when less than maximum output is required. Pump

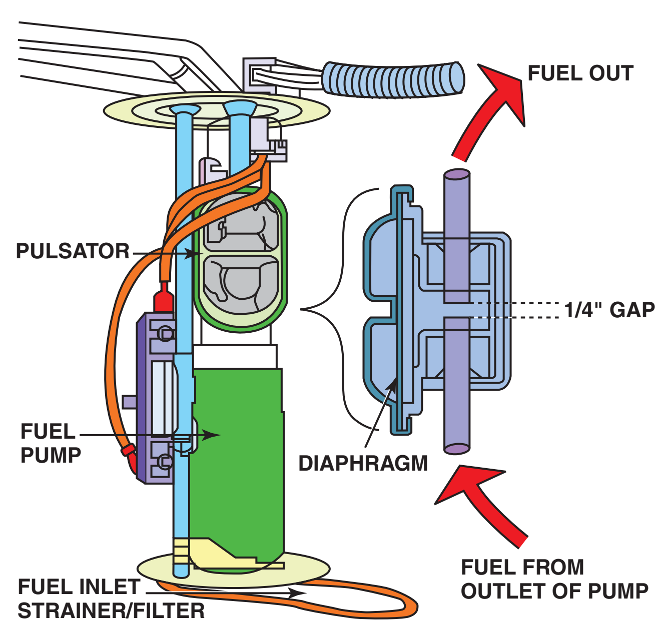


FIGURE 34–18 A typical fuel pulsator used mostly with roller vane-type pumps to help even out the pulsation in pressure that can cause noise.

speed and pressure can be regulated by controlling the voltage supplied to the pump with a resistor switched into the circuit, or by letting the engine-control computer pulse-width modulate (PWM) the voltage supply to the pump, through a separate fuel pump driver electronic module. With slower pump speed and pressure, less noise is produced.

FUEL FILTERS

Despite the care generally taken in refining, storing, and delivering gasoline, some impurities get into the automotive fuel system. Fuel filters remove dirt, rust, water, and other contamination from the gasoline before it can reach the fuel injectors. Most fuel filters are designed to filter particles that are 10 to 20 microns or larger in size.

The useful life of many filters is limited, but vehicles that use a returnless-type fuel injection system usually use filters that are part of the fuel pump assembly and do have any specified replacement interval. This means that they should last the life of the vehicle. If fuel filters are not replaced according to the manufacturer's recommendations, they can become clogged and restrict fuel flow.

In addition to using several different types of fuel filters, a single fuel system may contain two or more filters. The inline filter is located in the line between the fuel pump and the throttle body or fuel rail. ● **SEE FIGURE 34–19.** This filter protects the system from contamination, but does not protect the fuel pump. The inline filter usually is a metal or plastic container with a pleated paper element sealed inside.

Fuel filters may be mounted on a bracket on the fender panel, a shock tower, or another convenient place in the engine compartment. They may also be installed under the vehicle near the fuel tank. Fuel filters should be replaced according to the vehicle manufacturer's recommendations, which range from every 30,000 miles (48,000 km) to 100,000 miles (160,000 km) or longer. Fuel filters that are part of the fuel-pump module assemblies usually do not have any specified service interval.

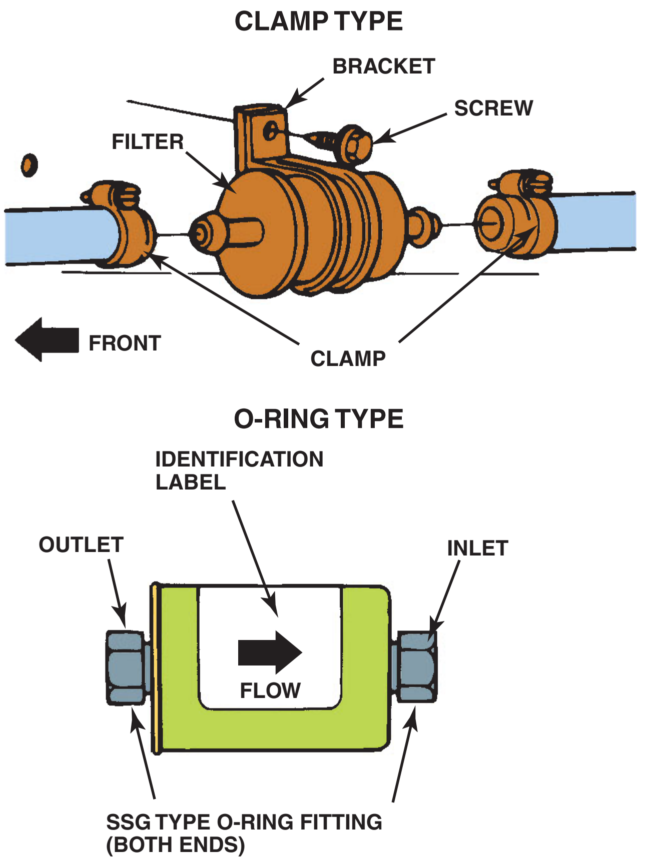


FIGURE 34–19 Inline fuel filters are usually attached to the fuel line with screw clamps or threaded connections. The fuel filter must be installed in the proper direction or a restricted fuel flow can result.

TECH TIP

Be Sure That the Fuel Filter Is Installed Correctly

The fuel filter has flow direction and if it is installed backwards, the vehicle will most likely have a restricted exhaust (low power at higher engine speeds and loads).

All injectors, throttle body or port, are fitted with one or more filter screens or strainers to remove any particles (generally 10 microns or 0.00039 in.) that might have passed through the other filters. These screens, which surround the fuel inlet, are on the side of throttle-body injectors and are inserted in the top of port injectors. ● **SEE FIGURE 34–20**.

FUEL-PUMP TESTING

Fuel-pump testing includes many different tests and procedures. Even though a fuel pump can pass one test, it does not mean that there is not a fuel-pump problem. For example, if the pump motor is rotating slower than normal, it may be able to produce the specified pressure, but not enough volume to meet the needs of the engine while operating under a heavy load.

TESTING FUEL-PUMP PRESSURE Fuel-pump-regulated pressure has become more important than ever with a more exact fuel control. Although an increase in fuel pressure does increase fuel volume to the engine, this is *not* the preferred method to add additional fuel as some units will not open correctly at the increased fuel pressure. On the other side of the discussion, many newer engines will not start when fuel pressure is just a few

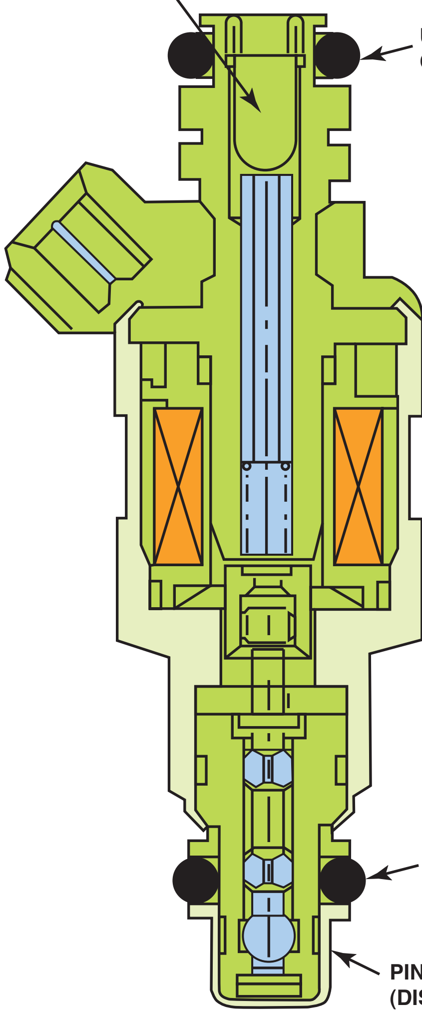
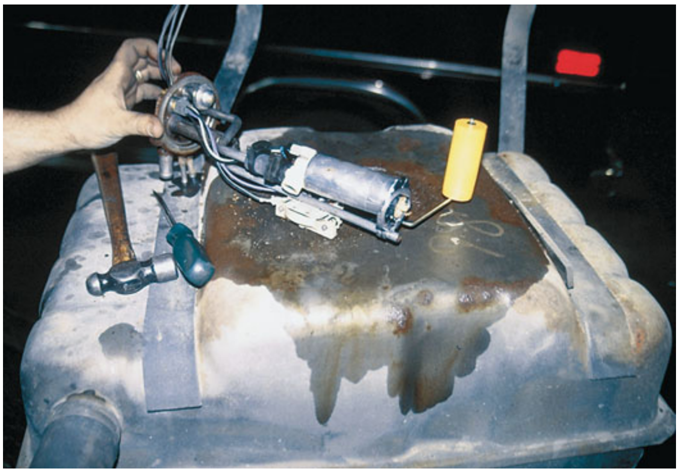


FIGURE 34–20 The final filter, also called a **filter basket**, is the last filter in the fuel system.

(a)



(b)

FIGURE 34–21 (a) A funnel helps in hearing if the electric fuel pump inside the gas tank is working. (b) If the pump is not running, check the wiring and current flow before going through the process of dropping the fuel tank to remove the pump.

PSI low. Correct fuel pressure is very important for proper engine operation. Most fuel-injection systems operate at either a low pressure of about 10 PSI or a high pressure of between 35 and 45 PSI.

Normal Operating Pressure	(PSI)	Maximum Pump Pressure (PSI)
Low-pressure TBI units	9–13	18–20
High-pressure TBI units	25–35	50–70
Port fuel-injection systems	35–45	70–90
Central port fuel injection (GM)	55–64	90–110

TECH TIP

The Ear Test

No, this is not a test of your hearing, but rather using your ear to check that the electric fuel pump is operating. The electric fuel pump inside the fuel tank is often difficult to hear running, especially in a noisy shop environment. A commonly used trick to better hear the pump is to use a funnel in the fuel filter neck. ● **SEE FIGURE 34–21.**

In both types of systems, maximum fuel-pump pressure is about double the normal operating pressure to ensure that a continuous flow of cool fuel is being supplied to the injector(s) to help prevent vapor from forming in the fuel system. Although

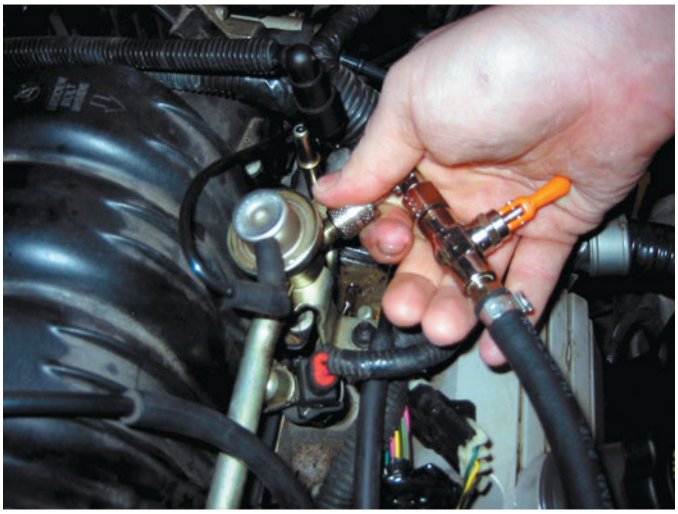


FIGURE 34–22 The Schrader valve on this General Motors 3800 V-6 is located next to the fuel-pressure regulator.

TECH TIP

The Rubber Mallet Trick

Often a no-start condition is due to an inoperative electric fuel pump. A common trick is to tap on the bottom of the fuel tank with a rubber mallet in an attempt to jar the pump motor enough to work. Instead of pushing a vehicle into the shop, simply tap on the fuel tank and attempt to start the engine. This is not a repair, but rather a confirmation that the fuel pump does indeed require replacement.

vapor or foaming in a fuel system can greatly affect engine operation, the cooling and lubricating flow of the fuel must be maintained to ensure the durability of injector nozzles.

To measure fuel-pump pressure, locate the Schrader valve and attach a fuel-pressure gauge. ● **SEE FIGURE 34–22.**

NOTE: Some vehicles, such as those with General Motors TBI fuel-injection systems, require a specific fuel-pressure gauge that connects to the fuel system. Always follow the manufacturers' recommendations and procedures.

REST PRESSURE TEST If the fuel pressure is acceptable, then check the system for leakdown. Observe the pressure gauge after five minutes. ● **SEE FIGURE 34–23.** The pressure should be the same as the initial reading. If not, then the pressure regulator, fuel-pump check valve, or the injectors are leaking.

DYNAMIC PRESSURE TEST To test the pressure dynamically, start the engine. If the pressure is vacuum referenced, then the pressure should change when the throttle is cycled. If it does not, then check the vacuum supply circuit. Remove the vacuum line from the regulator and inspect for any presence of fuel. ● **SEE FIGURE 34–24.** There should never be any fuel present on the vacuum side of the regulator diaphragm. When the engine speed is increased, the pressure reading should remain within the specifications.

Some engines do not use a vacuum-referenced regulator. The running pressure remains constant, which is typical for a mechanical returnless-type fuel system. On these systems, the pressure is higher than on return-type systems to help reduce the formation of fuel vapors in the system.

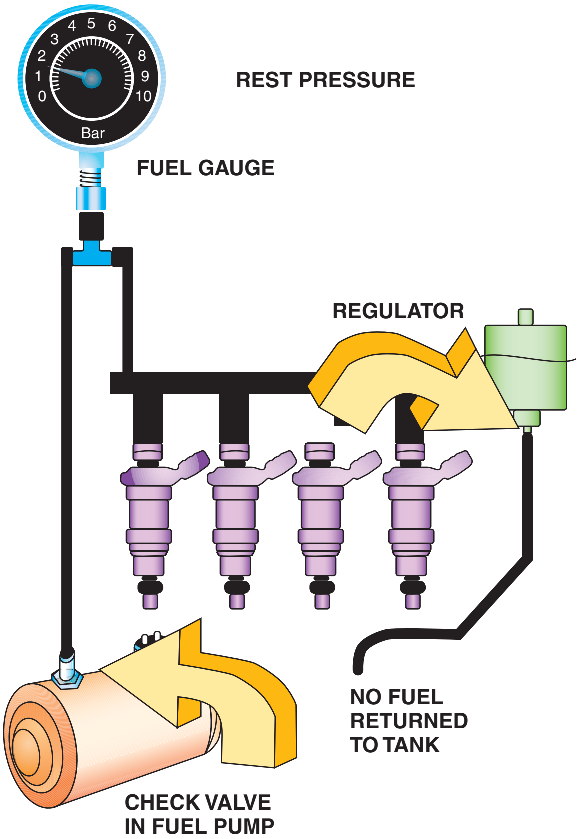


FIGURE 34–23 The fuel system should hold pressure if the system is leak free.

TECH TIP

The Fuel-Pressure Stethoscope Test

When the fuel pump is energized and the engine is not running, fuel should be heard flowing back to the fuel tank at the outlet of the fuel-pressure regulator. ● **SEE FIGURE 34–25.** If fuel is heard flowing through the return line, the fuel-pump pressure is higher than the regulator pressure. If no sound of fuel is heard, either the fuel pump or the fuel-pressure regulator is at fault.

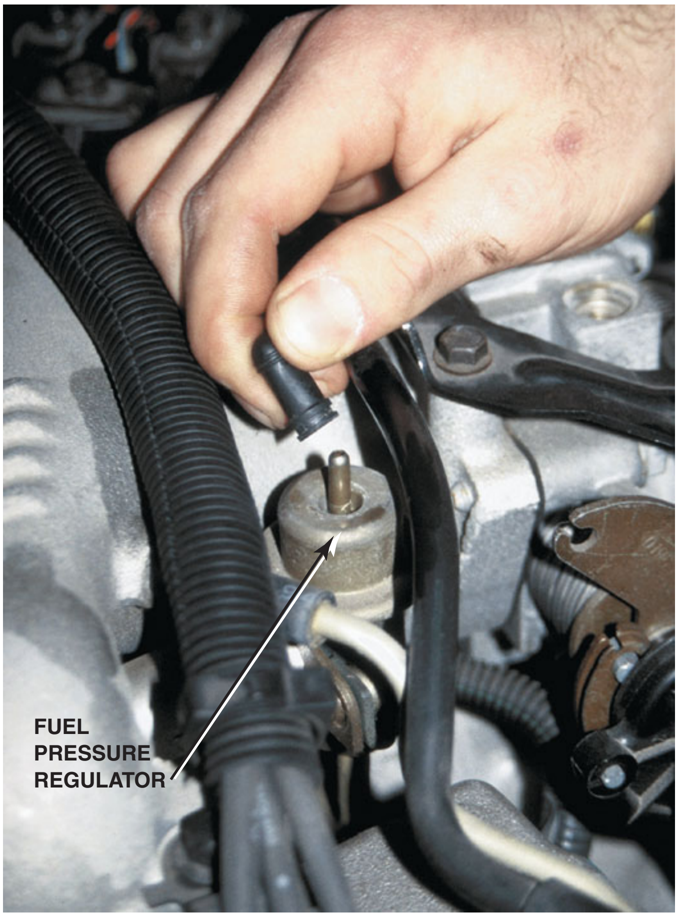


FIGURE 34–24 If the vacuum hose is removed from the fuel-pressure regulator when the engine is running, the fuel pressure should increase. If it does not increase, then the fuel pump is not capable of supplying adequate pressure or the fuel-pressure regulator is defective. If gasoline is visible in the vacuum hose, the regulator is leaking and should be replaced.

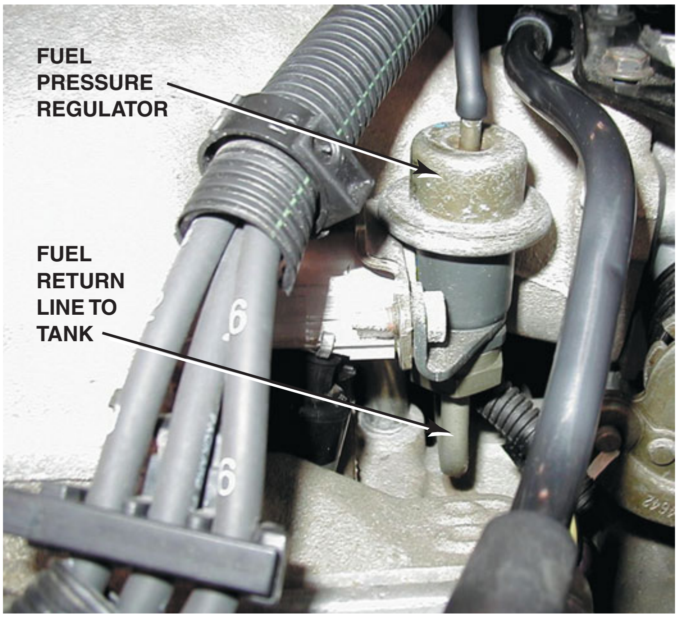


FIGURE 34–25 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel pump and fuel-pressure regulator are functioning correctly.

TESTING FUEL-PUMP VOLUME

Fuel pressure alone is not enough for proper engine operation. ● **SEE FIGURE 34–26.** Sufficient fuel capacity (flow) should be at least 2 pints (1 liter) every 30 seconds or 1 pint in 15 seconds. Fuel flow specifications are usually expressed in gallons per minute. A typical specification would be 0.5 gallons per minute or more. Volume testing is shown in ● **FIGURE 34–27.**

All fuel must be filtered to prevent dirt and impurities from damaging the fuel system components and/or engine. The first filter is inside the gas tank and is usually not replaceable separately but is attached to the fuel pump (if the pump is electric) and/or fuel gauge sending unit. The replaceable fuel filter is usually located between the fuel tank and the fuel rail or inlet to the fuel-injection system. Most vehicle manufacturers state in service information when to replace the fuel filter. Most newer vehicles, that use returnless-type fuel injection systems, do not have replaceable filters as they are built into the fuel pump module assembly. (Check the

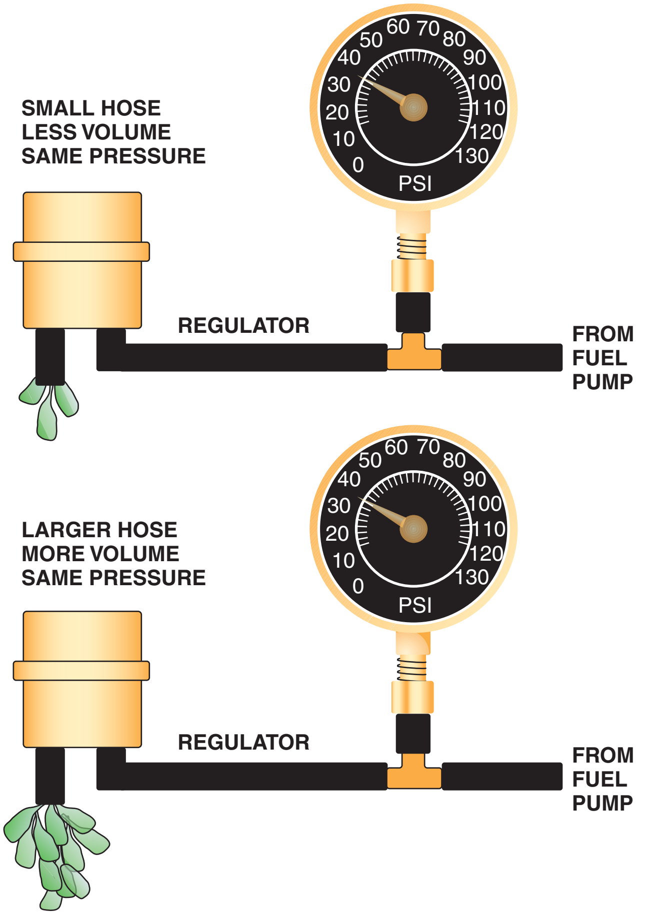


FIGURE 34–26 A fuel-pressure reading does not confirm that there is enough fuel volume for the engine to operate correctly.

FIGURE 34–27 A fuel system tester connected in series in the fuel system so all of the fuel used flows through the meter which displays the rate-of-flow and the fuel pressure.

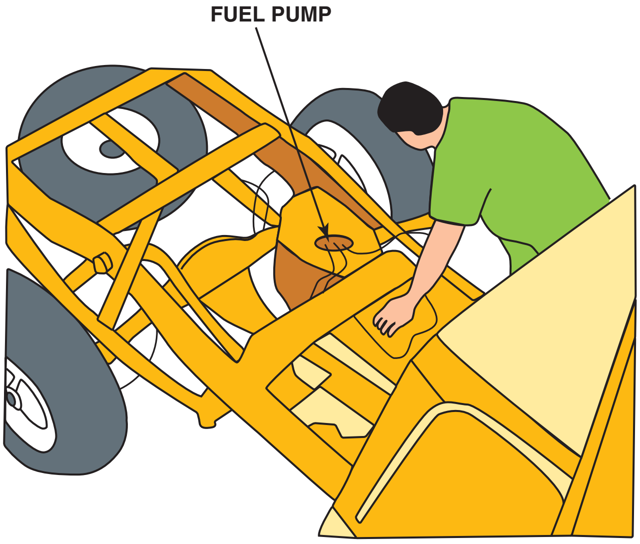


FIGURE 34–28 Removing the bed from a pickup truck makes gaining access to the fuel pump a lot easier.

vehicle manufacturers' recommendations for exact time and mileage intervals.)

If the fuel filter becomes partially clogged, the following are likely to occur:

1. There will be low power at higher engine speeds. The vehicle usually will not go faster than a certain speed (engine acts as if it has a built-in speed governor).
2. The engine will cut out or miss on acceleration, especially when climbing hills or during heavy-load acceleration.

A weak or defective fuel pump can also be the cause of the symptoms just listed. If an electric fuel pump for a fuel-injected engine becomes weak, additional problems include the following:

1. The engine may be hard to start.
2. There may be a rough idle and stalling.

TECH TIP

Quick and Easy Fuel Volume Test

Testing for pump volume involves using a specialized tester or a fuel-pressure gauge equipped with a hose to allow the fuel to be drawn from the system into a container with volume markings to allow for a volume measurement. This test can be hazardous because of flammable gasoline vapors. An alternative test involves connecting a fuel-pressure gauge to the system with the following steps:

STEP 1 Start the engine and observe the fuel-pressure gauge. The reading should be within factory specifications (typically between 35 PSI and 45 PSI).

STEP 2 Remove the hose from the fuel-pressure regulator. The pressure should increase if the system uses a demand-type regulator.

STEP 3 Rapidly accelerate the engine while watching the fuel-pressure gauge. If the fuel volume is okay, the fuel pressure should not drop more than 2 PSI. If the fuel pressure drops more than 2 PSI, replace the fuel filter and retest.

STEP 4 After replacing the fuel filter, accelerate the engine and observe the pressure gauge. If the pressure drops more than 2 PSI, replace the fuel pump.

NOTE: The fuel pump could still be delivering less than the specified volume of fuel, but as long as the volume needed by the engine is met, the pressure will not drop. If, however, the vehicle is pulling a heavy load, the demand for fuel volume may exceed the capacity of the pump.

TECH TIP

Remove the Bed to Save Time?

The electric fuel pump is easier to replace on many General Motors pickup trucks if the bed is removed. Access to the top of the fuel tank, where the access hole is located, for the removal of the fuel tank sender unit and pump is restricted by the bottom of the pickup truck bed. Rather than drop the tank, it is often much easier to use an engine hoist or a couple of other technicians to lift the bed from the frame after removing only a few fasteners. ● **SEE FIGURE 34–28.**

CAUTION: Be sure to clean around the fuel pump opening so that dirt or debris does not enter the tank when the fuel pump is removed.

3. There may be erratic shifting of the automatic transmission as a result of engine missing due to lack of fuel-pump pressure and/or volume.

CAUTION: Be certain to consult the vehicle manufacturers' recommended service and testing procedures before attempting to test or replace any component of a high-pressure electronic fuel-injection system.

FUEL-PUMP CURRENT DRAW TEST

Another test that can and should be performed on a fuel pump is to measure the current draw in amperes. This test is most often performed by connecting a digital multimeter set to read DC amperes and test the current draw. ● **SEE FIGURE 34–29** for the hookup for vehicles equipped with a fuel-pump relay. Compare the reading to factory specifications. See the chart for an example of typical fuel-pump current draw readings.

NOTE: Testing the current draw of an electric fuel pump may not indicate whether the pump is good. A pump that is not rotating may draw normal current.

Using a mini clamp on ammeter is a quick and easy way to measure fuel pump current. Clamp the inductive probe around a wire to the fuel pump or add a fused jumper wire to replace the fuel pump fuse. Start the engine and read the meter display.

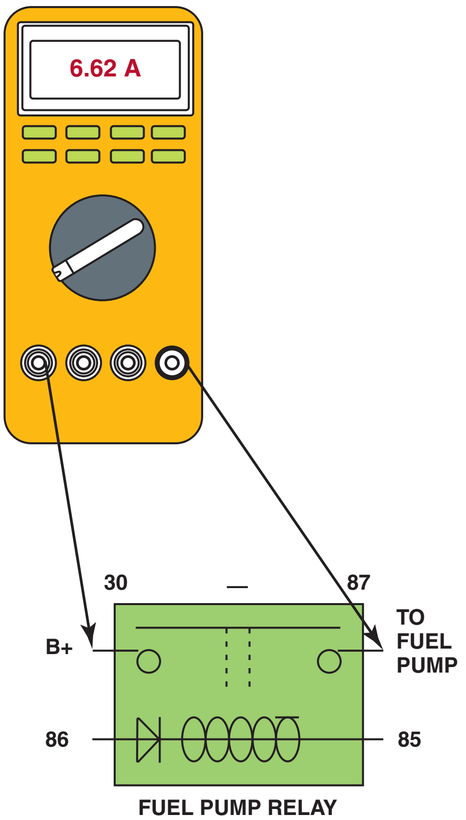


FIGURE 34–29 Hookup for testing fuel-pump current draw on any vehicle equipped with a fuel-pump relay.

Fuel-Pump Current Draw Table

Amperage Reading	Expected Value	Amperage Too High	Amperage Too Low
Throttle-Body Fuel-Injection Engines	2 to 5 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
Port Fuel-Injection Engines	4 to 8 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
Turbo Engines	6 to 10 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
GM CPI Truck Engines	8 to 12 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.

FUEL-PUMP REPLACEMENT

The following recommendations should be followed whenever replacing an electric fuel pump:

- Clean around the fuel pump retainer area before removing the fuel pump assembly.
- The fuel-pump strainer (sock) should be replaced with the new pump.
- If the original pump had a defector shield, it should always be used to prevent fuel return bubbles from blocking the inlet to the pump.
- Always check the interior of the fuel tank for evidence of contamination or dirt.
- Double-check that the replacement pump is correct for the application.
- Check that the wiring and electrical connectors are clean and tight.

Fuel Supply-Related Symptom Guide

Problem	Possible Causes
Pressure too high after engine start-up.	1. Defective fuel-pressure regulator 2. Restricted fuel return line 3. Excessive system voltage 4. Wrong fuel pump
Pressure too low after engine start-up.	1. Stuck-open pressure regulator 2. Low voltage 3. Poor ground 4. Plugged fuel filter 5. Faulty inline fuel pump 6. Faulty in-tank fuel pump 7. Partially clogged filter sock 8. Faulty hose coupling 9. Leaking fuel line 10. Wrong fuel pump 11. Leaking pulsator 12. Restricted accumulator 13. Faulty pump check valves 14. Faulty pump installation
Pressure drops off with key on/engine off. With key off, the pressure does not hold.	1. Leaky pulsator 2. Leaking fuel-pump coupling hose 3. Faulty fuel pump (check valves) 4. Faulty pressure regulator 5. Leaking fuel injector 6. Faulty installation 7. Lines leaking

SUMMARY

1. The fuel delivery system includes the following items:
   - Fuel tank
   - Fuel pump
   - Fuel filter(s)
   - Fuel lines
2. A fuel tank is either constructed of steel with a tin plating for corrosion resistance or polyethylene plastic.
3. Fuel tank filler tubes contain an anti-siphoning device.
4. Accident and rollover protection devices include check valves and inertia switches.
5. Most fuel lines are made of nylon plastic.
6. Electric fuel-pump types include: roller cell, gerotor, and turbine.
7. Fuel filters remove particles that are 10 to 20 microns or larger in size and should be replaced regularly.
8. Fuel pumps can be tested by checking:
   - Pressure
   - Volume
   - Specified current draw

REVIEW QUESTIONS

1. What are the two materials used to construct fuel tanks?
2. What are the three most commonly used pump designs?
3. What is the proper way to disconnect and connect plastic fuel line connections?
4. Where are the fuel filters located in the fuel system?
5. What accident and rollover devices are installed in a fuel delivery system?
6. What three methods can be used to test a fuel pump?

CHAPTER QUIZ

1. The first fuel filter in the sock inside the fuel tank normally filters particles larger than _____________.
   a. 0.001 to 0.003 in.
   b. 0.010 to 0.030 in.
   c. 10 to 20 microns
   d. 70 to 100 microns
2. If it is tripped, which type of safety device will keep the electric fuel pump from operating?
   a. Rollover valve
   b. Inertia switch
   c. Anti-siphoning valve
   d. Check valve
3. Fuel lines are constructed from _____________.
   a. Seamless steel tubing
   b. Nylon plastic
   c. Copper and/or aluminum tubing
   d. Both a and b are used
4. What prevents the fuel pump inside the fuel tank from catching the gasoline on fire?
   a. Electricity is not used to power the pump
   b. No air is around the motor brushes
   c. Gasoline is hard to ignite in a closed space
   d. All of the above
5. A good fuel pump should be able to supply how much fuel per minute?
   a. 1/4 pint
   b. 1/2 pint
   c. 1 pint
   d. 0.5 to 0.8 gallons
6. Technician A says that fuel pump modules are spring-loaded so that they can be compressed to fit into the opening. Technician B says that they are spring-loaded to allow for expansion and contraction of plastic fuel tanks. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Most fuel filters are designed to remove particles larger than _____________.
   a. 10 microns
   b. 20 microns
   c. 70 microns
   d. 100 microns
8. The amperage draw of an electric fuel pump is higher than specified. All of the following are possible causes *except:*
   a. Corroded electrical connections at the pump motor
   b. Clogged fuel filter
   c. Restriction in the fuel line
   d. Defective fuel pump
9. A fuel pump is being replaced for the third time. Technician A says that the gasoline could be contaminated. Technician B says that wiring to the pump could be corroded. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A fuel filter has been accidentally installed backwards. What is the most likely result?
    a. Nothing will be noticed
    b. Reduced fuel economy
    c. Lower power at higher engine speeds and loads
    d. Fuel system pulsation noises may be heard

chapter 35

FUEL-INJECTION COMPONENTS AND OPERATION

OBJECTIVES: After studying Chapter 35, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Describe how a port fuel-injection system works. • Describe the fuel injection modes of operation. • Discuss central port injection (CPI) systems. • Explain how a stepper motor works. • Discuss the purpose and function of the fuel-pressure regulator. • List the types of fuel-injection systems.

KEY TERMS: Demand delivery system (DDS) 508 • Electronic air control (EAC) 512 • Electronic returnless fuel system (ERFS) 507 • Flare 512 • Fuel rail 512 • Gang fired 504 • Idle speed control (ISC) motor 513 • Mechanical returnless fuel system (MRFS) 508 • Nonchecking 507 • Port fuel-injection 501 • Pressure control valve (PCV) 508 • Pressure vent valve (PVV) 508 • Sequential fuel injection (SFI) 504 • Throttle-body injection (TBI) 501

ELECTRONIC FUEL-INJECTION OPERATION

Electronic fuel-injection systems use the Powertrain control module (PCM) to control the operation of fuel injectors and other functions based on information sent to the PCM from the various sensors. Most electronic fuel-injection systems share the following:

1. Electric fuel pump (usually located inside the fuel tank)
2. Fuel-pump relay (usually controlled by the computer)
3. Fuel-pressure regulator (mechanically operated spring-loaded rubber diaphragm maintains proper fuel pressure)
4. Fuel-injector nozzle or nozzles

● **SEE FIGURE 35–1.** Most electronic fuel-injection systems use the computer to control these aspects of their operation:

1. **Pulsing the fuel injectors on and off.** The longer the injectors are held open, the greater the amount of fuel injected into the cylinder.
2. **Operating the fuel pump relay circuit.** The computer usually controls the operation of the electric fuel pump located inside (or near) the fuel tank. The computer uses signals from the ignition switch and RPM signals from the ignition module or system to energize the fuel-pump relay circuit.

NOTE: This is a safety feature, because if the engine stalls and the tachometer (engine speed) signal is lost, the computer will shut off (de-energize) the fuel-pump relay and stop the fuel pump.

Computer-controlled fuel-injection systems are normally reliable systems if the proper service procedures are followed. Fuel-injection systems use the gasoline flowing through the injectors to lubricate and cool the injector electrical windings and pintle valves.

NOTE: The fuel does not actually make contact with the electrical windings because the injectors have O-rings at the top and bottom of the winding spool to keep fuel out.

There are two types of electronic fuel-injection systems:

- **Throttle-body-injection (TBI)** type. A TBI system delivers fuel from a nozzle(s) into the air above the throttle plate. ● **SEE FIGURE 35–2.**
- **Port fuel-injection**-type. A port fuel-injection design uses a nozzle for each cylinder and the fuel is squirted into the intake manifold about 2 to 3 inches (70 to 100 mm) from the intake valve. ● **SEE FIGURE 35–3.**

SPEED-DENSITY FUEL-INJECTION SYSTEMS

Fuel-injection computer systems require a method for measuring the amount of air the engine is breathing in, in order to match the correct fuel delivery. There are two basic methods used:

1. Speed density
2. Mass airflow

The speed-density method does not require an air quantity sensor, but rather calculates the amount of fuel required by the

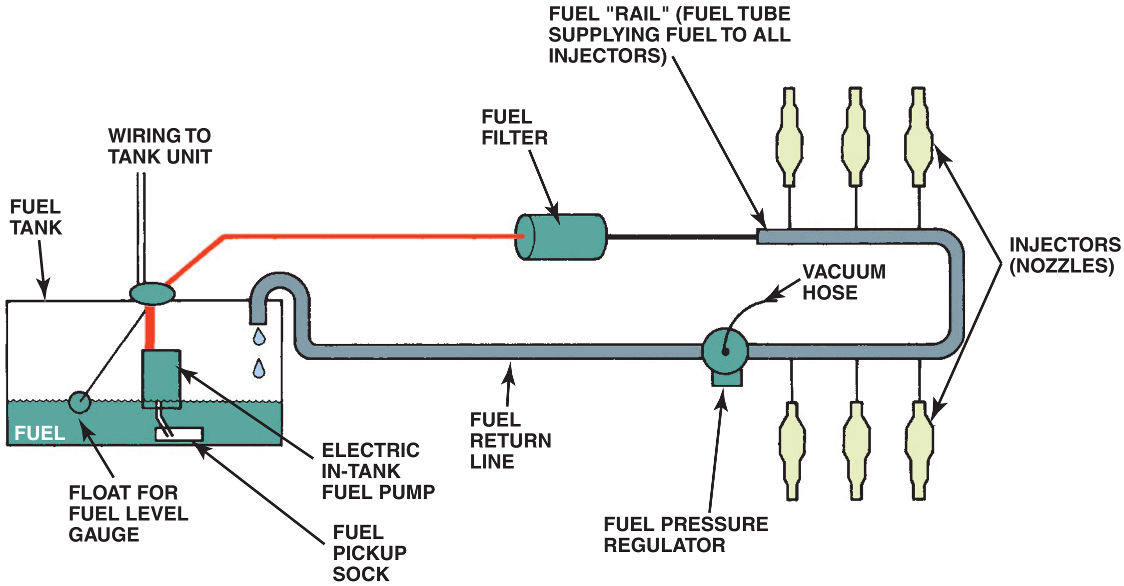


FIGURE 35–1 Typical port fuel-injection system, indicating the location of various components. Notice that the fuel-pressure regulator is located on the fuel return side of the system. The computer does not control fuel pressure. But does control the operation of the electric fuel pump (on most systems) and the pulsing on and off of the injectors.

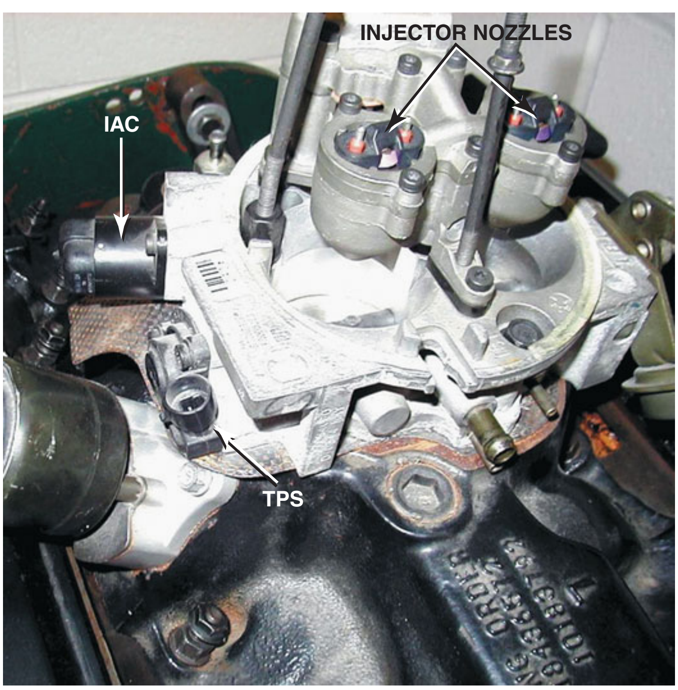


FIGURE 35–2 A dual-nozzle TBI unit on a Chevrolet 4.3-L V-6 engine. The fuel is squirted above the throttle plate where the fuel mixes with air before entering the intake manifold.

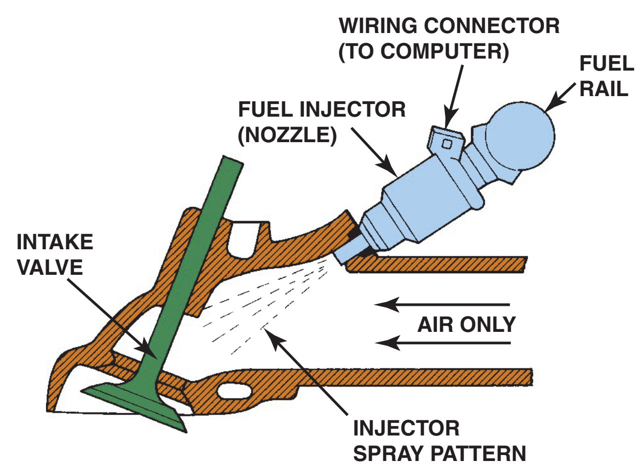


FIGURE 35–3 A typical port fuel-injection system squirts fuel into the low pressure (vacuum) of the intake manifold, about 2 to 3 in. (70 to 100 mm) from the intake valve.

engine. The computer uses information from sensors such as the MAP and TP to calculate the needed amount of fuel.

- **MAP sensor.** The value of the intake (inlet) manifold pressure (vacuum) is a direct indication of engine load.
- **TP sensor.** The position of the throttle plate and its rate of change are used as part of the equation to calculate the proper amount of fuel to inject.

TECH TIP

"Two Must-Do's"

For long service life of the fuel system always do the following:

1. Avoid operating the vehicle on a near-empty tank of fuel. The water or alcohol that may be in the tank becomes more concentrated when the fuel level is low. Dirt that settles near the bottom of the fuel tank can be drawn through the fuel system and cause damage to the pump and injector nozzles.
2. Replace the fuel filter at regular service intervals.

- **Temperature sensors.** Both engine coolant temperature (ECT) and intake air temperature (IAT) are used to calculate the density of the air and the need of the engine for fuel. A cold engine (low-coolant temperature) requires a richer air–fuel mixture than a warm engine.

On speed-density systems, the computer calculates the amount of air in each cylinder by using manifold pressure and engine RPM. The amount of air in each cylinder is the major factor in determining the amount of fuel needed. Other sensors provide information to modify the fuel requirements. The formula used to determine the injector pulse width (PW) in milliseconds (ms) is:

Injector pulse width = MAP/BARO × RPM/maximum RPM

The formula is modified by values from other sensors, including:

- Throttle position (TP)
- Engine coolant temperature (ECT)
- Intake air temperature (IAT)
- Oxygen sensor voltage (O2S)
- Adaptive memory

A fuel injector delivers atomized fuel into the airstream where it is instantly vaporized. All throttle-body (TB) fuel-injection systems and many multipoint (port) injection systems use the speed-density method of fuel calculation.

MASS AIRFLOW FUEL-INJECTION SYSTEMS

The formula used by fuel-injection systems that use a mass airflow (MAF) sensor to calculate the injection base pulse width is:

Injector pulse width = airflow/RPM

The formula is modified by other sensor values such as:

- Throttle position
- Engine coolant temperature
- Barometric pressure
- Adaptive memory

NOTE: Many four-cylinder engines do not use a MAF sensor because, due to the time interval between intake events, some reverse airflow can occur in the intake manifold. The MAF sensor would "read" this flow of air as being additional air entering the engine, giving the PCM incorrect airflow information. Therefore, most four-cylinder engines use the speed-density method of fuel control.

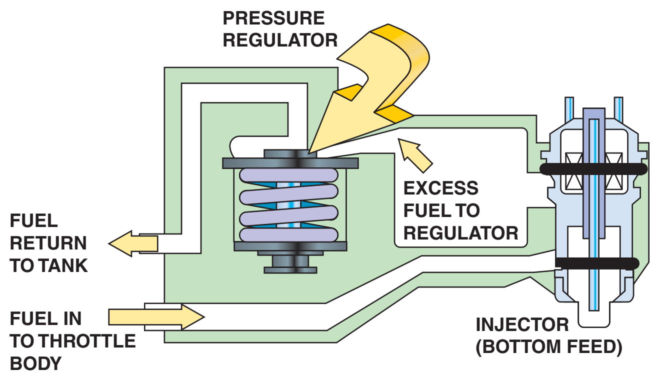


FIGURE 35–4 The tension of the spring in the fuel-pressure regulator determines the operating pressure on a throttle-body fuel-injection unit.

THROTTLE-BODY INJECTION

The computer controls injector pulses in one of two ways:

- Synchronized
- Nonsynchronized

If the system uses a synchronized mode, the injector pulses once for each distributor reference pulse. In some vehicles, when dual injectors are used in a synchronized system, the injectors pulse alternately. In a nonsynchronized system, the injectors are pulsed once during a given period (which varies according to calibration) completely independent of distributor reference pulses.

The injector always opens the same distance, and the fuel pressure is maintained at a controlled value by the pressure regulator. The regulators used on throttle-body injection systems are not connected to a vacuum like many port fuel-injection systems. The strength of the spring inside the regulator determines at what pressure the valve is unseated, sending the fuel back to the tank and lowering the pressure. ● **SEE FIGURE 35–4.** The amount of fuel delivered by the injector depends on the amount of time (on-time) that the nozzle is open. This is the injector pulse width—the on-time in milliseconds that the nozzle is open.

The PCM commands a variety of pulse widths to supply the amount of fuel that an engine needs at any specific moment.

- A long pulse width delivers more fuel.
- A short pulse width delivers less fuel.

PORT-FUEL INJECTION

The advantages of port fuel-injection design also are related to characteristics of intake manifolds:

- Fuel distribution is equal to all cylinders because each cylinder has its own injector. ● **SEE FIGURE 35–5.**

FREQUENTLY ASKED QUESTION

How Do the Sensors Affect the Pulse Width?

The base pulse width of a fuel-injection system is primarily determined by the value of the MAF or MAP sensor and engine speed (RPM). However, the PCM relies on the input from many other sensors to modify the base pulse width as needed. For example,

- **TP Sensor.** This sensor causes the PCM to command up to 500% (5 times) the base pulse width if the accelerator pedal is depressed rapidly to the floor. It can also reduce the pulse width by about 70% if the throttle is rapidly closed.
- **ECT.** The value of this sensor determines the temperature of the engine coolant, helps determine the base pulse width, and can account for up to 60% of the determining factors.
- **BARO.** The BARO sensor compensates for altitude and adds up to about 10% under high-pressure conditions and subtracts as much as 50% from the base pulse width at high altitudes.
- **IAT.** The intake air temperature is used to modify the base pulse width based on the temperature of the air entering the engine. It is usually capable of adding as much as 20% if very cold air is entering the engine or reduce the pulse width by up to 20% if very hot air is entering the engine.
- **O2S.** This is one of the main modifiers to the base pulse width and can add or subtract up to about 20% to 25% or more, depending on the oxygen sensor activity.

- The fuel is injected almost directly into the combustion chamber, so there is no chance for it to condense on the walls of a cold intake manifold.
- Because the manifold does not have to carry fuel to properly position a TBI unit, it can be shaped and sized to tune the intake airflow to achieve specific engine performance characteristics.

An EFI injector is simply a specialized solenoid. ● **SEE FIGURE 35–6.** It has an armature winding to create a magnetic field, and a needle (pintle), a disc, or a ball valve. A spring holds the needle, disc, or ball closed against the valve seat, and when energized, the armature winding pulls open the valve when it receives a current pulse from the Powertrain Control Module (PCM). When the solenoid is energized, it unseats the valve to inject fuel.

Electronic fuel-injection systems use a solenoid-operated injector to spray atomized fuel in timed pulses into the manifold or near the intake valve. ● **SEE FIGURE 35–7.** Injectors may be sequenced and fired in one of several ways, but their pulse width is determined and controlled by the engine computer.

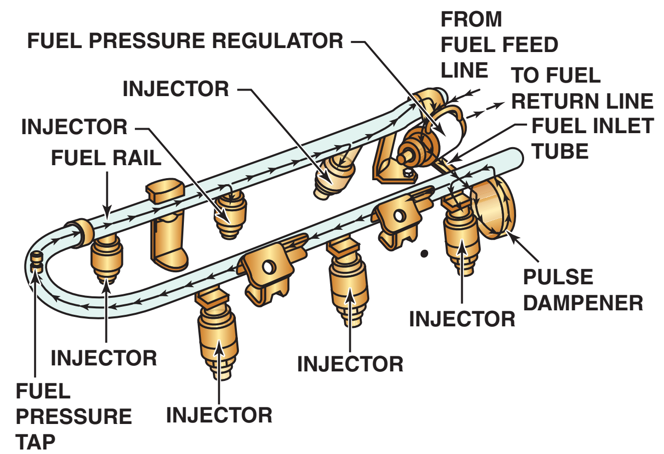


FIGURE 35–5 The injectors receive fuel and are supported by the fuel rail.

Port systems have an injector for each cylinder, but they do not all fire the injectors in the same way. Domestic systems use one of three ways to trigger the injectors:

- Grouped double-fire
- Simultaneous double-fire
- Sequential

GROUPED DOUBLE-FIRE This system divides the injectors into two equalized groups. The groups fire alternately; each group fires once each crankshaft revolution, or twice per four-stroke cycle. The fuel injected remains near the intake valve and enters the engine when the valve opens. This method of pulsing injectors in groups is sometimes called **gang fired**.

SIMULTANEOUS DOUBLE-FIRE This design fires all of the injectors at the same time once every engine revolution: two pulses per four-stroke cycle. Many port fuel-injection systems on four-cylinder engines use this pattern of injector firing. It is easier for engineers to program this system and it can make relatively quick adjustments in the air–fuel ratio, but it still requires the intake charge to wait in the manifold for varying lengths of time.

SEQUENTIAL Sequential firing of the injectors according to engine firing order is the most accurate and desirable method of regulating port fuel injection. However, it is also the most complex and expensive to design and manufacture. In this system, the injectors are timed and pulsed individually, much like the spark plugs are sequentially operated in firing order of the engine. This system is often called **sequential fuel injection** or **SFI.** Each cylinder receives one charge every two crankshaft revolutions, just before the intake valve opens. This means that the mixture is never static in the intake manifold and mixture adjustments can be made almost instantaneously between the firing of one injector and the next. A camshaft position sensor (CMP) signal or a special distributor reference pulse informs the PCM when the No. 1 cylinder is on its compression stroke. If the sensor fails or the reference pulse is interrupted, some injection systems shut down, while others revert to pulsing the injectors simultaneously.

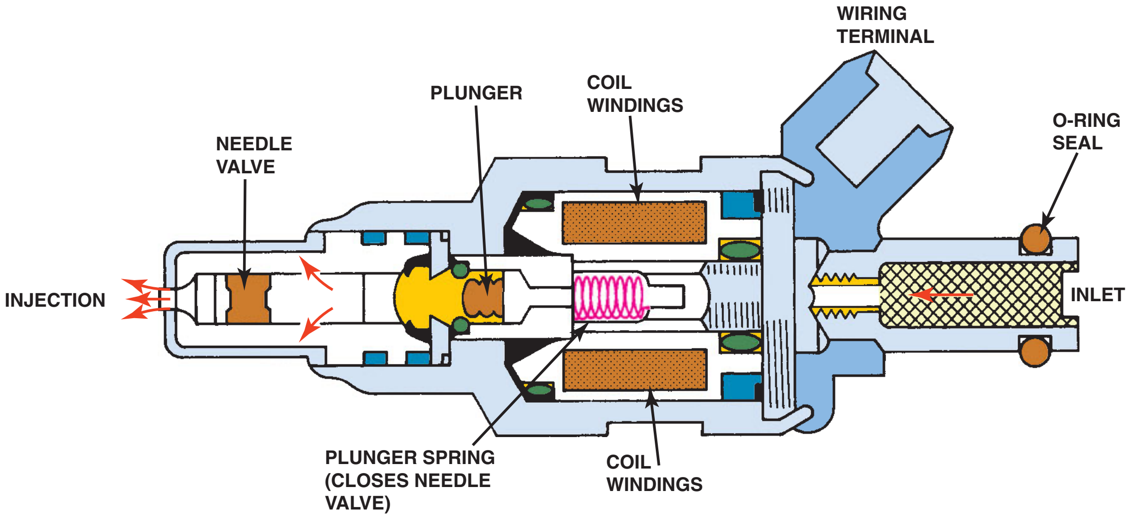


FIGURE 35–6 Cross-section of a typical port fuel-injection nozzle assembly. These injectors are serviced as an assembly only; no part replacement or service is possible except for replacement of external O-ring seals.

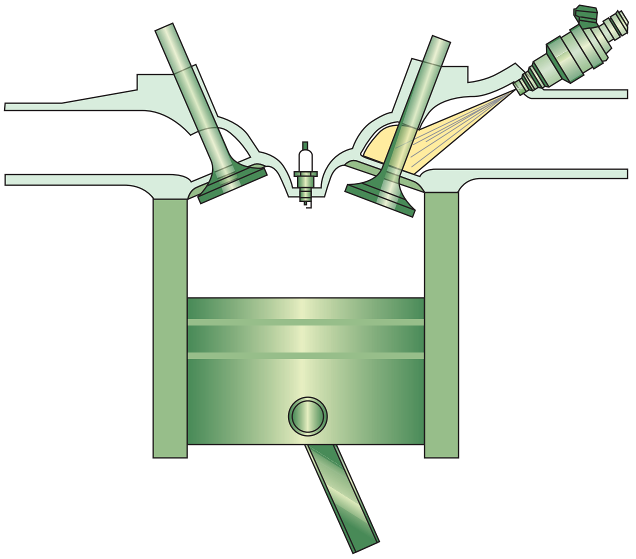


FIGURE 35–7 Port fuel injectors spray atomized fuel into the intake manifold about 3 inches (75 mm) from the intake valve.

FIGURE 35–8 A port fuel-injected engine that is equipped with long, tuned intake manifold runners.

? FREQUENTLY ASKED QUESTION

How Can It Be Determined If the Injection System Is Sequential?

Look at the color of the wires at the injectors. If a sequentially fired injector is used, then one wire color (the pulse wire) will be a different color for each injector. The other wire is usually the same color because all injectors receive voltage from some source. If a group- or batch-fired injection system is being used, then the wire colors will be the same for the injectors that are group fired. For example, a V-6 group-fired engine will have three injectors with a pink and blue wire (power and pulse) and the other three will have pink and green wires.

The major advantage of using port injection instead of the simpler throttle-body injection is that the intake manifolds on port fuel-injected engines only contain air, not a mixture of air and fuel. This allows the engine design engineer the opportunity to design long, "tuned" intake-manifold runners that help the engine produce increased torque at low engine speeds. ● **SEE FIGURE 35–8.**

NOTE: Some port fuel-injection systems used on engines with four or more valves per cylinder may use two injectors per cylinder. One injector is used all the time, and the second injector is operated by the computer when high engine speed and high-load conditions are detected by the computer. Typically, the second injector injects fuel into the high-speed intake ports of the manifold. This system permits good low-speed power and throttle responses as well as superior high-speed power.

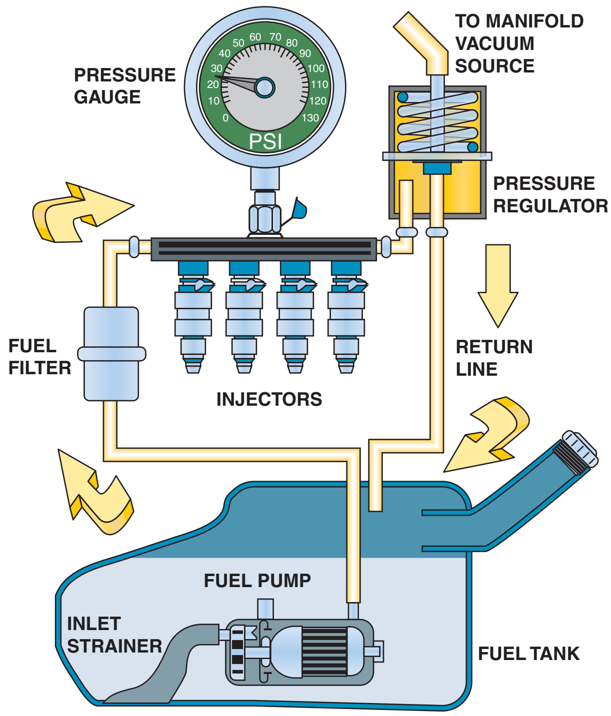


FIGURE 35–9 A typical port fuel-injected system showing a vacuum-controlled fuel-pressure regulator.

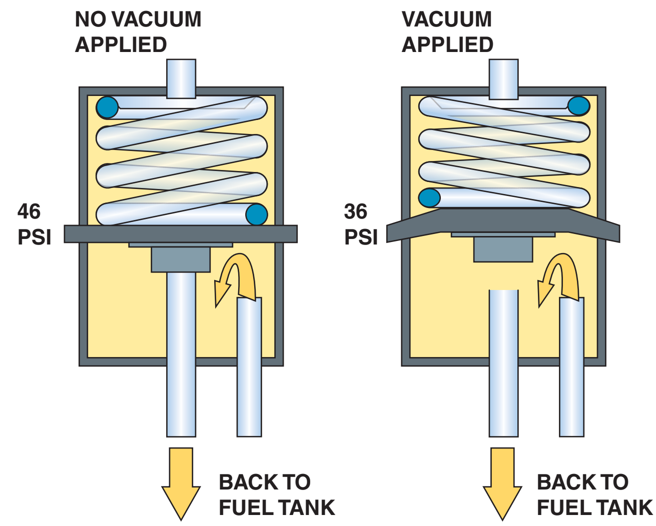


FIGURE 35–10 A typical fuel-pressure regulator that has a spring that exerts 46 pounds of force against the fuel. If 20 inches of vacuum are applied above the spring, the vacuum reduces the force exerted by the spring on the fuel, allowing the fuel to return to the tank at a lower pressure.

FUEL-PRESSURE REGULATOR

The pressure regulator and fuel pump work together to maintain the required pressure drop at the injector tips. The fuel-pressure regulator typically consists of a spring-loaded, diaphragm-operated valve in a metal housing.

Fuel-pressure regulators on fuel-return-type fuel-injection systems are installed on the return (downstream) side of the injectors at the end of the fuel rail, or are built into or mounted upon the throttle-body housing. Downstream regulation minimizes fuel-pressure pulsations caused by pressure drop across the injectors as the nozzles open. It also ensures positive fuel pressure at the injectors at all times and holds residual pressure in the lines when the engine is off. On mechanical returnless systems, the regulator is located back at the tank with the fuel filter.

In order for excess fuel (about 80% to 90% of the fuel delivered) to return to the tank, fuel pressure must overcome spring pressure on the spring-loaded diaphragm to uncover the return line to the tank. This happens when system pressure exceeds operating requirements. With TBI, the regulator is close to the injector tip, so the regulator senses essentially the same air pressure as the injector.

The pressure regulator used in a port fuel-injection system has an intake manifold vacuum line connection on the regulator vacuum chamber. This allows fuel pressure to be modulated by a combination of spring pressure and manifold vacuum acting on the diaphragm. ● **SEE FIGURES 35–9 AND 35–10.**

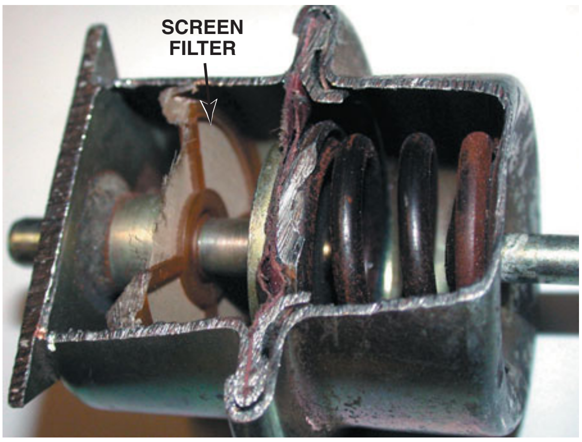


FIGURE 35–11 A lack of fuel flow could be due to a restricted fuel-pressure regulator. Notice the fine screen filter. If this filter were to become clogged, higher than normal fuel pressure would occur.

TECH TIP

Don't Forget the Regulator

Some fuel-pressure regulators contain a 10-micron filter. If this filter becomes clogged, a lack of fuel flow would result. ● **SEE FIGURE 35–11.**

In both TBI and port fuel-injection systems, the regulator shuts off the return line when the fuel pump is not running. This maintains pressure at the injectors for easy restarting after hot soak as well as reducing vapor lock.

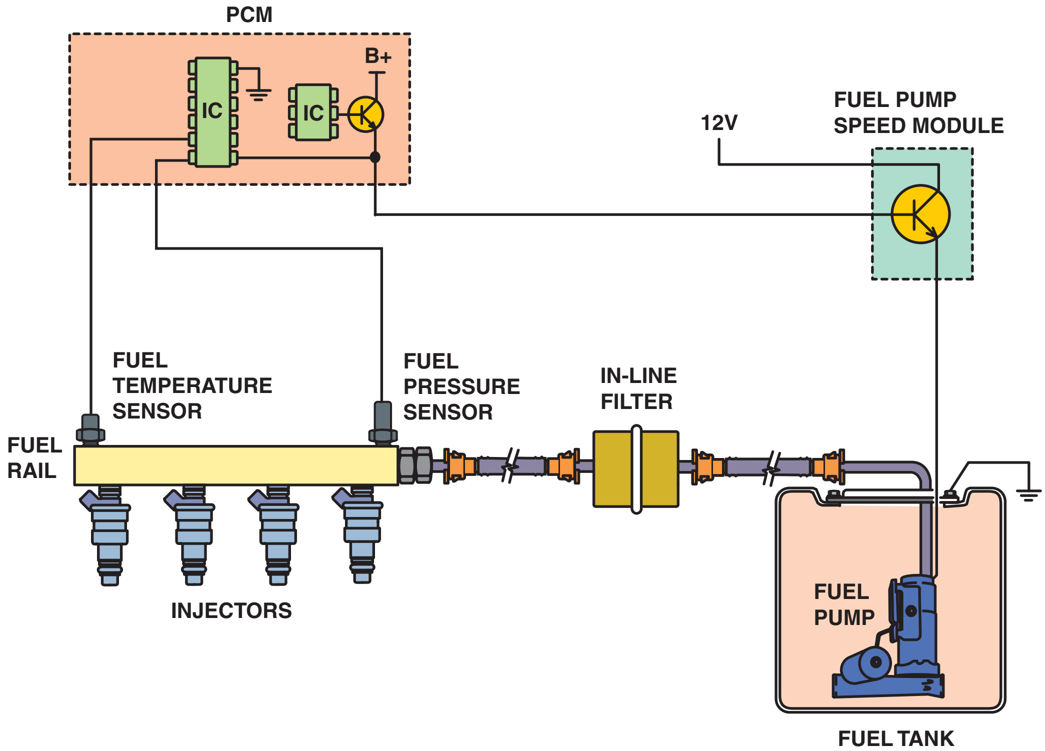


FIGURE 35–12 The fuel-pressure sensor and fuel-temperature sensor are often constructed together in one assembly to help give the PCM the needed data to control the fuel-pump speed.

NOTE: Some General Motors throttle-body units do not hold pressure and are called nonchecking.

Port fuel-injection systems generally operate with pressures at the injector of about 30 to 55 PSI (207 to 379 kPa), while TBI systems work with injector pressures of about 10 to 20 PSI (69 to 138 kPa). The difference in system pressures results from the difference in how the systems operate. Since injectors in a TBI system inject the fuel into the airflow at the manifold inlet (above the throttle), there is more time for atomization in the manifold before the air–fuel charge reaches the intake valve. This allows TBI injectors to work at lower pressures than injectors used in a port system.

Engine Operating Condition	Intake Manifold Vacuum	Fuel Pressure
Idle or cruise	High	Lower
Heavy load	Low	Higher

The computer can best calculate injector pulse width based on all sensors if the pressure drop across the injector is the same under all operating conditions. A vacuum-controlled fuel-pressure regulator allows the equal pressure drop by reducing the force exerted by the regulator spring at high vacuum (low-load condition), yet allowing the full force of the regulator spring to be exerted when the vacuum is low (high-engine-load condition).

VACUUM-BIASED FUEL-PRESSURE REGULATOR

The primary reason why many port fuel-injected systems use a vacuum-controlled fuel-pressure regulator is to ensure that there is a constant pressure drop across the injectors. In a throttle-body fuel-injection system, the injector squirts into the atmospheric pressure regardless of the load on the engine. In a port fuel-injected engine, however, the pressure inside the intake manifold changes as the load on the engine increases.

ELECTRONIC RETURNLESS FUEL SYSTEM

This system is unique because it does not use a mechanical valve to regulate rail pressure. Fuel pressure at the rail is sensed by a pressure transducer, which sends a low-level signal to a controller. The controller contains logic to calculate a signal to the pump power driver. The power driver contains a high-current transistor that controls the pump speed using pulse width modulation (PWM). This system is called the **electronic returnless fuel system (ERFS)**. ● **SEE FIGURE 35–12.** This

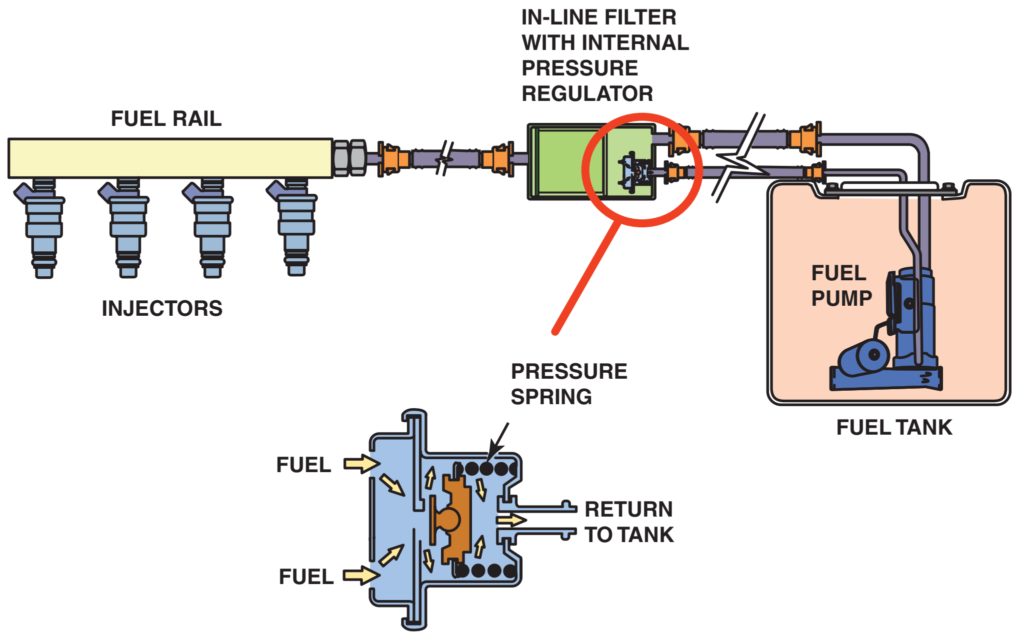


FIGURE 35–13 A mechanical returnless fuel system. The bypass regulator in the fuel filter controls fuel line pressure.

transducer can be differentially referenced to manifold pressure for closed-loop feedback, correcting and maintaining the output of the pump to a desired rail setting. This system is capable of continuously varying rail pressure as a result of engine vacuum, engine fuel demand, and fuel temperature (as sensed by an external temperature transducer, if necessary). A **pressure vent valve (PVV)** is employed at the tank to relieve overpressure due to thermal expansion of fuel. In addition, a supply-side bleed, by means of an in-tank reservoir using a supply-side jet pump, is necessary for proper pump operation.

MECHANICAL RETURNLESS FUEL SYSTEM

The first production returnless systems employed the **mechanical returnless fuel system (MRFS)** approach. This system has a bypass regulator to control rail pressure that is located in close proximity to the fuel tank. Fuel is sent by the in-tank pump to a chassis-mounted inline filter with excess fuel returning to the tank through a short return line. ● **SEE FIGURE 35–13.** The inline filter may be mounted directly to the tank, thereby eliminating the shortened return line. Supply pressure is regulated on the downstream side of the inline filter to accommodate changing restrictions throughout the filter's service life. This system is limited to constant rail pressure (*CRP) system calibrations, whereas with ERFS, the pressure transducer can be referenced to atmospheric pressure for CRP systems or differentially referenced to intake manifold pressure for constant differential injector pressure (**CIP) systems.

NOTE: *CRP is referenced to atmospheric pressure, has lower operating pressure, and is desirable for calibrations using speed/air density sensing. **CIP is referenced to manifold pressure, varies rail pressure, and is desirable in engines that use mass airflow sensing.

DEMAND DELIVERY SYSTEM (DDS)

Given the experience with both ERFS and MRFS, a need was recognized to develop new returnless technologies that could combine the speed control and constant injector pressure attributes of ERFS together with the cost savings, simplicity, and reliability of MRFS. This new technology also needed to address pulsation dampening/hammering and fuel transient response. Therefore, the **demand delivery system (DDS)** technology was developed.

A different form of demand pressure regulator has been applied to the fuel rail. It mounts at the head or port entry and regulates the pressure downstream at the injectors by admitting the precise quantity of fuel into the rail as consumed by the engine. Having demand regulation at the rail improves pressure response to flow transients and provides rail pulsation dampening. A fuel pump and a low-cost, high-performance bypass regulator are used within the appropriate fuel sender. ● **SEE FIGURE 35–14.** They supply a pressure somewhat higher than the required rail set pressure to accommodate dynamic line and filter pressure losses. Electronic pump speed control is accomplished using a smart regulator as an integral flow sensor. A **pressure control valve (PCV)** may also be used and can readily reconfigure an existing design fuel sender into a returnless sender.

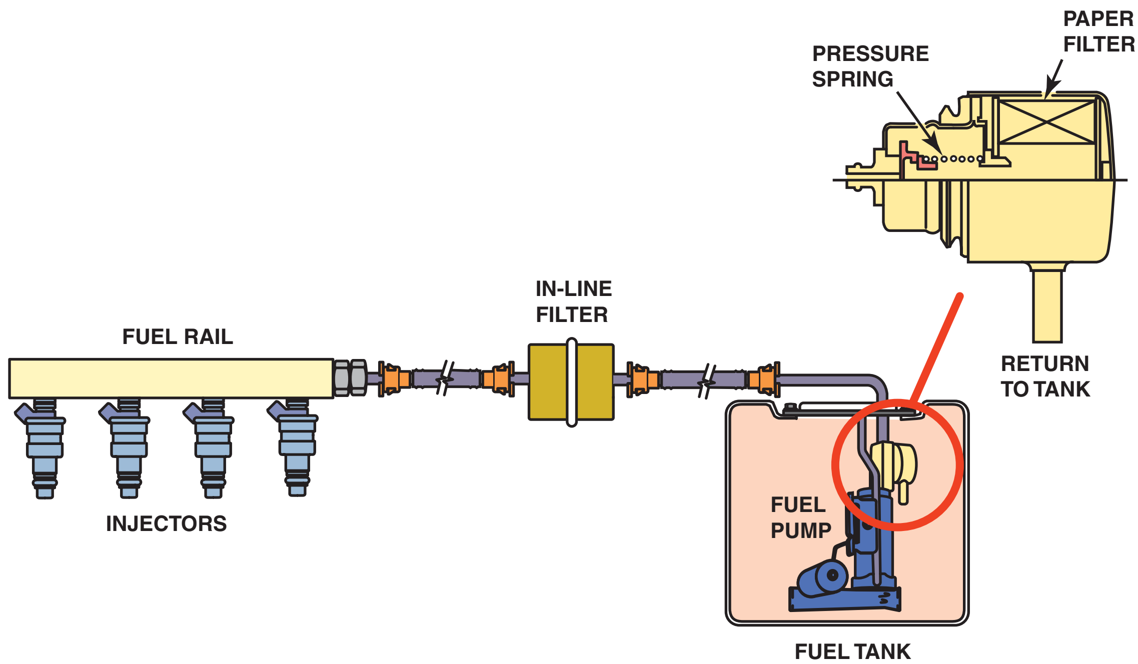


FIGURE 35–14 A demand delivery system uses a fuel pressure regulator attached to the fuel pump assembly.

? FREQUENTLY ASKED QUESTION

Why Are Some Fuel Rails Rectangular Shaped?

A port fuel-injection system uses a pipe or tubes to deliver fuel from the fuel line to the intended fuel injectors. This pipe or tube is called the **fuel rail**. Some vehicle manufacturers construct the fuel rail in a rectangular cross-section. ● **SEE FIGURE 35–15.** The sides of the fuel rail are able to move in and out slightly, thereby acting as a fuel pulsator evening out the pressure pulses created by the opening and closing of the injectors to reduce underhood noise. A round cross-section fuel rail is not able to deform and, as a result, some manufacturers have had to use a separate dampener.

FIGURE 35–15 A rectangular-shaped fuel rail is used to help dampen fuel system pulsations and noise caused by the injectors opening and closing.

FUEL INJECTORS

EFI systems use a 12 volt solenoid-operated injectors. ● **SEE FIGURE 35–16.** This electromagnetic device contains an armature and a spring-loaded needle valve or ball valve assembly. When the computer energizes the solenoid, voltage is applied to the solenoid coil until the current reaches a specified level. This permits a quick pull-in of the armature during turn-on. The armature is pulled off of its seat against spring force, allowing fuel to flow through the inlet filter screen to the spray nozzle, where it is sprayed in a pattern that varies with application. ● **SEE FIGURE 35–17.** The injector opens the same amount each time it is energized, so the amount of fuel injected depends on the length of time the injector remains open. By angling the director hole plates, the injector sprays fuel more directly at the intake valves, which further atomizes and vaporizes the fuel before it enters the combustion chamber. PFI injectors typically are a top-feed design in which fuel enters the top of the injector and passes through its entire length to keep it cool before being injected.

Ford introduced two basic designs of deposit-resistant injectors on some engines. The design, manufactured by Bosch, uses a four-hole director/metering plate similar to that used by the Rochester Multec injectors. The design manufactured by Nippondenso uses an internal upstream orifice in the adjusting tube. It also has a redesigned pintle/seat containing a wider tip opening that tolerates deposit buildup without affecting injector performance.

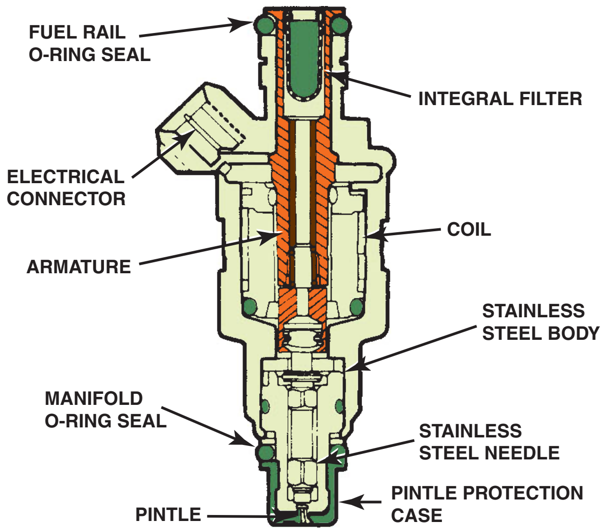


FIGURE 35–16 A multiport fuel injector. Notice that the fuel flows straight through and does not come in contact with the coil windings.

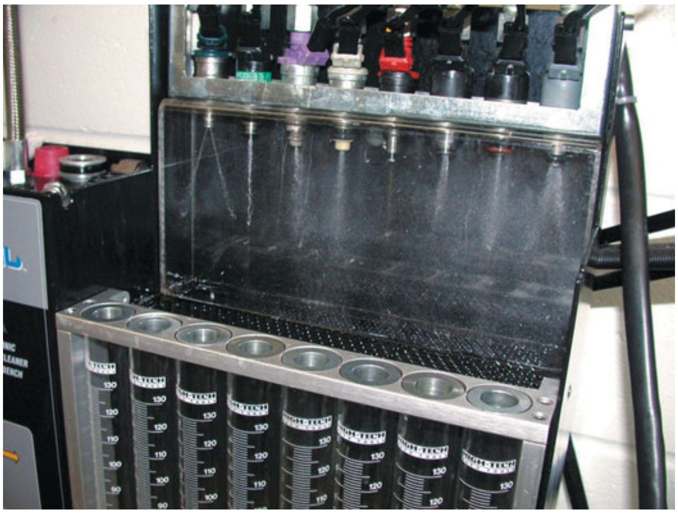


FIGURE 35–17 Each of the eight injectors shown are producing a correct spray pattern for the applications. While all throttle-body injectors spray a conical pattern, most port fuel injections do not.

CENTRAL PORT INJECTION

A cross between port fuel injection and throttle-body injection, CPI was introduced in the early 1990s by General Motors. The CPI assembly consists of a single fuel injector, a pressure regulator, and six poppet nozzle assemblies with nozzle tubes. ● **SEE FIGURE 35–18.** The central sequential fuel injection (CSFI) system has six injectors in place of just one used on the CPI unit.

When the injector is energized, its armature lifts off of the six fuel tube seats and pressurized fuel flows through the nozzle tubes to each poppet nozzle. The increased pressure causes each poppet nozzle ball to also lift from its seat, allowing fuel to flow from the nozzle. This hybrid injection system combines the single injector of a TBI system with the equalized fuel distribution of a PFI system. It eliminates the individual fuel rail while allowing more efficient manifold tuning than is otherwise possible with a TBI system. Newer versions use six individual solenoids to fire one for each cylinder. ● **SEE FIGURE 35–19.**

? FREQUENTLY ASKED QUESTION

How Can the Proper injector Size Be Determined?

Most people want to increase the output of fuel to increase engine performance. Injector sizing can sometimes be a challenge, especially if the size of injector is not known. In most cases, manufacturers publish the rating of injectors, in pounds of fuel per hour (lb/hr). The rate is figured with the injector held open at 3 bars (43.5 PSI). An important consideration is that larger flow injectors have a higher minimum flow rating. Here is a formula to calculate injector sizing when changing the mechanical characteristics of an engine.

Flow rate = hp × BSFC/# of cylinders × maximum duty cycle (% of on-time of the injectors)

- **hp** is the projected horsepower. Be realistic!
- **BSFC** is brake-specific fuel consumption in pounds per horsepower-hour. Calculated values are used for this, 0.4 to 0.8 lb. In most cases, start on the low side for naturally aspirated engines and the high side for engines with forced induction.
- **# of cylinders** is actually the number of injectors being used.
- **Maximum duty cycle** is considered at 0.8 (80%). Above this, the injector may overheat, lose consistency, or not work at all.

For example:

5.7 liter V-8 = 240 hp × 0.65/8 cylinders × 8
= 24.37 lb/hr injectors required

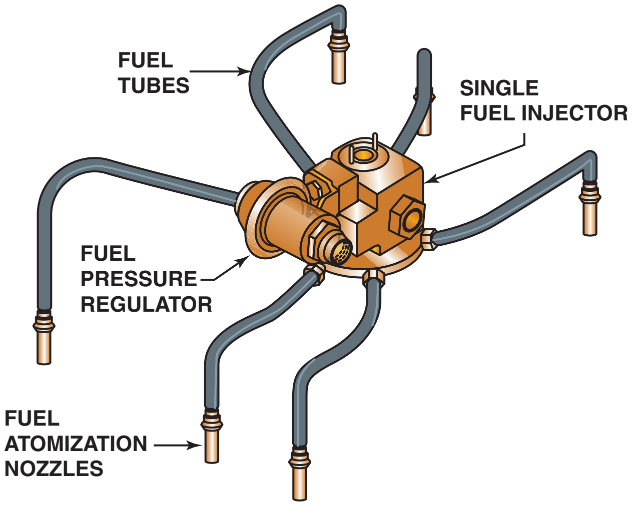


FIGURE 35–18 A central port fuel-injection system.

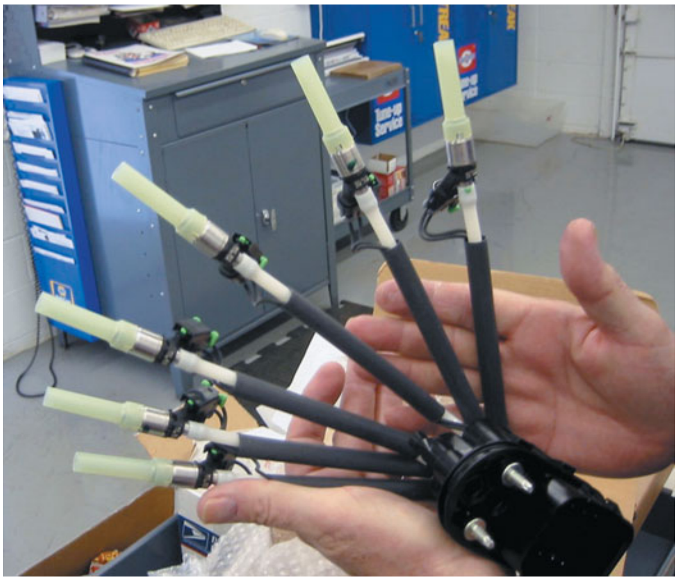


FIGURE 35–19 A factory replacement unit for a CSFI unit that has individual injectors at the ends that go into the intake manifold instead of poppet valves.

FREQUENTLY ASKED QUESTION

What Is Battery Voltage Correction?

Battery voltage correction is a program built into the PCM that causes the injector pulse width to increase if there is a drop in electrical system voltage. Lower battery voltage would cause the fuel injectors to open slower than normal and the fuel pump to run slower. Both of these conditions can cause the engine to run leaner than normal if the battery voltage is low. Because a lean air–fuel mixture can cause the engine to overheat, the PCM compensates for the lower voltage by adding a percentage to the injector pulse width. This richer condition will help prevent serious engine damage. The idle speed is also increased to turn the alternator faster if low battery voltage is detected.

FUEL-INJECTION MODES OF OPERATION

All fuel-injection systems are designed to supply the correct amount of fuel under a wide range of engine operating conditions. These modes of operation include:

Starting (cranking)	Acceleration enrichment
Clear flood	Deceleration enleanment
Idle (run)	Fuel shutoff

STARTING MODE When the ignition is turned to the start position, the engine cranks and the PCM energizes the fuel pump relay. The PCM also pulses the injectors on, basing the pulse width on engine speed and engine coolant temperature. The colder the engine is, the greater the pulse width. Cranking mode air–fuel ratio varies from about 1.5:1 at −40°F (−40°C) to 14.7:1 at 200°F (93°C).

CLEAR FLOOD MODE If the engine becomes flooded with too much fuel, the driver can depress the accelerator pedal to greater than 80% to enter the clear flood mode. When the PCM detects that the engine speed is low (usually below 600 RPM) and the throttle-position (TP) sensor voltage is high (WOT), the injector pulse width is greatly reduced or even shut off entirely, depending on the vehicle.

OPEN-LOOP MODE Open-loop operation occurs during warm-up before the oxygen sensor can supply accurate information to the PCM. The PCM determines injector pulse width based on values from the MAF, MAP, TP, ECT, and IAT sensors.

CLOSED-LOOP MODE Closed-loop operation is used to modify the base injector pulse width as determined by feedback from the oxygen sensor to achieve proper fuel control.

ACCELERATION ENRICHMENT MODE During acceleration, the throttle-position (TP) voltage increases, indicating that a richer air–fuel mixture is required. The PCM then supplies a longer injector pulse width and may even supply extra pulses to supply the needed fuel for acceleration.

DECELERATION ENLEANMENT MODE When the engine decelerates, a leaner air–fuel mixture is required to help reduce emissions and to prevent deceleration backfire. If the deceleration is rapid, the injector may be shut off entirely for a short time and then pulsed on enough to keep the engine running.

FUEL SHUTOFF MODE Besides shutting off fuel entirely during periods of rapid deceleration, PCM also shuts off the injector when the ignition is turned off to prevent the engine from continuing to run.

IDLE CONTROL

Port fuel-injection systems generally use an auxiliary air bypass to control idle speed. ● **SEE FIGURE 35–20.** This air bypass or regulator provides needed additional airflow, and thus more fuel. The engine needs more power when cold to maintain its normal idle speed to overcome the increased friction from cold lubricating oil. It does this by opening an intake air passage to let more air into the engine just as depressing the accelerator pedal would open the throttle valve, allowing more air into the engine. The system is calibrated to maintain engine idle speed at a specified value regardless of engine temperature.

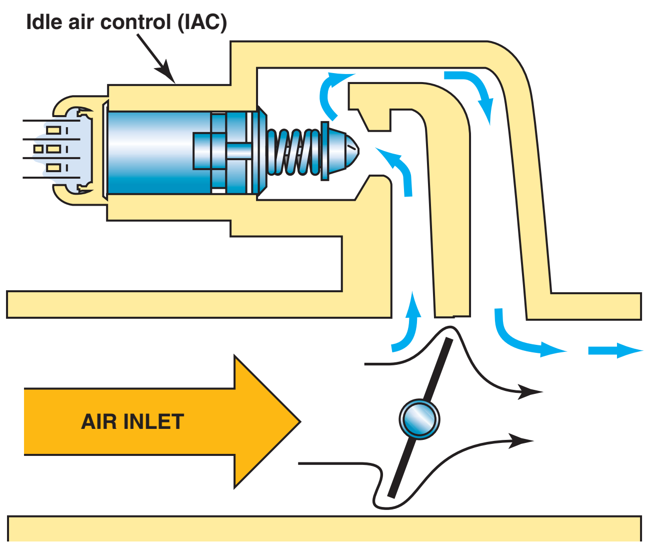


FIGURE 35–20 The small arrows indicate the air bypassing the throttle plate in the closed throttle position. This air is called minimum air. The air flowing through the IAC (blue arrows) is the airflow that determines the idle speed.

Most PFI systems use an idle air control (IAC) motor to regulate idle bypass air. The IAC is computer-controlled, and is either a solenoid-operated valve or a stepper motor that regulates the airflow around the throttle. The idle air control valve is also called an **electronic air control (EAC)** valve.

When the engine stops, most IAC units will retract outward to get ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine **flare**. If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).

STEPPER MOTOR OPERATION

A digital output is used to control stepper motors. Stepper motors are direct-current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion.

A common use for stepper motors is as an idle air control (IAC) valve, which controls engine idle speeds and prevents stalls due to changes in engine load. When used as an IAC, the stepper motor is usually a reversible DC motor that moves in increments, or steps. The motor moves a shaft back and forth to operate a conical valve. When the conical valve is moved back, more air bypasses the throttle plates and enters the engine, increasing idle speed. As the conical valve moves inward, the idle speed decreases.

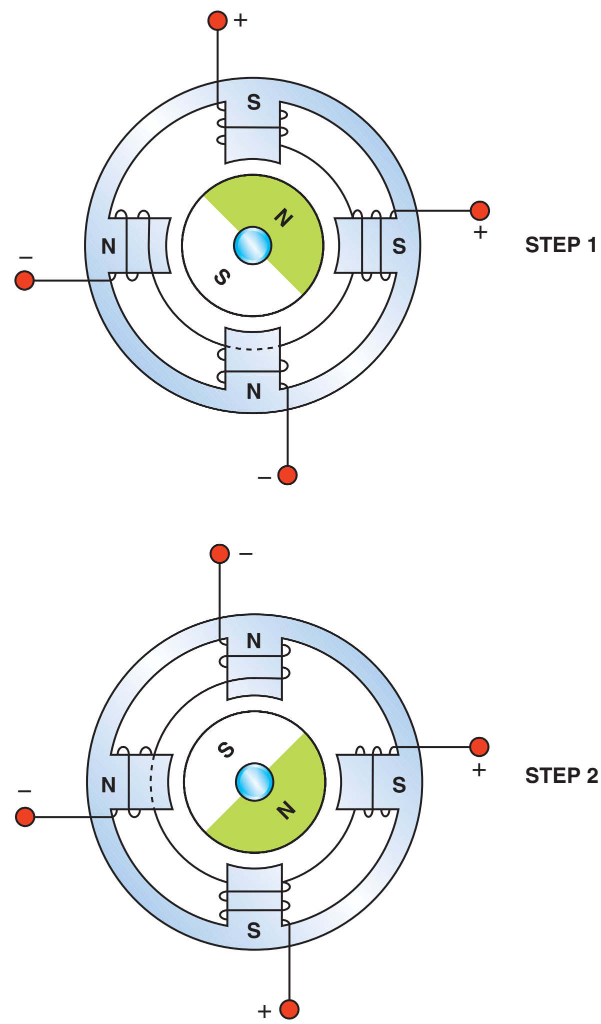


FIGURE 35–21 Most stepper motors use four wires, which are pulsed by the computer to rotate the armature in steps.

When using a stepper motor that is controlled by the PCM, it is very easy for the PCM to keep track of the position of the stepper motor. By counting the number of steps that have been sent to the stepper motor, the PCM can determine the relative position of the stepper motor. While the PCM does not actually receive a feedback signal from the stepper motor, it does know how many steps forward or backward the motor should have moved.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate 90 degrees at a time. Each 90-degree pulse is recorded by the computer as a “count” or “step”; therefore, the name given to this type of motor. ● **SEE FIGURE 35–21.**

FREQUENTLY ASKED QUESTION

Why Does the Idle Air Control Valve Use Milliamperes?

Some Chrysler vehicles, such as the Dodge minivan, use linear solenoid idle air control valves (LSIAC). The PCM uses regulated current flow through the solenoid to control idle speed and the scan tool display is in milliamperes (mA).

Closed position = 180 to 200 mA
Idle = 300 to 450 mA
Light cruise = 500 to 700 mA
Fully open = 900 to 950 mA

Idle airflow in a TBI system travels through a passage around the throttle and is controlled by a stepper motor. In some applications, an externally mounted permanent magnet motor called the **idle speed control (ISC) motor** mechanically advances the throttle linkage to advance the throttle opening.

SUMMARY

1. A fuel-injection system includes the electric fuel pump and fuel pump relay, fuel-pressure regulator, and fuel injectors (nozzles).
2. The two types of fuel-injection systems are the throttle-body design and the port fuel-injection design.
3. The two methods of fuel-injection control are the speed-density system, which uses the MAP to measure the load on the engine, and the mass airflow, which uses the MAF sensor to directly measure the amount of air entering the engine.
4. The amount of fuel supplied by fuel injectors is determined by how long they are kept open. This opening time is called the pulse width and is measured in milliseconds.
5. The fuel-pressure regulator is usually located on the fuel return on return-type fuel-injection systems.
6. TBI-type fuel-injection systems do not use a vacuum-controlled fuel-pressure regulator, whereas many port fuel-injection systems use a vacuum-controlled regulator to monitor equal pressure drop across the injectors.
7. Other fuel designs include the electronic returnless, the mechanical returnless, and the demand delivery systems.

REVIEW QUESTIONS

1. What are the two basic types of fuel-injection systems?
2. What is the purpose of the vacuum-controlled (biased) fuel-pressure regulator?
3. How many sensors are used to determine the base pulse width on a speed-density system?
4. How many sensors are used to determine the base pulse width on a mass airflow system?
5. What are the three types of returnless fuel injection systems?

CHAPTER QUIZ

1. Technician A says that the fuel pump relay is usually controlled by the PCM. Technician B says that a TBI injector squirts fuel above the throttle plate. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Why are some fuel rails rectangular in shape?
   a. Increases fuel pressure
   b. Helps keep air out of the injectors
   c. Reduces noise
   d. Increases the speed of the fuel through the fuel rail

3. Which fuel-injection system uses the MAP sensor as the primary sensor to determine the base pulse width?
   a. Speed density
   b. Mass airflow
   c. Demand delivery
   d. Mechanical returnless
4. Why is a vacuum line attached to a fuel-pressure regulator on many port-fuel-injected engines?
   a. To draw fuel back into the intake manifold through the vacuum hose
   b. To create an equal pressure drop across the injectors
   c. To raise the fuel pressure at idle
   d. To lower the fuel pressure under heavy engine load conditions to help improve fuel economy
5. Which sensor has the greatest influence on injector pulse width besides the MAF sensor?
   a. IAT
   b. BARO
   c. ECT
   d. TP
6. Technician A says that the port fuel-injection injectors operate using 5 volts from the computer. Technician B says that sequential fuel injectors all use a different wire color on the injectors. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Which type of port fuel-injection system uses a fuel temperature and/or fuel-pressure sensor?
   a. All port-fuel-injected engines
   b. TBI units only
   c. Electronic returnless systems
   d. Demand delivery systems
8. Dampeners are used on some fuel rails to ______________.
   a. Increase the fuel pressure in the rail
   b. Reduce (decrease) the fuel pressure in the rail
   c. Reduce noise
   d. Trap dirt and keep it away from the injectors
9. Where is the fuel-pressure regulator located on a vacuum-biased port fuel-injection system?
   a. In the tank
   b. At the inlet of the fuel rail
   c. At the outlet of the fuel rail
   d. Near or on the fuel filter
10. What type of device is used in a typical idle air control?
   a. DC motor
   b. Stepper motor
   c. Pulsator-type actuator
   d. Solenoid

chapter 36

ELECTRONIC THROTTLE CONTROL SYSTEM

OBJECTIVES: After studying Chapter 36, the reader will be able to: • Prepare for ASE test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Describe the purpose and function of an electronic throttle control (ETC) system. • Explain how an electronic throttle control system works. • List the parts of a typical electronic throttle control system. • Describe how to diagnose faults in an electronic throttle control system.

KEY TERMS: Accelerator pedal position (APP) sensor 515 • Coast-down stall 521 • Default position 517 • Drive-by-wire 515 • Electronic throttle control (ETC) 515 • Fail safe position 517 • Neutral position 517 • Servomotor 517 • Throttle position (TP) sensor 515

ELECTRONIC THROTTLE CONTROL (ETC) SYSTEM

ADVANTAGES OF ETC The absence of any mechanical linkage between the throttle pedal and the throttle body requires the use of an electric actuator motor. The electronic throttle system has the following advantages over the conventional cable:

- Eliminates the mechanical throttle cable, thereby reducing the number of moving parts.
- Eliminates the need for cruise control actuators and controllers.
- Helps reduce engine power for traction control (TC) and electronic stability control (ESC) systems.
- Used to delay rapid applications of torque to the transmission/transaxle to help improve driveability and to smooth shifts.
- Helps reduce pumping losses by using the electronic throttle to open at highway speeds with greater fuel economy. The electronic throttle control (ETC) opens the throttle to maintain engine and vehicle speed as the Powertrain Control Module (PCM) leans the air–fuel ratio, retards ignition timing, and introduces additional exhaust gas recirculation (EGR) to reducing pumping losses.
- Used to provide smooth engine operation, especially during rapid acceleration.
- Eliminates the need for an idle air control valve.

The electronic throttle can be called **drive-by-wire,** but most vehicle manufacturers use the term **electronic throttle control (ETC)** to describe the system that opens the throttle valve electrically.

PARTS INVOLVED The typical ETC system includes the following components:

1. **Accelerator pedal position (APP)** sensor, also called accelerator pedal sensor (APS)
2. The electronic throttle actuator (servomotor), which is part of the electronic throttle body
3. A **throttle position (TP) sensor**
4. An electronic control unit, which is usually the Powertrain Control Module (PCM)
   ● **SEE FIGURE 36–1.**

NORMAL OPERATION OF THE ETC SYSTEM

Driving a vehicle equipped with an electronic throttle control (ETC) system is about the same as driving a vehicle with a conventional mechanical throttle cable and throttle valve. However, the driver may notice some differences, which are to be considered normal. These normal conditions include:

- The engine may not increase above idle speed when depressing the accelerator pedal when the gear selector is in PARK.
- If the engine speed does increase when the accelerator is depressed with the transmission in PARK or NEUTRAL, the engine speed will likely be limited to less than 2000 RPM.
- While accelerating rapidly, there is often a slight delay before the engine responds. ● **SEE FIGURE 36–2.**

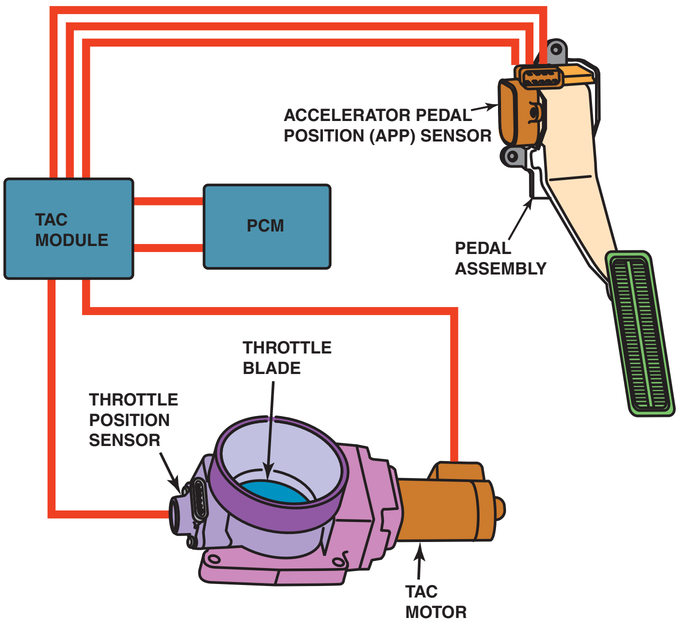


FIGURE 36–1 The throttle pedal is connected to the accelerator pedal position (APP) sensor. The electronic throttle body includes a throttle position sensor to provide throttle angle feedback to the vehicle computer. Some systems use a Throttle Actuator Control (TAC) module to operate the throttle blade (plate).

- While at cruise speed, the accelerator pedal may or may not cause the engine speed to increase if the accelerator pedal is moved slightly.

ACCELERATOR PEDAL POSITION SENSOR

CABLE-OPERATED SYSTEM Honda Accords until 2008 model year used a cable attached to the accelerator pedal to operate the APP sensor located under the hood. A similar arrangement was used in Dodge RAM trucks in 2003. In both of these applications, the throttle cable was simply moving the APP sensor and not moving the throttle plate. The throttle plate is controlled by the PCM and moved by the electronic throttle control motor.

TWO SENSORS The accelerator pedal position sensor uses two and sometimes three separate sensors, which act together to give accurate accelerator pedal position information to the controller, but also are used to check that the sensor is working properly. They function just like a throttle position sensor, and two are needed for proper system function. One APP sensor output signal increases as the pedal is depressed and the other signal decreases. The controller compares the signals with a look-up table to determine the pedal position. Using two or three signals improves redundancy should one sensor fail, and allows the PCM to quickly detect a malfunction. When three sensors are used, the third signal can either decrease or increase with pedal position, but its voltage range will still be different from the other two. ● **SEE FIGURE 36–3.**

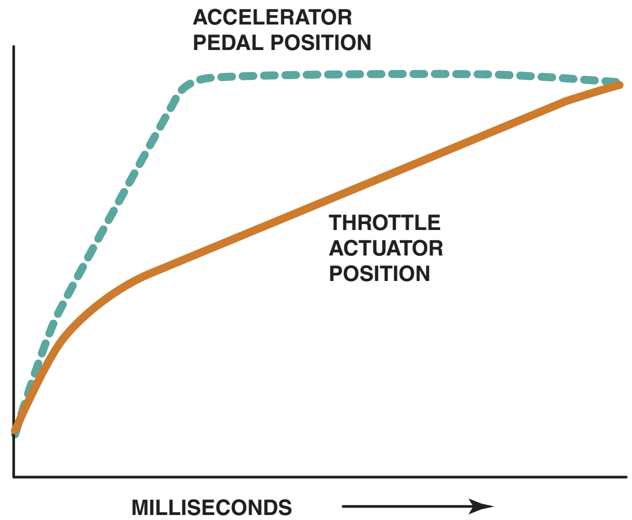


FIGURE 36–2 The opening of the throttle plate can be delayed as long as 30 milliseconds (0.030 sec.) to allow time for the amount of fuel needed to catch up to the opening of the throttle plate.

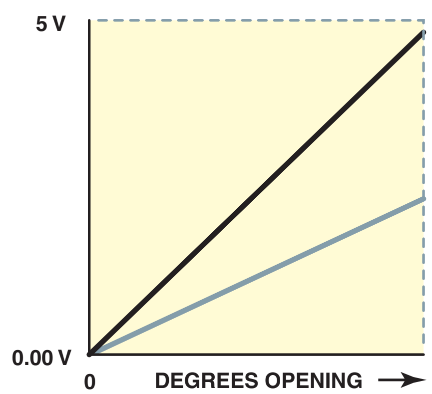


FIGURE 36–3 A typical accelerator pedal position (APP) sensor, showing two different output voltage signals that are used by the PCM to determine accelerator pedal position. Two (or three in some applications) are used as a double check because this is a safety-related sensor.

THROTTLE BODY ASSEMBLY

The throttle body assembly contains the following components:

- Throttle plate
- Electric actuator DC motor
- Dual throttle position (TP) sensors
- Gears used to multiply the torque of the DC motor
- Springs used to hold the throttle plate in the default location

FREQUENTLY ASKED QUESTION

What Is the "Spring Test"?

The spring test is a self-test performed by the PCM whenever the engine is started. The PCM operates the throttle to check if it can react to the command and return to the default (home) position. This self-test is used by the PCM to determine that the spring and motor are working correctly and may be noticed by some vehicle owners by the following factors:

- A slight delay in the operation of the starter motor. The PCM performs this test when the ignition switch is turned to the "on" position. While it takes just a short time to perform the test, it can be sensed by the driver that there could be a fault in the ignition switch or starter motor circuits.
- A slight "clicking" sound may also be heard coming from under the hood when the ignition is turned on. This is normal and is related to the self-test on the throttle as it opens and closes.

THROTTLE PLATE AND SPRING The throttle plate is held slightly open by a concentric clock spring. The spring applies a force that will close the throttle plate if power is lost to the actuator motor. The spring is also used to open the throttle plate slightly from the fully closed position.

ELECTRONIC THROTTLE BODY MOTOR The actuator is a DC electric motor and is often called a **servomotor.** The throttle plate is held in a **default position** by a spring inside the throttle body assembly. This partially open position, also called the **neutral position** or the **fail safe position,** is about 16% to 20% open. This default position varies depending on the vehicle and usually results in an engine speed of 1200 to 1500 RPM.

- The throttle plate is driven closed to achieve speeds lower than the default position, such as idle speed.
- The throttle plate is driven open to achieve speeds higher than the default position, such as during acceleration. ● **SEE FIGURE 36–4.**

The throttle plate motor is driven by a bidirectional pulse-width modulated (PWM) signal from the PCM or electronic throttle control module using an H-bridge circuit. ● **SEE FIGURE 36–5a, b.**

The H-bridge circuit is controlled by the Powertrain Control Module (PCM) by:

- Reversing the polarity of power and ground brushes to the DC motor
- Pulse-width modulating (PWM) the current through the motor

The PCM monitors the position of the throttle from the two throttle position (TP) sensors. The PCM then commands the throttle plate to the desired position. ● **SEE FIGURE 36–6.**

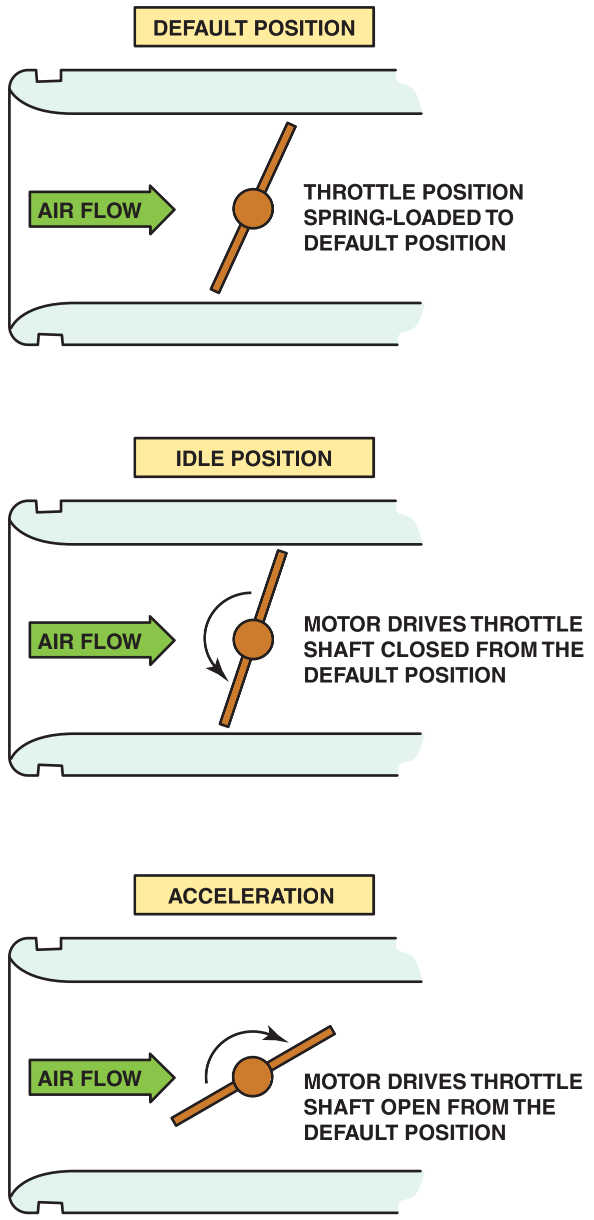


FIGURE 36–4 The default position for the throttle plate is in slightly open position. The servomotor then is used to close it for idle and open it during acceleration.

FREQUENTLY ASKED QUESTION

Why Not Use a Stepper Motor for ETC?

A stepper motor is a type of motor that has multiple windings and is pulsed by a computer to rotate a certain number of degrees when pulsed. The disadvantage is that a stepper motor is too slow to react compared with a conventional DC electric motor and is the reason a stepper motor is not used in electronic throttle control systems.

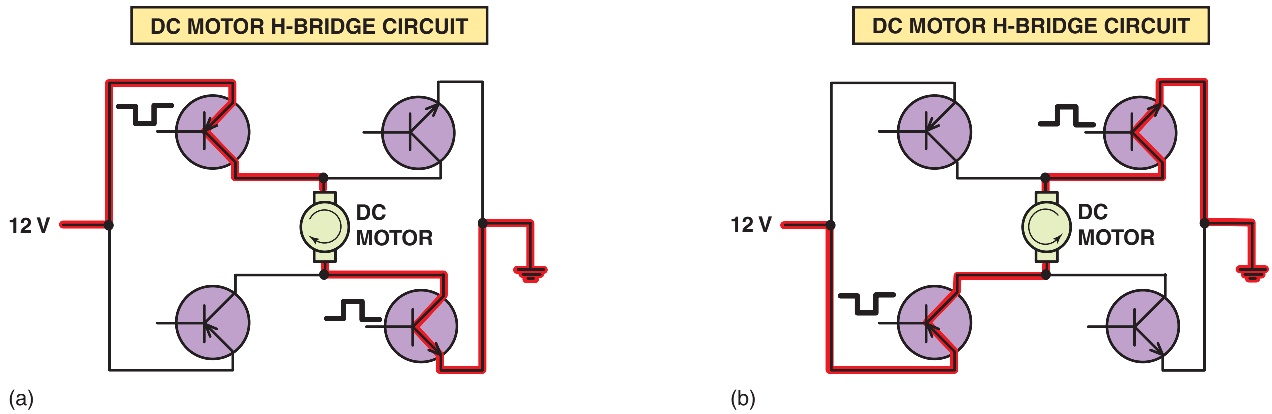


FIGURE 36–5 (a) An H-bridge circuit is used to control the direction of the DC electric motor of the electronic throttle control unit. (b) To reverse the direction of operation, the polarity of the current through the motor is reversed.

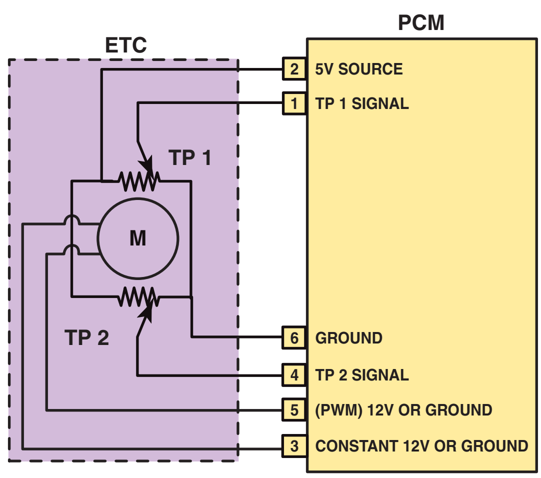


FIGURE 36–6 Schematic of a typical electronic throttle control (ETC) system. Note that terminal #5 is always pulse-width modulated and that terminal #3 is always constant, but both power and ground are switched to change the direction of the motor.

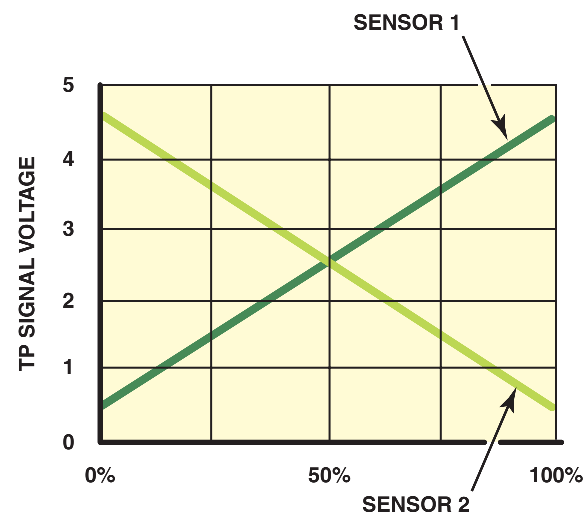


FIGURE 36–7 The two TP sensors used on the throttle body of an electronic throttle body assembly produce opposite voltage signals as the throttle is opened. The total voltage of both combined at any throttle plate position is 5 volts.

THROTTLE POSITION (TP) SENSOR

Two throttle position (TP) sensors are used in the throttle body assembly to provide throttle position signals to the PCM. Two sensors are used as a fail-safe measure and for diagnosis. There are two types of TP sensors used in electronic throttle control (ETC) systems: potentiometers and Hall-effect.

THREE-WIRE POTENTIOMETER SENSORS These sensors use a 5-volt reference from the PCM and produce an analog (variable) voltage signal that is proportional to the throttle plate position. The two sensors produce opposite signals as the throttle plate opens:

- One sensor starts at low voltage (about 0.5 V) and increases as the throttle plate is opened.
- The second sensor starts at a higher voltage (about 4.5 V) and produces a lower voltage as the throttle plate is opened. ● **SEE FIGURE 36–7.**

? FREQUENTLY ASKED QUESTION

How Do You Calibrate a New APP Sensor?

Whenever an accelerator pedal position (APP) sensor is replaced, it should be calibrated before it will work correctly. Always check service information for the exact procedure to follow after APP sensor replacement. Here is a typical example of the procedure:

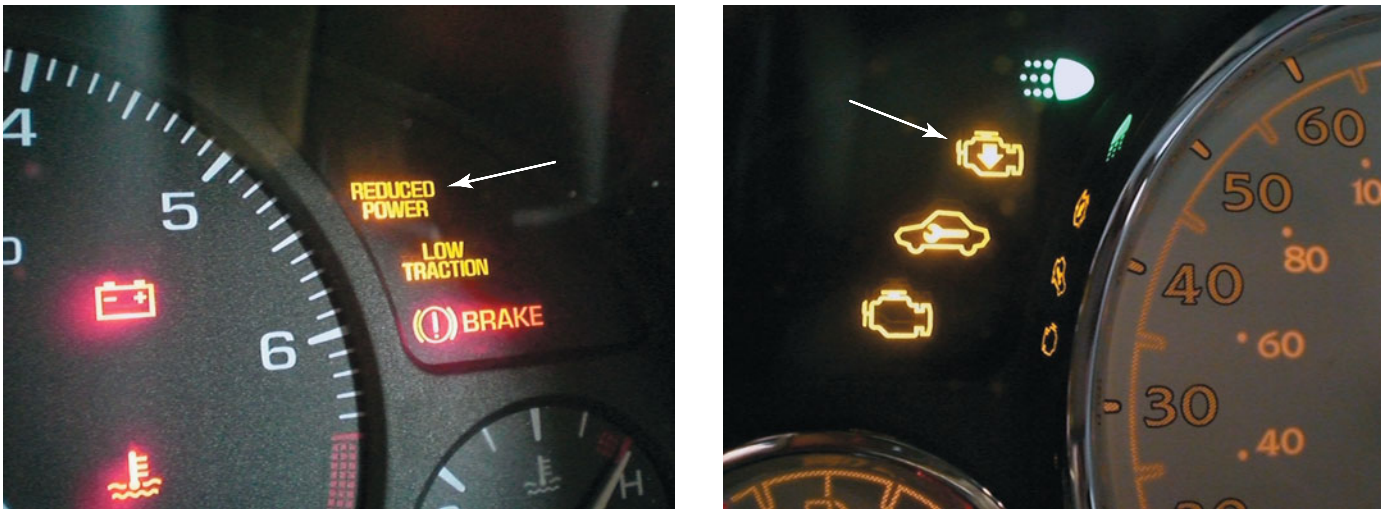
STEP 1 Make sure accelerator pedal is fully released.

STEP 2 Turn the ignition switch on (engine off) and wait at least 2 seconds.

STEP 3 Turn the ignition switch off and wait at least 10 seconds.

STEP 4 Turn the ignition switch on (engine on) and wait at least 2 seconds.

STEP 5 Turn the ignition switch off and wait at least 10 seconds.



(a) (b)

FIGURE 36–8 (a) A "reduced power" warning light indicates a fault with the electronic throttle control system on some General Motors vehicles. (b) A symbol showing an engine with an arrow pointing down is used on some General Motors vehicles to indicate a fault with the electronic throttle control system.

HALL-EFFECT TP SENSORS Some vehicle manufacturers, Honda for example, use a non-contact Hall-effect throttle position sensor. Because there is not physical contact, this type of sensor is less likely to fail due to wear.

DIAGNOSIS OF ELECTRONIC THROTTLE CONTROL SYSTEMS

FAULT MODE Electronic throttle control (ETC) systems can have faults like any other automatic system. Due to the redundant sensors in accelerator pedal position (APP) sensors and throttle position (TP) sensor, many faults result in a "*limp home*" situation instead of a total failure. The limp home mode is also called the "*fail-safe mode*" and indicates the following actions performed by the Powertrain Control Module (PCM).

- Engine speed is limited to the default speed (about 1200 to 1600 RPM).
- There is slow or no response when the accelerator pedal is depressed.
- The cruise control system is disabled.
- A diagnostic trouble code (DTC) is set.
- An ETC warning lamp on the dash will light. The warning lamp may be labeled differently, depending on the vehicle manufacturer. For example:
  - General Motors vehicle—Reduced power lamp (● **SEE FIGURE 36–8**)
  - Ford—Wrench symbol (amber or green) (● **SEE FIGURE 36–9**)
  - Chrysler—Red lightning bolt symbol (● **SEE FIGURE 36–10**)
- The engine will run and can be driven slowly. This limp-in mode operation allows the vehicle to be driven off of the road and to a safe location.

FIGURE 36–9 A wrench symbol warning lamp on a Ford vehicle. The symbol can also be green.

The ETC may enter the limp-in mode if any of the following has occurred:

- Low battery voltage has been detected
- PCM failure
- One TP and the MAP sensor have failed
- Both TP sensors have failed
- The ETC actuator motor has failed
- The ETC throttle spring has failed

FIGURE 36–10 A symbol used on a Chrysler vehicle indicating a fault with the electronic throttle control.

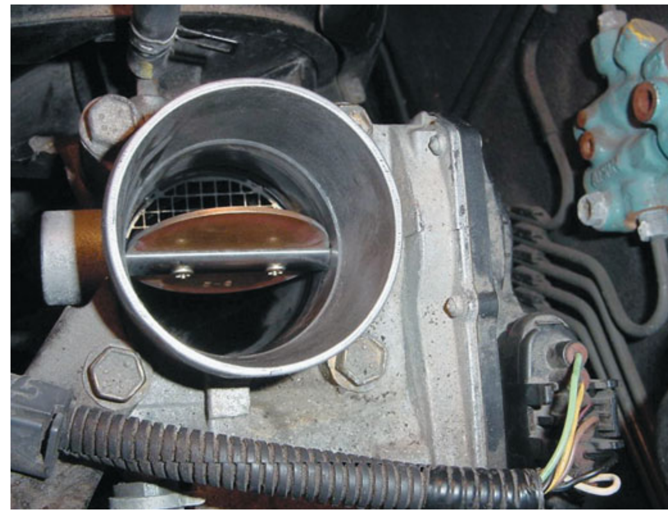


FIGURE 36–11 The throttle plate stayed where it was moved, which indicates that there is a problem with the electronic throttle body control assembly.

REAL WORLD FIX

The High Idle Toyota

The owner of a Toyota Camry complained that the engine would idle at over 1200 RPM compared with a normal 600 to 700 RPM. The vehicle would also not accelerate. Using a scan tool, a check for diagnostic trouble codes showed one code: P2101—"TAC motor circuit low."

Checking service information led to the inspection of the electronic throttle control throttle body assembly. With the ignition key out of the ignition and the inlet air duct off the throttle body, the technician used a screwdriver to push gently to see if the throttle plate worked.

Normal operation—The throttle plate should move and then spring back quickly to the default position.

Abnormal operation—If the throttle plate stays where it is moved or does not return to the default position, there is a fault with the throttle body assembly. ● **SEE FIGURE 36–11.**

Solution: The technician replaced the throttle body assembly with an updated version and proper engine operation was restored. The technician disassembled the old throttle body and found it was corroded inside due to moisture entering the unit through the vent hose. ● **SEE FIGURE 36–12.**

VACUUM LEAKS The electronic throttle control (ETC) system is able to compensate for many vacuum leaks. A vacuum leak at the intake manifold for example will allow air into the engine that is not measured by the mass airflow sensor. The ETC system will simply move the throttle as needed to achieve the proper idle speed to compensate for the leak.

DIAGNOSTIC PROCEDURE If a fault occurs in the ETC system, check service information for the specified procedure to follow for the vehicle being checked. Most vehicle service information includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Use a factory scan tool or an aftermarket scan tool with original equipment capability and check for diagnostic trouble codes (DTCs).

STEP 3 If there are stored diagnostic trouble codes, follow service information instructions for diagnosing the system.

STEP 4 If there are no stored diagnostic trouble codes, check scan tool data for possible fault areas in the system.

SCAN TOOL DATA Scan data related to the electronic throttle control system can be confusing. Typical data and the meaning include:

- **APP indicated angle.** The scan tool will display a percentage ranging from 0% to 100%. When the throttle is released, the indicated angle should be 0%. When the throttle is depressed to wide open, the reading should indicate 100%.
- **TP desired angle.** The scan tool will display a percentage ranging from 0% to 100%. This represents the desired throttle angle as commanded by the driver of the vehicle.
- **TP indicated angle.** The TP indicated angle is the angle of the measured throttle opening and it should agree with the TP desired angle.
- **TP sensors 1 and 2.** The scan tool will display "agree" or "disagree." If the PCM or throttle actuator control (TAC) module receives a voltage signal from one of the TP sensors that is not in the proper relationship to the other TP sensor, the scan tool will display disagree.

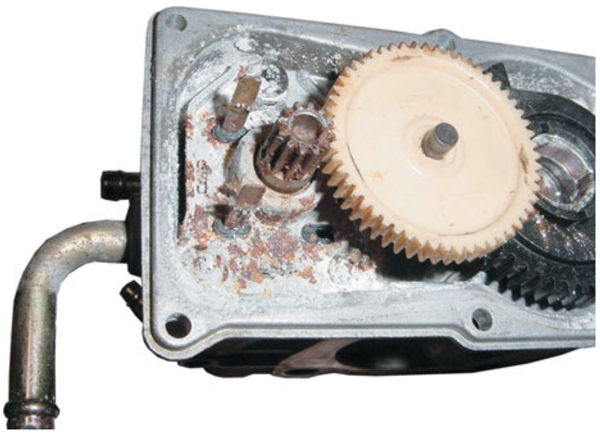


FIGURE 36–12 A corroded electronic throttle control assembly shown with the cover removed.

ETC THROTTLE FOLLOWER TEST

On some vehicles, such as many Chrysler vehicles, the operation of the electronic throttle control can be tested using a factory or factory-level scan tool. To perform this test, use the "throttle follower test" procedure as shown on the scan tool. An assistant is needed to check that the throttle plate is moving as the accelerator pedal is depressed. This test cannot be done normally because the PCM does not normally allow the throttle plate to be moved unless the engine is running.

SERVICING ELECTRONIC THROTTLE SYSTEMS

ETC-RELATED PERFORMANCE ISSUES The only service that an electronic throttle control system may require is a cleaning of the throttle body. Throttle body cleaning is a routine service procedure on port fuel-injected engines and is still needed when the throttle is being opened by an electric motor rather than a throttle cable tied to a mechanical accelerator pedal. The throttle body may need cleaning if one or more of the following symptoms are present:

- Lower than normal idle speed
- Rough idle
- Engine stalls when coming to a stop (called a **coast-down stall**)

If any of the above conditions exists, a throttle body cleaning will often correct these faults.

CAUTION: Some vehicle manufacturers add a nonstick coating to the throttle assembly and warn that cleaning could remove this protective coating. Always follow the vehicle manufacturer's recommended procedures.

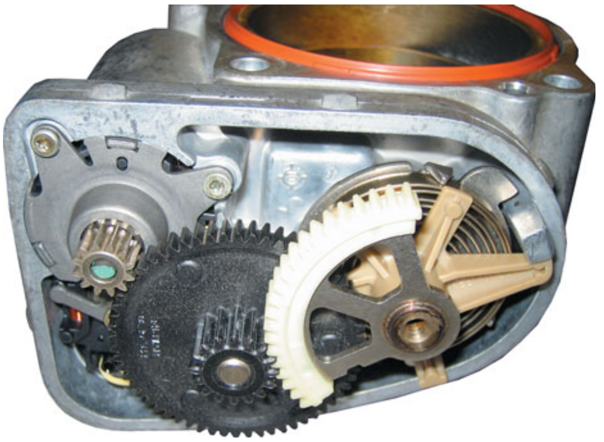


FIGURE 36–13 Notice the small motor gear on the left drives a larger plastic gear (black), which then drives the small gear in mesh with the section of a gear attached to the throttle plate. This results in a huge torque increase from the small motor and helps explain why it could be dangerous to insert a finger into the throttle body assembly.

THROTTLE BODY CLEANING PROCEDURE Before attempting to clean a throttle body on an engine equipped with an electronic throttle control system, be sure that the ignition key is out of the vehicle and the ready light is off if working on a Toyota/Lexus hybrid electric vehicle to avoid the possibility of personal injury.

WARNING

The electric motor that operates the throttle plate is strong enough to cut off a finger. ● **SEE FIGURE 36–13.**

To clean the throttle, perform the following steps:

STEP 1 With the ignition off and the key removed from the ignition, remove the air inlet hose from the throttle body.

STEP 2 Spray throttle body cleaner onto a shop cloth.

STEP 3 Open the throttle body and use the shop cloth to remove the varnish and carbon deposits from the throttle body housing and throttle plate.

CAUTION: Do not spray cleaner into the throttle body assembly. The liquid cleaner could flow into and damage the throttle position (TP) sensors.

STEP 4 Reinstall the inlet hose being sure that there are no air leaks between the hose and the throttle body assembly.

STEP 5 Start the engine and allow the PCM to learn the correct idle. If the idle is not correct, check service information for the specified procedures to follow to perform a throttle relearn.

THROTTLE BODY RELEARN PROCEDURE When installing a new throttle body or Powertrain Control Module (PCM) or sometimes after cleaning the throttle body, the throttle position has to be learned by the PCM. After the following conditions have been met, a typical throttle body relearn procedure for a General Motors vehicle includes:

- Accelerator pedal released
- Battery voltage higher than 8 volts
- Vehicle speed must be zero
- Engine coolant temperature (ECT) higher than 40°F (5°C) and lower than 212°F (100°C)
- Intake air temperature (IAT) higher than 40°F (5°C)
- No throttle diagnostic trouble codes set

If all of the above conditions are met, perform the following steps:

STEP 1 Turn the ignition on (engine off) for 30 seconds.

STEP 2 Turn the ignition off and wait 30 seconds.

Start the engine and the idle learn procedure should cause the engine to idle at the correct speed.

SUMMARY

1. Using an electronic throttle control (ETC) system on an engine has many advantages over a conventional method that uses a mechanical cable between the accelerator pedal and the throttle valve.
2. The major components of an electronic throttle control system include:
   - Accelerator pedal position (APP) sensor
   - Electronic throttle control actuator motor and spring
   - Throttle position (TP) sensor
   - Electronic control unit
3. The throttle position (TP) sensor is actually two sensors that share the 5-volt reference from the PCM and produce opposite signals as a redundant check.
4. Limp-in mode is commanded if there is a major fault in the system, which can allow the vehicle to be driven enough to be pulled off the road to safety.
5. The diagnostic procedure for the ETC system includes verifying the customer concern, using a scan tool to check for diagnostic trouble codes, and checking the value of the TP and APP sensors.
6. Servicing the ETC system includes cleaning the throttle body and throttle plate.

REVIEW QUESTIONS

1. What parts can be deleted if an engine uses an electronic throttle control (ETC) system instead of a conventional accelerator pedal and cable to operate the throttle valve?
2. How can the use of an electronic throttle control (ETC) system improve fuel economy?
3. How is the operation of the throttle different on a system that uses an electronic throttle control system compared with a conventional mechanical system?
4. What component parts are included in an electronic throttle control system?
5. What is the default or limp-in position of the throttle plate?
6. What dash warning light indicates a fault with the ETC system?

CHAPTER QUIZ

1. The use of an electronic throttle control (ETC) system allows the elimination of all except ____________.
   a. Accelerator pedal
   b. Mechanical throttle cable (most systems)
   c. Cruise control actuator
   d. Idle air control
2. The throttle plate is spring loaded to hold the throttle slightly open how far?
   a. 3% to 5%
   b. 8% to 10%
   c. 16% to 20%
   d. 22% to 28%

3. The throttle plate actuator motor is what type of electric motor?
   - a. Stepper motor
   - b. DC motor
   - c. AC motor
   - d. Brushless motor
4. The actuator motor is controlled by the PCM through what type of circuit?
   - a. Series
   - b. Parallel
   - c. H-bridge
   - d. Series-parallel
5. When does the PCM perform a self-test of the ETC system?
   - a. During cruise speed when the throttle is steady
   - b. During deceleration
   - c. During acceleration
   - d. When the ignition switch is first rotated to the on position before the engine starts
6. The throttle position sensor used in the throttle body assembly of an electronic throttle control (ETC) system is what type?
   - a. A single potentiometer
   - b. Two potentiometers that read in the opposite direction
   - c. A Hall-effect sensor
   - d. Either b or c
7. A green wrench symbol is displayed on the dash. What does this mean?
   - a. A fault in the ETC in a Ford has been detected
   - b. A fault in the ETC in a Honda has been detected
   - c. A fault in the ETC in a Chrysler has been detected
   - d. A fault in the ETC in a General Motors vehicle has been detected
8. A technician is checking the operation of the electronic throttle control system by depressing the accelerator pedal with the ignition in the on (run) position (engine off). What is the most likely result if the system is functioning correctly?
   - a. The throttle goes to wide open when the accelerator pedal is depressed all the way
   - b. No throttle movement
   - c. The throttle will open partially but not all of the way
   - d. The throttle will perform a self-test by closing and then opening to the default position
9. With the ignition off and the key out of the ignition, what should happen if a technician uses a screwdriver and gently pushes on the throttle plate in an attempt to open the valve?
   - a. Nothing. The throttle should be kept from moving by the motor, which is not energized with the key off.
   - b. The throttle should move and stay where it is moved and not go back unless moved back.
   - c. The throttle should move, and then spring back to the home position when released.
   - d. The throttle should move closed, but not open further than the default position.
10. The throttle body may be cleaned (if recommended by the vehicle manufacturer) if what conditions are occurring?
   - a. Coast-down stall
   - b. Rough idle
   - c. Lower-than-normal idle speed
   - d. Any of the above

chapter 37

FUEL-INJECTION SYSTEM DIAGNOSIS AND SERVICE

OBJECTIVES: After studying Chapter 37, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Explain how to test the fuel injection system using a scan tool. • Explain how to check a fuel-pressure regulator. • Describe how to test fuel injectors. • Explain how to diagnose electronic fuel-injection problems. • Describe how to service the fuel-injection system.

KEY TERMS: Graphing multimeter (GMM) 525 • IAC counts 526 • Idle air control (IAC) 533 • Noid light 527 • Peak-and-hold injector 532 • Pressure transducer 525 • Saturation 532

PORT FUEL-INJECTION PRESSURE REGULATOR DIAGNOSIS

Most port-fuel-injected engines use a vacuum hose connected to the fuel-pressure regulator. At idle, the pressure inside the intake manifold is low (high vacuum). Manifold vacuum is applied above the diaphragm inside the fuel-pressure regulator. This reduces the pressure exerted on the diaphragm and results in a lower, about 10 PSI (69 kPa), fuel pressure applied to the injectors. To test a vacuum-controlled fuel-pressure regulator, follow these steps:

1. Connect a fuel-pressure gauge to monitor the fuel pressure.
2. Locate the fuel-pressure regulator and disconnect the vacuum hose from the regulator.

   NOTE: If gasoline drips out of the vacuum hose when removed from the fuel-pressure regulator, the regulator is defective and will require replacement.

3. With the engine running at idle speed, reconnect the vacuum hose to the fuel-pressure regulator while watching the fuel-pressure gauge. The fuel pressure should drop (about 10 PSI or 69 kPa) when the hose is reattached to the regulator.
4. Using a hand-operated vacuum pump, apply vacuum (20 in. Hg) to the regulator. The regulator should hold vacuum. If the vacuum drops, replace the fuel-pressure regulator. ● **SEE FIGURE 37–1.**

FIGURE 37–1 If the vacuum hose is removed from the fuel-pressure regulator when the engine is running, the fuel pressure should increase. If it does not increase, then the fuel pump is not capable of supplying adequate pressure or the fuel-pressure regulator is defective. If gasoline is visible in the vacuum hose, the regulator is leaking and should be replaced.

NOTE: Some vehicles do not use a vacuum-regulated fuel-pressure regulator. Many of these vehicles use a regulator located inside the fuel tank that supplies a constant fuel pressure to the fuel injectors.

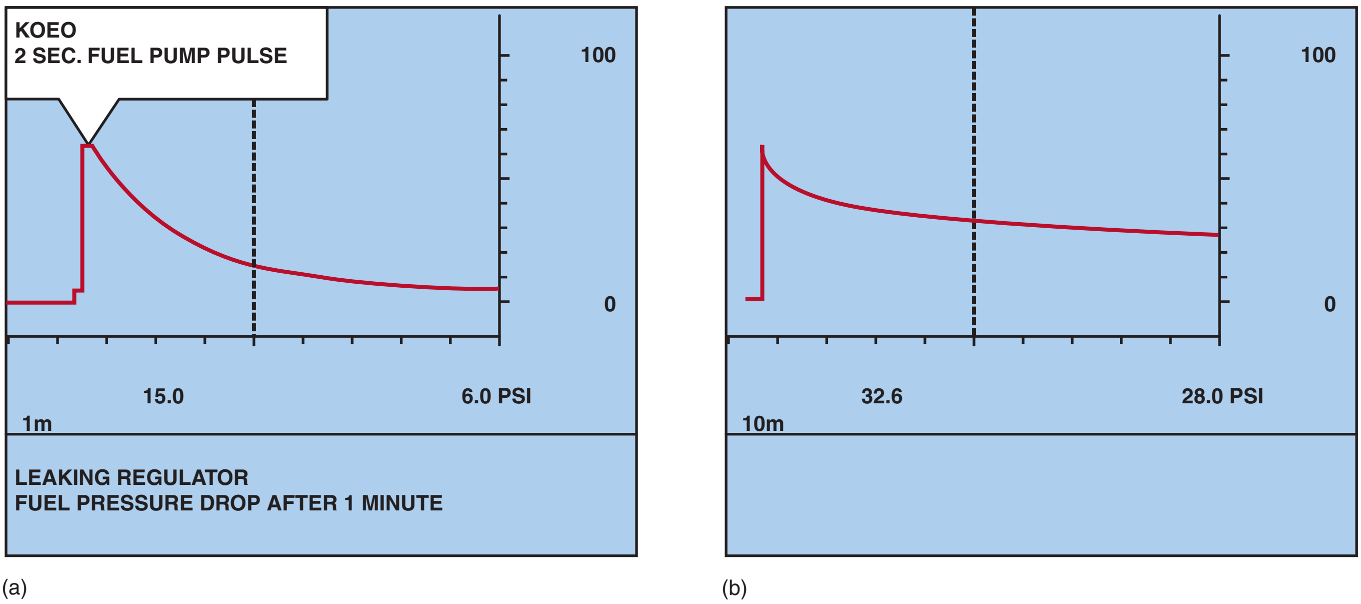


FIGURE 37–2 (a) A fuel-pressure graph after key on, engine off (KOEO) on a TBI system. (b) Pressure drop after 10 minutes on a normal port fuel-injection system.

> **TECH TIP**
>
> **Pressure Transducer Fuel Pressure Test**
>
> Using a **pressure transducer** and a **graphing multimeter (GMM)** or digital storage oscilloscope (DSO) allows the service technician to view the fuel pressure over time. ● **SEE FIGURE 37–2(a).** Note that the fuel pressure dropped from 15 PSI down to 6 PSI on a TBI-equipped vehicle after just one minute. A normal pressure holding capability is shown in ● **FIGURE 37–2(b)** when the pressure dropped only about 10% after 10 minutes on a port-fuel injection system.

DIAGNOSING ELECTRONIC FUEL-INJECTION PROBLEMS USING VISUAL INSPECTION

All fuel-injection systems require the proper amount of clean fuel delivered to the system at the proper pressure and the correct amount of filtered air. The following items should be carefully inspected before proceeding to more detailed tests.

- Check the air filter and replace as needed.
- Check the air induction system for obstructions.
- Check the conditions of all vacuum hoses. Replace any hose that is split, soft (mushy), or brittle.

FIGURE 37–3 A clogged PCV system caused the engine oil fumes to be drawn into the air cleaner assembly. This is what the technician discovered during a visual inspection on this TBI system.

- Check the positive crankcase ventilation (PCV) valve for proper operation or replacement as needed. ● **SEE FIGURE 37–3.**

  NOTE: The use of an incorrect PCV valve can cause a rough idle or stalling.

- Check all fuel-injection electrical connections for corrosion or damage.
- Check for gasoline at the vacuum port of the fuel-pressure regulator if the vehicle is so equipped. Gasoline in the vacuum hose at the fuel-pressure regulator indicates that the regulator is defective and requires replacement.

FIGURE 37–4 All fuel injectors should make the same sound with the engine running at idle speed. A lack of sound indicates a possible electrically open injector or a break in the wiring. A defective computer could also be the cause of a lack of clicking (pulsing) of the injectors.

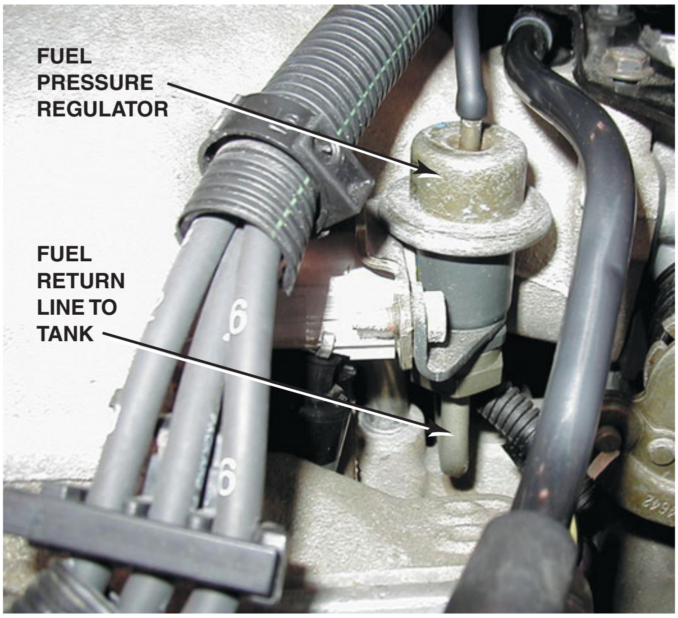


FIGURE 37–5 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel-pump and fuel-pressure regulator are functioning correctly.

TECH TIP

Stethoscope Fuel-Injection Test

A commonly used test for injector operation is to listen to the injector using a stethoscope with the engine operating at idle speed. ● **SEE FIGURE 37–4.** All injectors should produce the same clicking sound. If any injector makes a clunking or rattling sound, it should be tested further or replaced. With the engine still running, place the end of the stethoscope probe to the return line from the fuel-pressure regulator. ● **SEE FIGURE 37–5.** Fuel should be heard flowing back to the fuel tank if the fuel-pump pressure is higher than the fuel-regulator pressure. If no sound of fuel is heard, then either the fuel pump or the fuel-pressure regulator is at fault.

TECH TIP

Quick and Easy Leaking Injector Test

Leaking injectors may be found by disabling the ignition, unhooking all injectors, and checking exhaust for hydrocarbons (HC) using a gas analyzer while cranking the engine (maximum HC = 300 PPM). This test does not identity which injector is leaking but it does confirm that one or more injector is leaking.

SCAN TOOL VACUUM LEAK DIAGNOSIS

If a vacuum (air) leak occurs on an engine equipped with a speed-density-type of fuel injection, the extra air would cause the following to occur:

- The idle speed increases due to the extra air just as if the throttle pedal was depressed.
- The MAP sensor reacts to the increased air from the vacuum leak as an additional load on the engine.
- The computer increases the injector pulse width slightly longer due to the signal from the MAP sensor.
- The air–fuel mixture remains unchanged.
- The idle air control (IAC) counts will decrease, thereby attempting to reduce the engine speed to the target idle speed stored in the computer memory. ● **SEE FIGURE 37–6.**

Therefore, one of the best indicators of a vacuum leak on a speed-density fuel-injection system is to look at the IAC counts or percentage. Normal **IAC counts** or percentage is usually 15 to 25. A reading of less than 5 indicates a vacuum leak.

If a vacuum leak occurs on an engine equipped with a mass airflow-type fuel-injection system, the extra air causes the following to occur:

- The engine will operate leaner-than-normal because the extra air has not been measured by the MAF sensor.
- The idle speed will likely be lower due to the leaner-than-normal air–fuel mixture.
- The idle air control (IAC) counts or percentage will often increase in an attempt to return the engine speed to the target speed stored in the computer.

FIGURE 37–6 Using a scan tool to check for IAC counts or percentage as part of a diagnostic routine.

TECH TIP

No Spark, No Squirt

Most electronic fuel-injection computer systems use the ignition primary (pickup coil or crank sensor) pulse as the trigger for when to inject (squirt) fuel from the injectors (nozzles). If this signal were not present, no fuel would be injected. Because this pulse is also necessary to trigger the module to create a spark from the coil, it can be said that "no spark" could also mean "no squirt." Therefore, if the cause of a no-start condition is observed to be a lack of fuel injection, do not start testing or replacing fuel-system components until the ignition system is checked for proper operation.

PORT FUEL-INJECTION SYSTEM DIAGNOSIS

To determine if a port fuel-injection system—including the fuel pump, injectors, and fuel-pressure regulator—is operating correctly, take the following steps.

1. Attach a fuel-pressure gauge to the Schrader valve on the fuel rail. ● **SEE FIGURE 37–7.**
2. Turn the ignition key on or start the engine to build up the fuel-pump pressure (often about 35 to 45 PSI. Always check service information for the specified fuel pressure).
3. Wait 20 minutes and observe the fuel pressure retained in the fuel rail and note the PSI reading. The fuel pressure should not drop more than 20 PSI (140 kPa) in 20 minutes.

FIGURE 37–7 Checking the fuel pressure using a fuel-pressure gauge connected to the Schrader valve.

If the drop is less than 20 PSI in 20 minutes, everything is okay; if the drop is *greater,* then there is a possible problem with:

- The check valve in the fuel pump
- Leaking injectors, lines, or fittings
- A defective (leaking) fuel-pressure regulator

To determine which unit is defective, perform the following:

- Reenergize the electric fuel pump.
- Clamp the fuel *supply* line, and wait 10 minutes (see Caution box). If the pressure drop does not occur, replace the fuel pump. If the pressure drop still occurs, continue with the next step.
- Repeat the pressure buildup of the electric pump and clamp the fuel return line. If the pressure drop time is now okay, replace the fuel-pressure regulator.
- If the pressure drop still occurs, one or more of the injectors is leaking. Remove the injectors with the fuel rail and hold over paper. Replace those injectors that drip one or more drops after 10 minutes with pressurized fuel.

CAUTION: Do not clamp plastic fuel lines. Connect shut-off valves to the fuel system to shut off supply and return lines. ● **SEE FIGURE 37–8.**

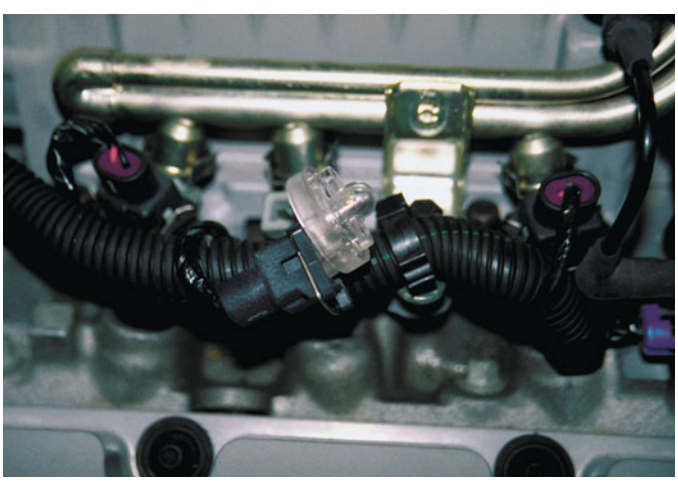
TESTING FOR AN INJECTOR PULSE

One of the first checks that should be performed when diagnosing a no-start condition is whether the fuel injectors are being pulsed by the computer. Checking for proper pulsing of the injector is also important in diagnosing a weak or dead cylinder.

A **noid light** is designed to electrically replace the injector in the circuit and to flash if the injector circuit is working correctly. ● **SEE FIGURE 37–9.** To use a noid light, disconnect the

FIGURE 37–8 Shutoff valves must be used on vehicles equipped with plastic fuel lines to isolate the cause of a pressure drop in the fuel system.

(a)



(b)

FIGURE 37–9 (a) Noid lights are usually purchased as an assortment so that one is available for any type or size of injector wiring connector. (b) The connector is unplugged from the injector and a noid light is plugged into the harness side of the connector. The noid light should flash when the engine is being cranked if the power circuit and the pulsing to ground by the computer are functioning normally.

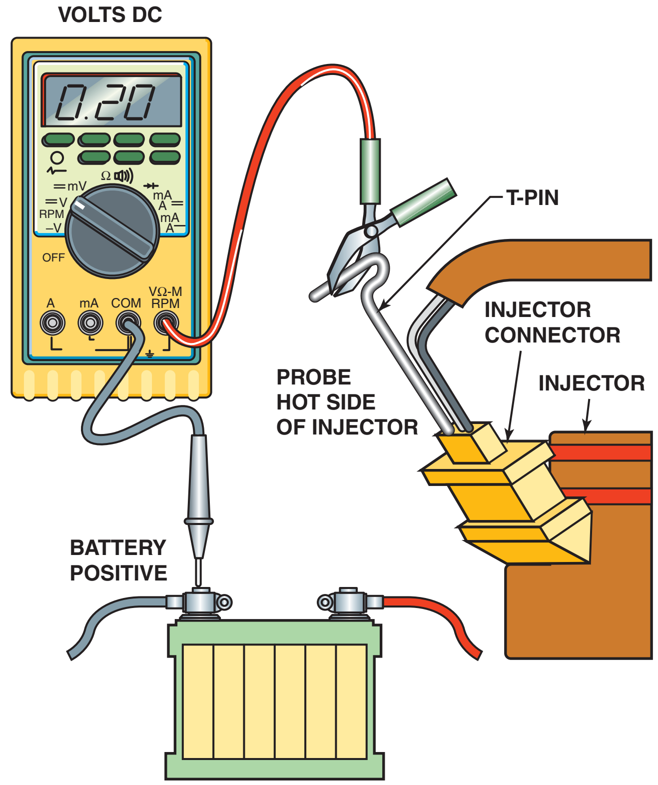


FIGURE 37–10 Use a DMM set to read DC volts to check the voltage drop of the positive circuit to the fuel injector. A reading of 0.5 volt or less is generally considered to be acceptable.

electrical connector at the fuel injector and plug the noid light into the injector harness connections. Crank or start the engine. The noid light should flash regularly.

NOTE: The term *noid* is simply an abbreviation of the word *solenoid.* Injectors use a movable iron core and are therefore solenoids. Therefore, a noid light is a replacement for the solenoid (injector).

Possible noid light problems and causes include the following:

1. **The light is off and does not flash.** The problem is an open in either the power side or ground side (or both) of the injector circuit.
2. **The noid light flashes dimly.** A dim noid light indicates excessive resistance or low voltage available to the injector. Both the power and ground side must be checked.
3. **The noid light is on and does not flash.** If the noid light is on, then both a power and a ground are present. Because the light does not flash (blink) when the engine is being cranked or started, then a short-to-ground fault exists either in the computer itself or in the wiring between the injector and the computer.

CAUTION: A noid lamp must be used with caution. The computer may show a good noid light operation and have low supply voltage. ● **SEE FIGURE 37–10.**

CHECKING FUEL-INJECTOR RESISTANCE

Each port fuel injector must deliver an equal amount of fuel or the engine will idle roughly or perform poorly.

The electrical balance test involves measuring the injector coil-winding resistance. For best engine operation, all injectors should have the same electrical resistance. To measure the resistance, carefully release the locking feature of the connector and remove the connector from the injector.

Injector Resistance Table

Manufacturer	Injector Application	Resistance Values
General Motors		
	Quad 4	1.95–2.15 Ω
	CPI Vortec 4.3L	1.48–1.52 Ω
	MFI Bosch Style Injector (1985–1989) 2.8L	15.95–16.35 Ω
	MFI Black Multec Injector 2.8L, 3.1L, 3.3L, 3.4L	11.8–12.6 Ω
	MFI 3800	14.3–14.7 Ω
	MFI 3.8L, 5.0L, 5.7L	15.8–16.6 Ω
	MFI 5.7 LT5-ZR1	11.8–12.6 Ω
	TBI 220 Series 2.8L, 3.1L, 4.3L, 5.0L, 5.7L, 7.4L	1.16–1.36 Ω
	TBI 295 Series 4.3L, 6.0L, 7.0L	1.42–1.62 Ω
	TBI 700 Series 2.0L, 2.2L, 2.5L	1.42–1.62 Ω
Chrysler		
	MFI Early Years through 1992 (majority of)	2.4 Ω
	MFI Later Years after 1992 (majority of)	14.5 Ω
	TBI Low-Pressure Systems (majority of)	1.3 Ω
	TBI High-Pressure Systems (majority of)	0.7 Ω
Ford		
	MFI (majority of)	15.0–18.0 Ω
	TBI Low-Pressure 1.9L (1987–1990)	1.0–2.0 Ω
	TBI Low-Pressure 2.3L (1985–1987)	1.0–2.0 Ω
	TBI Low-Pressure 2.5L (1986–1990)	1.0–2.0 Ω
	TBI High-Pressure 3.8L (1984–1987)	1.5–2.5 Ω
	TBI High-Pressure 5.0L (1981–1985)	1.5–3.5 Ω

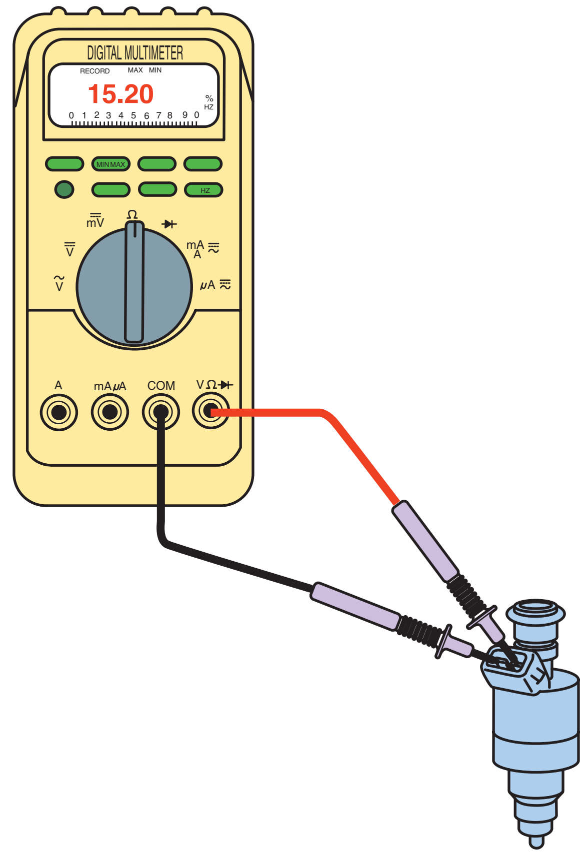


FIGURE 37–11 An ohmmeter is connected to the injector electrical terminals to read injector coil resistance.

NOTE: Some engines require specific procedures to gain access to the injectors. Always follow the manufacturers' recommended procedures.

With an ohmmeter, measure the resistance across the injector terminals. Be sure to use the low-ohms feature of the digital ohmmeter to read in tenths (0.1) of an ohm. ● **SEE FIGURES 37–11 AND 37–12.** Check service information for the resistance specification of the injectors. Measure the resistance of all of the injectors. Replace any injector that does not fall within the resistance range of the specification. The resistance of the injectors should be measured twice—once when the engine (and injectors) are cold and once after the engine has reached normal operating temperature. If any injector resistance is not equal to specifications, make certain that the terminals of the injector are electrically sound, and perform other tests to confirm an injector problem before replacement.

MEASURING RESISTANCE OF GROUPED INJECTORS

Many vehicles are equipped with a port fuel-injection system that "fires" two or more injectors at a time. For example, a V-6 may group all three injectors on one bank to pulse on at the same

FIGURE 37–12 To measure fuel-injector resistance, a technician constructed a short wiring harness with a double banana plug that fits into the V and COM terminals of the meter and an injector connector at the other end. This setup makes checking resistance of fuel injectors quick and easy.

TECH TIP

Equal Resistance Test

All fuel injectors should measure the specified resistance. However the specification often indicates the temperature of the injectors be at room temperature and of course will vary according to the temperature. Rather than waiting for all of the injectors to achieve room temperature, measure the resistance and check that they are all within 0.4 ohm of each other. To determine the difference, record the resistance of each injector and then subtract the lowest resistance reading from the highest resistance reading to get the difference. If more than 0.4 ohm then further testing will be needed to verify defective injector(s).

time. Then the other three injectors will be pulsed on. This sequence alternates. To measure the resistance of these injectors, it is often easiest to measure each group of three that is wired in parallel. The resistance of three injectors wired in parallel is one-third of the resistance of each individual injector. For example,

Injector resistance = 12 ohms (Ω)

Three injectors in parallel = 4 ohms (Ω)

A V-6 has two groups of three injectors. Therefore, both groups should measure the same resistance. If both groups measure 4 ohms, then it is likely that all six injectors are okay. However, if one group measures only 2.9 ohms and the other group measures 4 ohms, then it is likely that one or more fuel injectors are defective (shorted). This means that the technician now has reasonable cause to remove the intake manifold to get access to each injector for further testing. ● **SEE FIGURE 37–13.**

(a)

(b)

FIGURE 37–13 (a) The meter is connected to read one group of three 12-ohm injectors. The result should be 4 ohms and this reading is a little low indicating that at least one injector is shorted (low resistance). (b) This meter is connected to the other group of three injectors and indicates that most, if not all three, injectors are shorted. The technician replaced all six injectors and the engine ran great.

MEASURING RESISTANCE OF INDIVIDUAL INJECTORS

While there are many ways to check injectors, the first test is to measure the resistance of the coil inside and compare it to factory specifications. ● **SEE FIGURE 37–14.** If the injectors are not accessible, check service information for the location of the electrical connector for the injectors. Unplug the connector and measure the resistance of each injector at the injector side of the connector. Use service information to determine the wire colors for the power side and the pulse side of each injector.

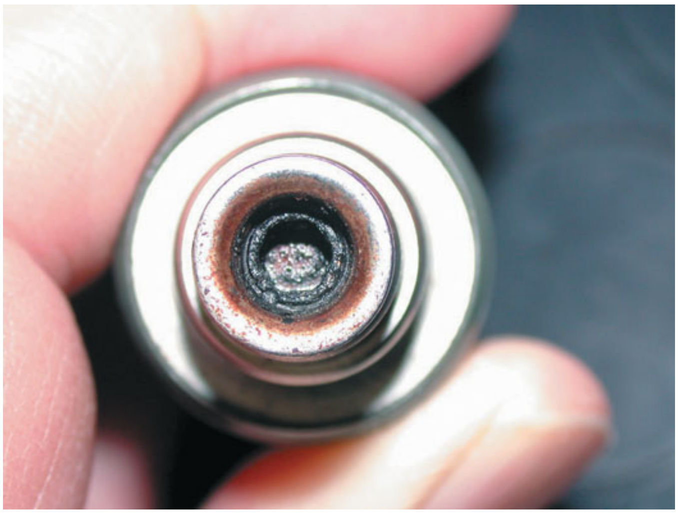


FIGURE 37–14 If an injector has the specified resistance, this does not mean that it is okay. This injector had the specified resistance yet it did not deliver the correct amount of fuel because it was clogged.

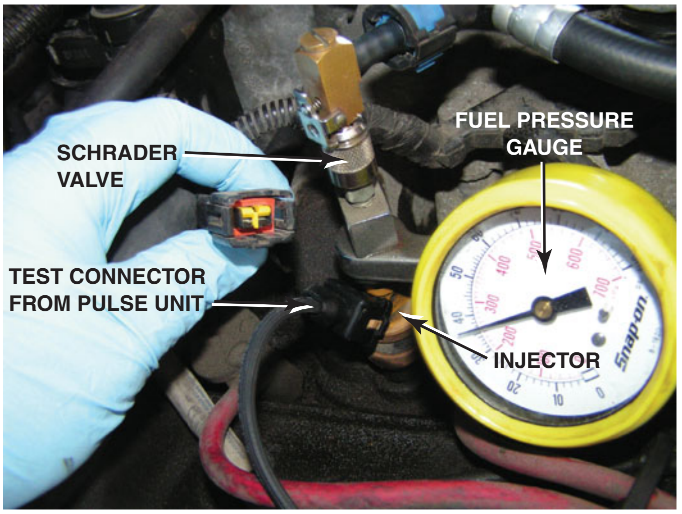


FIGURE 37–15 After connecting a pressure gauge, unplug the electrical connector from an injector and attach the test lead from the pulse unit to the injector.

PRESSURE-DROP BALANCE TEST

The pressure balance test involves using an electrical timing device to pulse the fuel injectors on for a given amount of time, usually 500 ms or 0.5 second, and observing the drop in pressure that accompanies the pulse. If the *fuel flow* through each injector is equal, the drop in pressure in the system will be equal. Most manufacturers recommend that the pressures be within about 1.5 PSI (10 kPa) of each other for satisfactory engine performance. This test method not only tests the electrical functioning of the injector (for definite time and current pulse), but also tests for mechanical defects that could affect fuel flow amounts.

The purpose of running this injector balance test is to determine which injector is restricted, inoperative, or delivering fuel differently than the other injectors. Replacing a complete set of injectors can be expensive. The basic tools needed are:

- Accurate pressure gauge with pressure relief
- Injector pulser with time control
- Necessary injector connection adapters
- Safe receptacle for catching and disposing of any fuel released

STEP 1 Attach the pressure gauge to the fuel delivery rail on the supply side. Make sure the connections are safe and leakproof.

STEP 2 Attach the injector pulser to the first injector to be tested.

STEP 3 Turn the ignition key to the on position to prime the fuel rail. Note the static fuel-pressure reading.

STEP 4 Activate the pulser for the timed firing pulses.

STEP 5 Note and record the new static rail pressure after the injector has been pulsed. ● **SEE FIGURE 37–15.**

STEP 6 Reenergize the fuel pump and repeat this procedure for all of the engine injectors.

STEP 7 Compare the two pressure readings and compute the pressure drop for each injector. Compare the pressure drops of the injectors to each other. Any variation in pressure drops will indicate an uneven fuel delivery rate between the injectors.

For example:

Injector	1	2	3	4	5	6
Initial pressure	40	40	40	40	40	40
Second pressure	30	30	35	30	20	30
Pressure drop	10	10	5	10	20	10
Possible problem	OK	OK	Restriction	OK	Leak	OK

INJECTOR VOLTAGE-DROP TESTS

Another test of injectors involves pulsing the injector and measuring the voltage drop across the windings as current is flowing. A typical voltage-drop tester is shown in ● **FIGURE 37–16.** The tester, which is recommended for use by General Motors Corporation, pulses the injector while a digital multimeter is connected to the unit, which will display the voltage drop as the current flows through the winding.

CAUTION: Do not test an injector using a pulse-type tester more than one time without starting the engine to help avoid a hydrostatic lock caused by the flow of fuel into the cylinder during the pulse test.

FIGURE 37–16 An injector tester being used to check the voltage drop through the injector while the tester is sending current through the injectors. This test is used to check the coil inside the injector. This same tester can be used to check for equal pressure drop of each injector by pulsing the injector on for 500 ms.

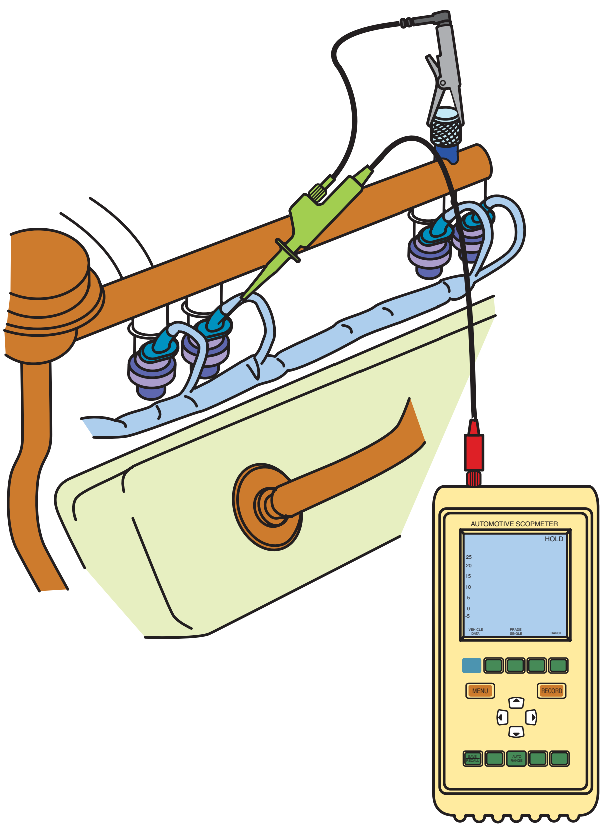


FIGURE 37–17 A digital storage oscilloscope can be easily connected to an injector by carefully back probing the electrical connector.

Record the highest voltage drop observed on the meter display during the test. Repeat the voltage-drop test for all of the injectors. The voltage drop across each injector should be within 0.1 volt of each other. If an injector has a higher-than-normal voltage drop, the injector windings have higher-than-normal resistance.

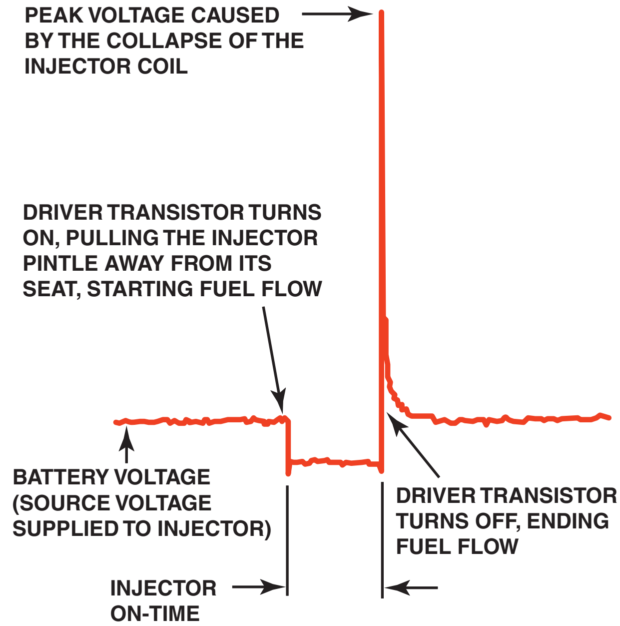


FIGURE 37–18 The injector on-time is called the pulse width. *(Courtesy of Fluke Corporation)*

SCOPE-TESTING FUEL INJECTORS

A scope (analog or digital storage) can be connected into each injector circuit. There are three types of injector drive circuits and each type of circuit has its own characteristic pattern. ● **SEE FIGURE 37–17** for an example of how to connect a scope to read a fuel-injector waveform.

SATURATED SWITCH TYPE In a saturated switch-type injector-driven circuit, voltage (usually a full 12 volts) is applied to the injector. The ground for the injector is provided by the vehicle computer. When the ground connection is completed, current flows through the injector windings. Due to the resistance and inductive reactance of the coil itself, it requires a fraction of a second (about 3 milliseconds or 0.003 seconds) for the coil to reach **saturation** or maximum current flow. Most saturated switch-type fuel injectors have 12 to 16 ohms of resistance. This resistance, as well as the computer switching circuit, control and limit the current flow through the injector. A voltage spike occurs when the computer shuts off (opens the injector ground-side circuit) the injectors. ● **SEE FIGURE 37–18.**

PEAK-AND-HOLD TYPE A **peak-and-hold** type is typically used for TBI and some port low-resistance injectors. Full battery voltage is applied to the injector and the ground side is controlled through the computer. The computer provides a high initial current flow (about 4 amperes) to flow through the injector windings to open the injector core. Then the computer reduces the current to a lower level (about 1 ampere). The hold current

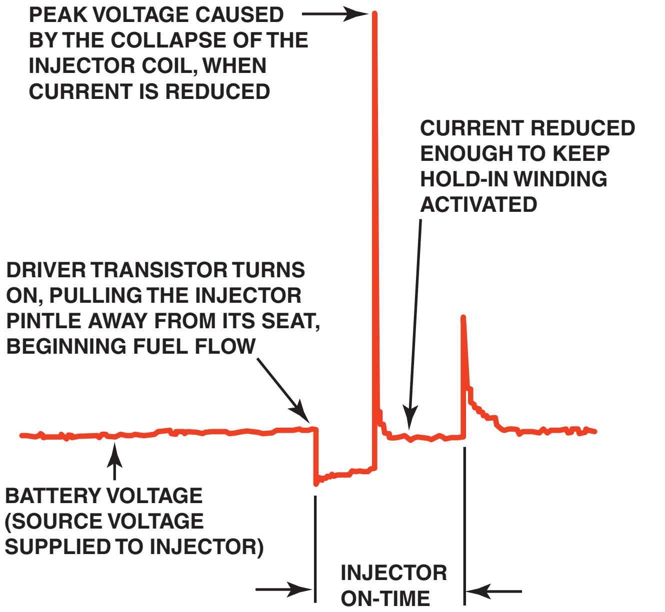


FIGURE 37–19 A typical peak-and-hold fuel-injector waveform. Most fuel injectors that measure less than 6 ohms will usually display a similar waveform.

FIGURE 37–20 A set of six reconditioned injectors. The sixth injector is barely visible at the far right.

is enough to keep the injector open, yet conserves energy and reduces the heat buildup that would occur if the full current flow remains on as long as the injector is commanded on. Typical peak-and-hold-type injector resistance ranges from 2 to 4 ohms.

The scope pattern of a typical peak-and-hold-type injector shows the initial closing of the ground circuit, then a voltage spike as the current flow is reduced. Another voltage spike occurs when the lower level current is turned off (opened) by the computer. ● **SEE FIGURE 37–19.**

PULSE-WIDTH MODULATED TYPE A pulse-width modulated type of injector drive circuit uses lower-resistance coil injectors. Battery voltage is available at the positive terminal of the injector and the computer provides a variable-duration connection to ground on the negative side of the injector. The computer can vary the time intervals that the injector is grounded for very precise fuel control.

Each time the injector circuit is turned off (ground circuit opened), a small voltage spike occurs. It is normal to see multiple voltage spikes on a scope connected to a pulse-width modulated type of fuel injector.

? FREQUENTLY ASKED QUESTION

If Three of Six Injectors Are Defective, Should I Also Replace the Other Three?

This is a good question. Many service technicians "recommend" that the three good injectors also be replaced along with the other three that tested as being defective. The reasons given by these technicians include:

- All six injectors have been operating under the same fuel, engine, and weather conditions.
- The labor required to replace all six is just about the same as replacing only the three defective injectors.
- Replacing all six at the same time helps ensure that all of the injectors are flowing the same amount of fuel so that the engine is operating most efficiently.

With these ideas in mind, the customer should be informed and offered the choice. Complete sets of injectors such as those in ● **FIGURE 37–20** can be purchased at a reasonable cost.

IDLE AIR SPEED CONTROL DIAGNOSIS

On an engine equipped with fuel injection (TBI or port injection), the idle speed is controlled by increasing or decreasing the amount of air bypassing the throttle plate. Again, an electronic stepper motor or pulse-width modulated solenoid is used to maintain the correct idle speed. This control is often called the **idle air control (IAC)**. ● **SEE FIGURES 37–21 THROUGH 37–23.**

When the engine stops, most IAC units will retract outward to get ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine-flare. If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).

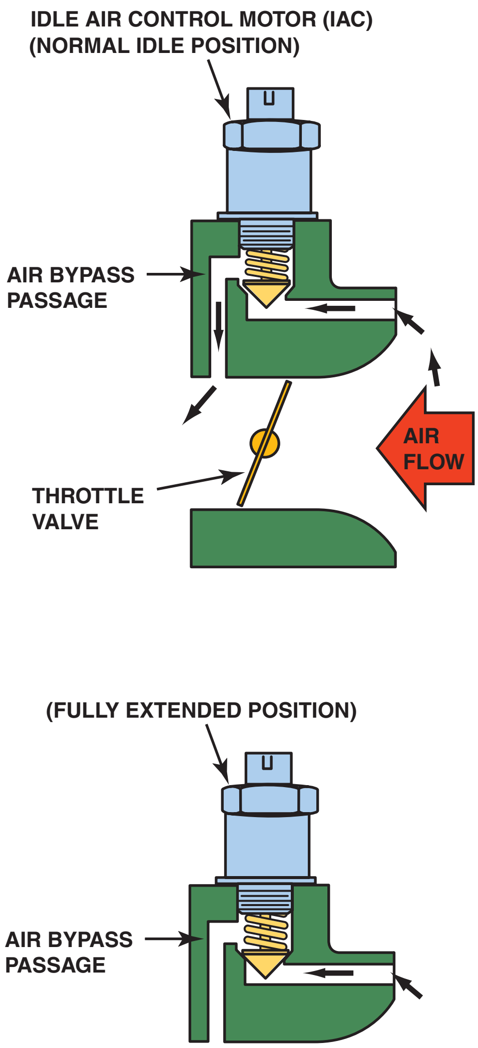


FIGURE 37–21 An IAC controls idle speed by controlling the amount of air that passes around the throttle plate. More airflow results in a higher idle speed.

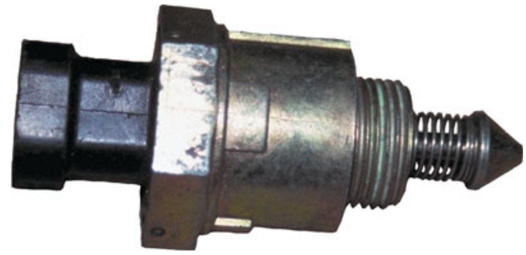


FIGURE 37–22 A typical IAC.

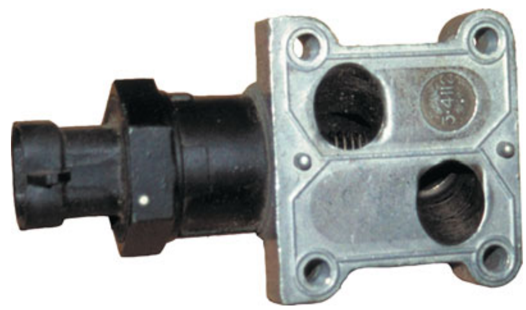


FIGURE 37–23 Some IAC units are purchased with the housing as shown. Carbon buildup in these passages can cause a rough or unstable idling or stalling.

REAL WORLD FIX

There Is No Substitute for a Thorough Visual Inspection

An intermittent "check engine" light and a random-misfire diagnostic trouble code (DTC) P0300 was being diagnosed. A scan tool did not provide any help because all systems seemed to be functioning normally. Finally, the technician removed the engine cover and discovered a mouse nest. ● **SEE FIGURE 37–24.**

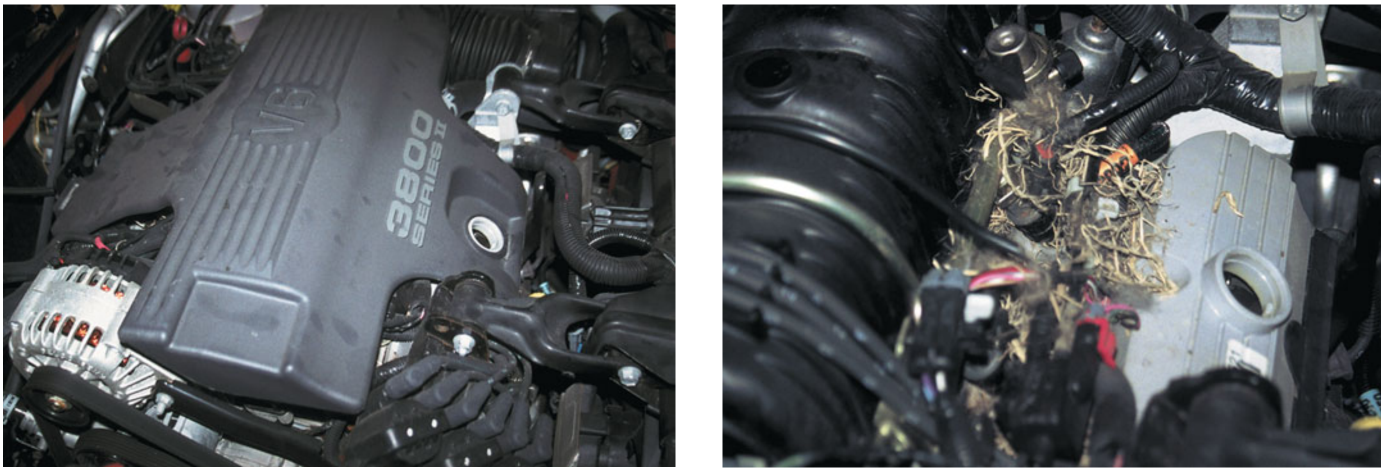
FUEL-INJECTION SERVICE

After many years of fuel-injection service, some service technicians still misunderstand the process of proper fuel-system handling. Much has been said over the years with regard to when and how to perform injector cleaning. Some manufacturers have suggested methods of cleaning while others have issued bulletins to prohibit any cleaning at all.

All engines using fuel injection do require some type of fuel-system maintenance. Normal wear and tear with underhood temperatures and changes in gasoline quality contribute to the buildup of olefin wax, dirt, water, and many other additives. Unique to each engine is an idle air-control design that also may contribute different levels of carbon deposits.

Fuel-injection system service should include the following operations:

1. **Check fuel-pump operating pressure and volume.** The missing link here is volume. Most working technicians assume that if the pressure is correct, the volume is also okay. Hook up a fuel-pressure tester to the fuel rail inlet to quickly test the fuel pressure with the engine running. At the same time, test the volume of the pump by sending fuel into the holding tank. (One ounce per second is the usual specification.) ● **SEE FIGURE 37–25.** A two-line system tester is the recommended procedure to use and is attached to the fuel inlet and the return on the fuel rail. The vehicle onboard system is looped and returns fuel to the tank.
2. **Test the fuel-pressure regulator for operation and leakage.** At this time, the fuel-pressure regulator would be tested for operational pressure and proper regulation, including leakage. Below are some points to consider:
   - Good pressure does not mean proper volume. For example, a clogged filter may test okay on pressure but the restriction may not allow proper volume under load. ● **SEE FIGURE 37–26.**



(a) (b)

FIGURE 37–24 (a) Nothing looks unusual when the hood is first opened. (b) When the cover is removed from the top of the engine, a mouse or some other animal nest is visible. The animal had already eaten through a couple of injector wires. At least the cause of the intermittent misfire was discovered.

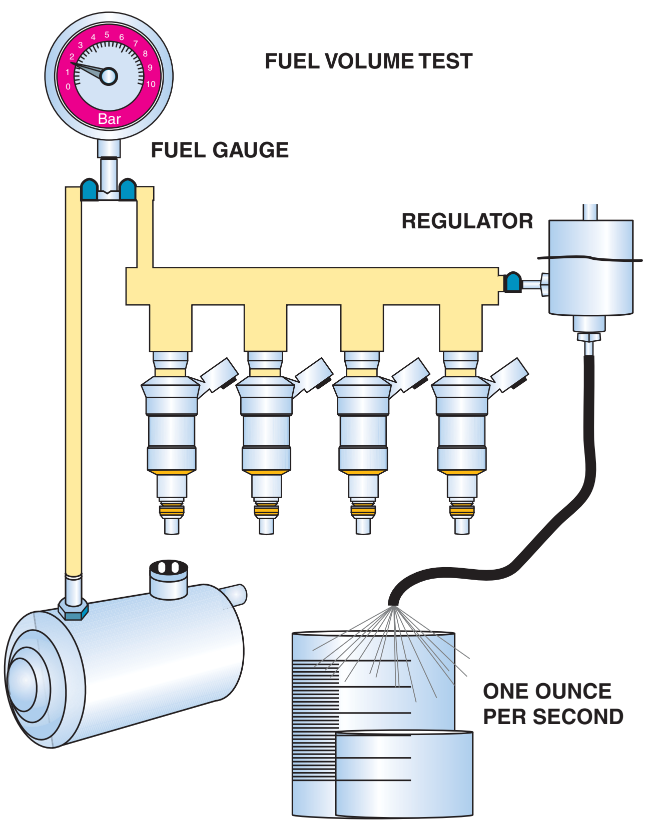


FIGURE 37–25 Checking fuel-pump volume using a hose from the outlet of the fuel-pressure regulator into a calibrated container.

- It is a good idea to use the vehicle's own gasoline to service the system versus a can of shop gasoline that has been sitting around for some time.
- Pressure regulators do fail and a lot more do not properly shut off fuel, causing higher-than-normal pump wear and shorter service life.

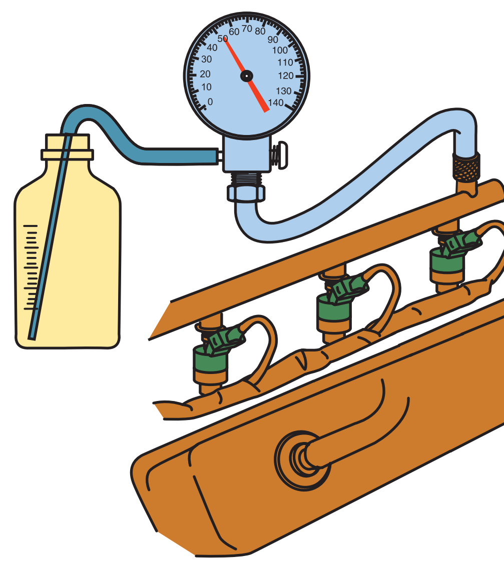


FIGURE 37–26 Testing fuel-pump volume using a fuel-pressure gauge with a bleed hose inserted into a suitable container. The engine is running during this test.

3. **Flush the entire fuel rail and upper fuel-injector screens including the fuel-pressure regulator.** Raise the input pressure to a point above regulator setting to allow a constant flow of fuel through the inlet pressure side of the system, through the fuel rail, and out the open fuel-pressure regulator. In most cases the applied pressure is 75 to 90 PSI (517 to 620 kPa), but will be maintained by the presence of a regulator. At this point, cleaning chemical is added to the fuel at a 5:1 mixture and allowed to flow through the system for 15 to 30 minutes. ● **SEE FIGURE 37–27.** Results are best on a hot engine with the fuel supply looped and the engine not running. Below are some points to consider:
   - This flush is the fix most vehicles need first. The difference is that the deposits are removed to a remote tank

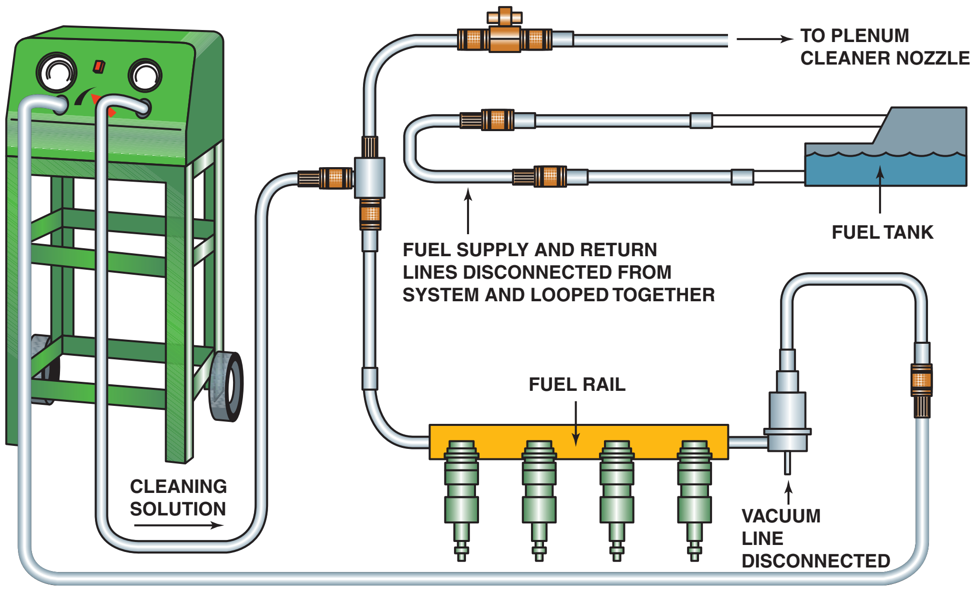


FIGURE 37–27 A typical two-line cleaning machine hookup, showing an extension hose that can be used to squirt a cleaning solution into the throttle body while the engine is running on the cleaning solution and gasoline mixture. Typical two-line cleaning machines include Carbon Clean, Auto Care, Injector Test, DeCarbon, or Motor-Vac.

and filter versus attempting to soften the deposits and blow them through the upper screens.

- Most injectors use a 10-micron final filter screen. A 25% restriction in the upper screen would increase the injector on-time approximately 25%.
- **Clean the fuel injectors.** Start the engine and adjust the output pressure closer to regulator pressure or lower than in the previous steps. Lower pressure will cause the pulse width to open up somewhat longer and allow the injectors to be cleaned. Slow speed (idle) position will take a longer time frame and operating temperature will be reached. Clean injectors are the objective, but the chemical should also decarbon the engine valves, pistons, and oxygen sensor.

4. **Decarbon the engine assembly.** On most vehicles, the injector spray will help the decarboning process. On others, you may need to enhance the operation with external addition of a mixture through the PCV hose, throttle plates, or idle air controls.
5. **Clean the throttle plate and idle air control passages.** Doing this service alone on most late-model engines will show a manifold vacuum increase of up to 2 in. Hg. Stop the engine and clean the areas as needed, then use a handheld fuel injector connected in parallel with the pressure hose, along with a pulser to allow cleaning of the throttle plates with the same chemical as injectors are running on. ● **SEE FIGURE 37–28.** This works well as air is drawn into IAC passages on a running engine and will clean the passages without IAC removal.
6. **Relearn the onboard computer.** Some vehicles may have been running in such a poor state of operation that the onboard computer may need to be relearned. Consult service information for the suggested relearn procedures for each particular vehicle.

This service usually takes approximately one hour for the vehicle to run out of fuel and the entire service to be performed. The good thing is that the technician may do other services while this

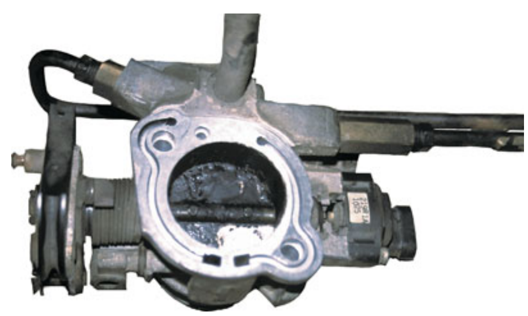


FIGURE 37–28 To thoroughly clean a throttle body, it is sometimes best to remove it from the vehicle.

TECH TIP

Check the Injectors at the "Bends and the Ends"

Injectors that are most likely to become restricted due to clogging of the filter basket screen are the injectors at the ends of the rail especially on returnless systems where dirt can accumulate. Also the injectors that are located at the bends of the fuel rail are also subject to possible clogging due to the dirt being deposited where the fuel makes a turn in the rail.

TECH TIP

Be Sure to Clean the Fuel Rail

Whenever you service the fuel injectors, or if you suspect that there may be a fuel-injector problem, remove the entire fuel rail assembly and check the passages for contamination. Always thoroughly clean the rail when replacing fuel injectors.

is being performed. Some technicians may install a set of plugs or change the fuel filter while the engine is flushing. This service should restore the fuel system to original operations.

Fuel-Injection Symptom Chart

Symptom	Possible Causes
Hard cold starts	• Low fuel pressure • Leaking fuel injectors • Contaminated fuel • Low-volatility fuel • Dirty throttle plate
Garage stalls	• Low fuel pressure • Insufficient fuel volume • Restricted fuel injector • Contaminated fuel • Low-volatility fuel
Poor cold performance	• Low fuel pressure • Insufficient fuel volume • Contaminated fuel • Low-volatility fuel
Tip-in hesitation (hesitation just as the accelerator pedal is depressed)	• Low fuel pressure • Insufficient fuel volume • Intake valve deposits • Contaminated fuel • Low-volatility fuel

FUEL-SYSTEM SCAN TOOL DIAGNOSTICS

FUEL TRIM VALUES Diagnosing a faulty fuel system can be a difficult task. However, it can be made easier by utilizing the information available via the serial data stream. By observing the long-term fuel trim and the short-term fuel trim, we can determine how the fuel system is performing. Short-term fuel trim and long-term fuel trim can help us to zero in on specific areas of trouble. Readings should be taken at idle and at 3000 RPM. Use the following chart as a guide.

Condition	Long-Term Fuel Trim at Idle	Long-Term Fuel Trim at 3000 RPM
System normal	0% ± 10%	0% ± 10%
Vacuum leak	HIGH	OK
Fuel flow problem	OK	HIGH
Low fuel pressure	HIGH	HIGH
High fuel pressure	*OK or LOW	*OK or LOW

*High fuel pressure will affect trim at idle, at 3000 RPM, or both.

IAC COUNTS A scan tool can be used to check the counts or steps needed to control the idle speed. With the engine at normal operating temperature , the fallowing IAC position as displayed on a scan tool will help with fuel system diagnosis.

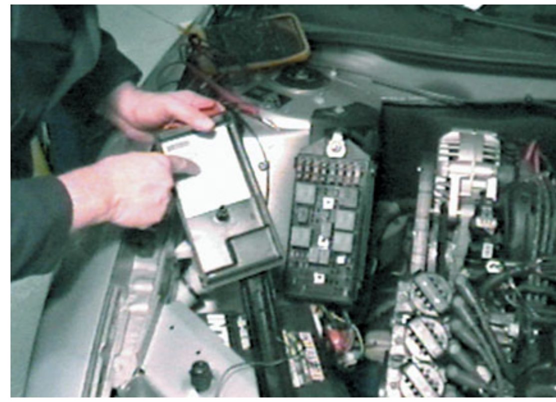
Normal- Normal idle air control counts should be 25-35 counts or percentage.

Lower-than-normal- If the IAC counts or percent age is less than 5 then there could be a vacuum leak (speed density system) or false air on some mass air flow engines.

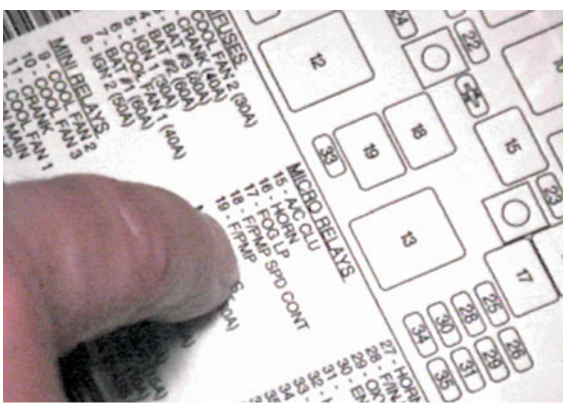
Higher-than-normal- If the counts or percentage is higher than 50, then this could be due to an excessive drag on the engine or a dirty throttle body or throttle plate.

FUEL-PUMP RELAY CIRCUIT DIAGNOSIS

1 The tools needed to diagnose a circuit containing a relay include a digital multimeter (DMM), a fused jumper wire, and an assortment of wiring terminals.



2 Start the diagnosis by locating the relay center. It is under the hood on this General Motors vehicle, so access is easy. Not all vehicles are this easy.



3 The chart under the cover for the relay center indicates the location of the relay that controls the electric fuel pump.

4 Locate the fuel-pump relay and remove by using a puller if necessary. Try to avoid rocking or twisting the relay to prevent causing damage to the relay terminals or the relay itself.

5 Terminals 85 and 86 represent the coil inside the relay. Terminal 30 is the power terminal, 87a is the normally closed contact, and 87 is the normally open contact.

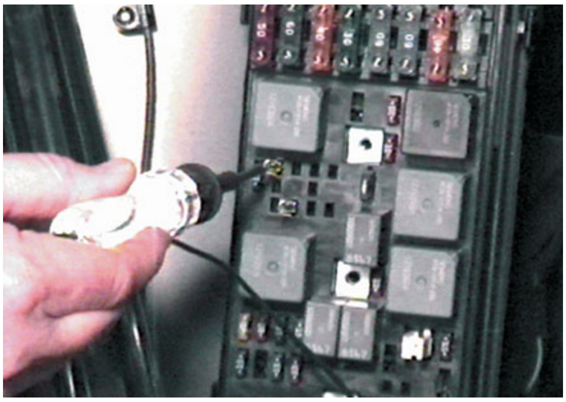
6 The terminals are also labeled on most relays.

7 To help make good electrical contact with the terminals without doing any harm, select the proper-size terminal from the terminal assortment.

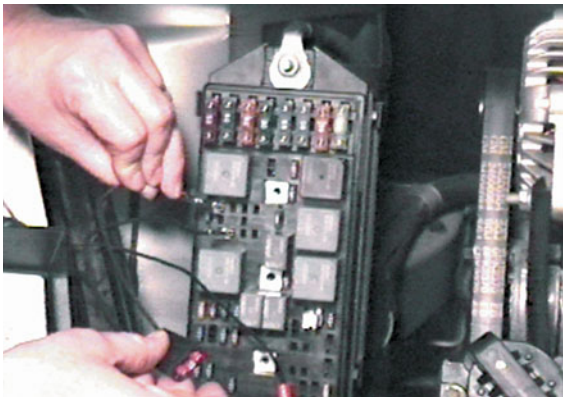
8 Insert the terminals into the relay socket in 30 and 87.

9 To check for voltage at terminal 30, use a test light or a voltmeter. Start by connecting the alligator clip of the test light to the positive (+) terminal of the battery.

10 Touch the test light to the negative (−) terminal of the battery or a good engine ground to check the test light.



11 Connect the ground lead of the test light to a good ground and check for voltage at terminal 30 of the relay. The ignition may have to be in the on (run) position.



12 To check to see if the electric fuel pump can be operated from the relay contacts, use a fused jumper wire and touch the relay contacts that correspond to terminals 30 and 87 of the relay.

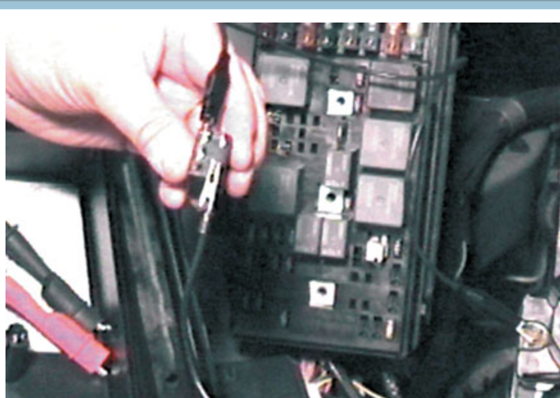
CONTINUED ▶

13 Connect the leads of the meter to contacts 30 and 87 of the relay socket. The reading of 4.7 amperes is okay because the specification is 4 to 8 amperes.

14 Set the meter to read ohms (Ω) and measure the resistance of the relay coil. The usual reading for most relays is between 60 and 100 ohms.

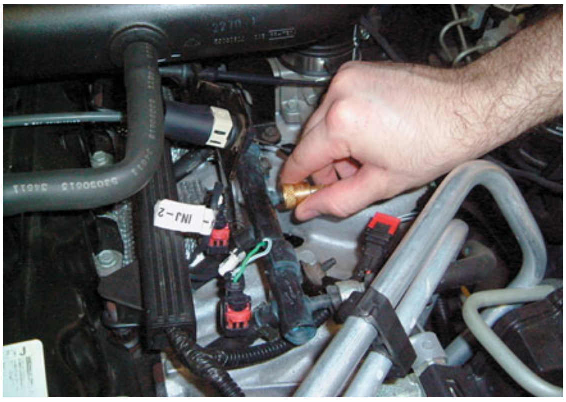
15 Measure between terminal 30 and 87a. Terminal 87a is the normally closed contact, and there should be little, if any, resistance between these two terminals, as shown.

16 To test the normally open contacts, connect one meter lead to terminal 30 and the other lead to terminal 87. The ohmmeter should show an open circuit by displaying OL.

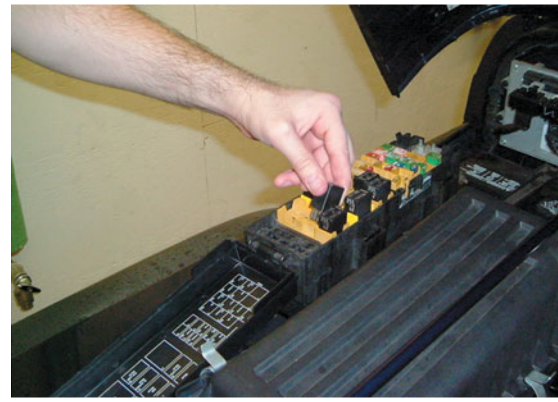


17 Connect a fused jumper wire to supply 12 volts to terminal 86 and a ground to terminal 85 of the relay. If the relay clicks, then the relay coil is able to move the armature (movable arm) of the relay.

18 After testing, be sure to reinstall the relay and the relay cover.



1 Start the fuel injector cleaning process by bringing the vehicle's engine up to operating temperature. Shut off the engine, remove the cap from the fuel rail test port, and install the appropriate adapter.



2 The vehicle's fuel pump is disabled by removing its relay or fuse. In some cases, it may be necessary to disconnect the fuel pump at the tank if the relay or fuse powers more than just the pump.

3 Turn the outlet valve of the canister to the OFF or CLOSED position.

4 Remove the fuel injector cleaning canister's top and regulator assembly. Note that there is an O-ring seal located here that must be in place for the canister's top to seal properly.

5 Pour the injection system cleaning fluid into the open canister. Rubber gloves are highly recommended for this step as the fluid is toxic.

6 Replace the canister's top (making sure it is tight) and connect its hose to the fuel rail adapter. Be sure that the hose is routed away from exhaust manifolds and other hazards.

CONTINUED ▶

7 Hang the canister from the vehicle's hood and adjust the air pressure regulator to full OPEN position (CCW).

8 Connect shop air to the canister and adjust the air pressure regulator to the desired setting. Canister pressure can be read directly from the gauge.

9 Canister pressure should be adjusted to 5 PSI below system fuel pressure. An alternative for return-type systems is to block the fuel return line to the tank.

10 Open the outlet valve on the canister.

11 Start the vehicle's engine and let run at 1000–1500 RPM. The engine is now running on fuel injector cleaning fluid provided by the canister.

12 Continue the process until the canister is empty and the engine stalls. Remove the cleaning equipment, enable the vehicle's fuel pump, and run the engine to check for leaks.

SUMMARY

1. A typical fuel-injection system fuel pressure should not drop more than 20 PSI in 20 minutes.
2. A noid light can be used to check for the presence of an injector pulse.
3. Injectors can be tested for resistance and should be within 0.3 to 0.4 ohms of each other.
4. Different designs of injectors have a different scope waveform depending on how the computer pulses the injector on and off.
5. An idle air control unit controls idle speed and can be tested for proper operation using a scan tool.

REVIEW QUESTIONS

1. List the ways fuel injectors can be tested.
2. List the steps necessary to test a fuel-pressure regulator.
3. Describe why it may be necessary to clean the throttle plate of a port fuel-injected engine.

CHAPTER QUIZ

1. Most port fuel-injected engines operate on how much fuel pressure?
   - **a.** 3 to 5 PSI (21 to 35 kPa)
   - **b.** 9 to 13 PSI (62 to 90 kPa)
   - **c.** 35 to 45 PSI (240 to 310 kPa)
   - **d.** 55 to 65 PSI (380 to 450 kPa)
2. Fuel injectors can be tested using _____________.
   - **a.** An ohmmeter
   - **b.** A stethoscope
   - **c.** A scope
   - **d.** All of the above
3. Throttle-body fuel-injection systems use what type of injector driver?
   - **a.** Peak and hold
   - **b.** Saturated switch
   - **c.** Pulse-width modulated
   - **d.** Pulsed
4. Port fuel-injection systems generally use what type of injector driver?
   - **a.** Peak and hold
   - **b.** Saturated switch
   - **c.** Pulse-width modulated
   - **d.** Pulsed
5. The vacuum hose from the fuel-pressure regulator was removed from the regulator and gasoline dripped out of the hose. Technician A says that is normal and that everything is okay. Technician B says that one or more of the injectors may be defective, causing the fuel to get into the hose. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. The fuel pressure drops rapidly when the engine is turned off. Technician A says that one or more injectors could be leaking. Technician B says that a defective check valve in the fuel pump could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. In a typical port fuel-injection system, which injectors are most subject to becoming restricted?
   - **a.** Any of them equally
   - **b.** The injectors at the end of the rail on a returnless system
   - **c.** The injectors at the bends in the rail
   - **d.** Either b or c
8. What component pulses the fuel injector on most vehicles?
   - **a.** Powertrain control module (PCM)
   - **b.** Ignition module
   - **c.** Crankshaft sensor
   - **d.** Both b and c
9. Fuel-injection service is being discussed. Technician A says that the throttle plate(s) should be cleaned. Technician B says that the fuel rail should be cleaned. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. If the throttle plate needs to be cleaned, what symptoms will be present regarding the operation of the engine?
    - **a.** Stalls
    - **b.** Rough idle
    - **c.** Hesitation on acceleration
    - **d.** All of the above

chapter 38

VEHICLE EMISSION STANDARDS AND TESTING

OBJECTIVES: After studying Chapter 38, the reader will be able to: • Prepare for ASE A8 certification test content area "D" (Emissions Control Systems Diagnosis and Repair) and ASE L1 certification test content area "F" (I/M Failure Diagnosis). • Discuss emission standards. • Identify the reasons why excessive amounts of HC, CO, and NO_x exhaust emissions are created. • Describe how to baseline a vehicle after an exhaust emission failure. • List acceptable levels of HC, CO, CO_2, and O_2 with and without a catalytic converter. • List four possible causes for high readings for HC, CO, and NO_x.

KEY TERMS: Acceleration simulation mode (ASM) 547 • ASM 25/25 test 547 • ASM 50/15 test 547 • Clean Air Act Amendments (CAAA) • Federal Test Procedure (FTP) 546 • I/M 240 test 548 • Lean indicator 551 • Non-methane hydrocarbon (NMHC) 549 • Ozone 551 • Rich indicator 550 • Sealed Housing for Evaporative Determination (SHED) test 546 • Smog 551 • State Implementation Plan (SIP) 546

EMISSION STANDARDS IN THE UNITED STATES

In the United States, emissions standards are managed by the Environmental Protection Agency (EPA) as well as some U.S. state governments. Some of the strictest standards in the world are formulated in California by the California Air Resources Board (CARB).

TIER 1 AND TIER 2 Federal emission standards are set by the **Clean Air Act Amendments (CAAA)** of 1990 grouped by tier. All vehicles sold in the United States must meet Tier 1 standards that went into effect in 1994 and are the least stringent. Additional Tier 2 standards have been optional since 2001, and was fully phased in by 2009. The current Tier 1 standards are different between automobiles and light trucks (SUVs, pickup trucks, and minivans), but Tier 2 standards will be the same for both types of vehicles.

There are several ratings that can be given to vehicles, and a certain percentage of a manufacturer's vehicles must meet different levels in order for the company to sell its products in affected regions. Beyond Tier 1, and in order by stringency, are the following levels:

- **TLEV Transitional Low-Emission Vehicle.** More stringent for HC than Tier 1.
- **LEV:** (also known as: **LEV I**) **Low-Emission Vehicle,** an intermediate California standard about twice as stringent as Tier 1 for HC and NO_x.

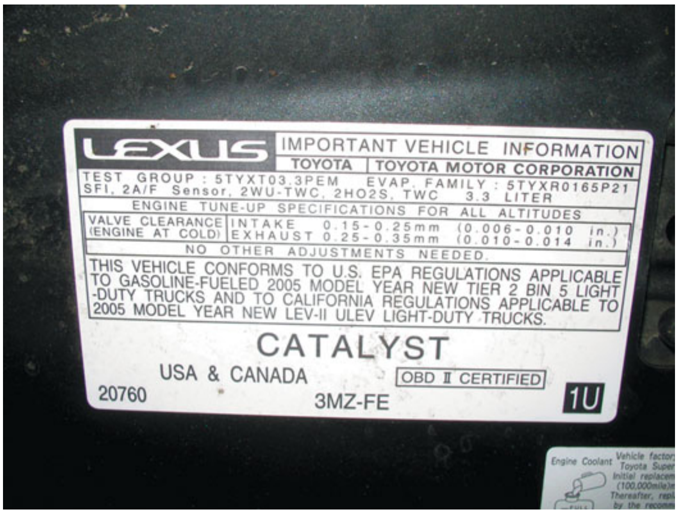


FIGURE 38–1 The underhood decal showing that this Lexus RX-330 meets both national (Tier 2; BIN 5) and California LEV-II (ULEV) regulation standards.

- **ULEV** (also known as **ULEV I): Ultra-Low-Emission Vehicle.** A stronger California standard emphasizing very low HC emissions.
- **ULEV II: Ultra-Low-Emission Vehicle.** A cleaner-than-average vehicle certified under the Phase II LEV standard. Hydrocarbon and carbon monoxide emissions levels are nearly 50% lower than those of a LEV II-certified vehicle. ● **SEE FIGURE 38–1.**
- **SULEV: Super-Ultra-Low-Emission Vehicle.** A California standard even tighter than ULEV, including much

lower HC and NO_x emissions; roughly equivalent to Tier 2 Bin 2 vehicles.

- **ZEV: Zero-Emission Vehicle.** A California standard prohibiting any tailpipe emissions. The ZEV category is largely restricted to electric vehicles and hydrogen-fueled vehicles. In these cases, any emissions that are created are produced at another site, such as a power plant or hydrogen reforming center, unless such sites run on renewable energy.

NOTE: A battery-powered electric vehicle charged from the power grid will still be up to 10 times cleaner than even the cleanest gasoline vehicles over their respective lifetimes.

- **PZEV: Partial Zero-Emission Vehicle.** Compliant with the SULEV standard; additionally has near-zero evaporative emissions and a 15-year/150,000-mile warranty on its emission control equipment.

Tier 2 standards are even more stringent. Tier 2 variations are appended with "II," such as LEV II or SULEV II. Other categories have also been created:

- **ILEV: Inherently Low-Emission Vehicle** - a vehicle certified to meet the transitional low-emission vehicle standards established by the California Air Resources Board (CARB)
- **AT-PZEV: Advanced Technology Partial Zero-Emission Vehicle.** If a vehicle meets the PZEV standards and is using high-technology features, such as an electric motor or high-pressure gaseous fuel tanks for compressed natural gas, it qualifies as an AT-PZEV. Hybrid electric vehicles such as the Toyota Prius can qualify, as can internal combustion engine vehicles that run on natural gas (CNG), such as the Honda Civic GX. These vehicles are classified as "partial" ZEV because they receive partial credit for the number of ZEV vehicles that automakers would otherwise be required to sell in California.
- **NLEV: National Low-Emission Vehicle.** All vehicles nationwide must meet this standard, which started in 2001.

FEDERAL EPA BIN NUMBER The higher the tier number, the newer the regulation; the lower the bin number, the cleaner the vehicle. The Toyota Prius is a very clean Bin 3, while the Hummer H2 is a dirty Bin 11. ● **SEE CHARTS 38–1, 38–2, AND 38–3.**

SMOG EMISSION INFORMATION New vehicles are equipped with a sticker that shows the relative level of smog-causing emissions created by the vehicle compared to others on the market. Smog-causing emissions include unburned hydrocarbons (HC) and oxides of nitrogen (NO_x). ● **SEE FIGURE 38–2.**

CALIFORNIA STANDARDS The pre-2004 California Air Resources Board (CARB) standards as a whole were known as LEV I. Within that, there were four possible ratings: Tier 1, TLEV, LEV, and ULEV. The newest CARB rating system (since January 1, 2004) is known as LEV II. Within that rating system there are three primary ratings: LEV, ULEV, and SULEV. States other than California are given the option to use the federal EPA standards, or they can adopt California's standards.

CERTIFICATION LEVEL	NMOG (G/MI)	CO (G/MI)	NO_x (G/MI)
Bin 1	0.0	0.0	0.0
Bin 2	0.010	2.1	0.02
Bin 3	0.055	2.1	0.03
Bin 4	0.070	2.1	0.04
Bin 5	0.090	4.2	0.07
Bin 6	0.090	4.2	0.10
Bin 7	0.090	4.2	0.15
Bin 8a	0.125	4.2	0.20
Bin 8b	0.156	4.2	0.20
Bin 9a	0.090	4.2	0.30
Bin 9b	0.130	4.2	0.30
Bin 9c	0.180	4.2	0.30
Bin 10a	0.156	4.2	0.60
Bin 10b	0.230	6.4	0.60
Bin 10c	0.230	6.4	0.60
Bin 11	0.230	7.3	0.90

CHART 38–1

EPA Tier 2—120,000-Mile Tailpipe Emission Limits. NMOG stands for non-methane organic gases which is a measure of all gases except those often created naturally by animals. After January 2007, the highest allowable Bin is 8.
Source: Data compiled from the Environmental Protection Agency (EPA).

NOTE: The bin number is determined by the type and weight of the vehicle.

U.S. EPA VEHICLE INFORMATION PROGRAM (THE HIGHER THE SCORE, THE LOWER THE EMISSIONS)	
SELECTED EMISSIONS STANDARDS	SCORE
Bin 1 and ZEV	10
PZEV	9.5
Bin 2	9
Bin 3	8
Bin 4	7
Bin 5 and LEV II cars	6
Bin 6	5
Bin 7	4
Bin 8	3
Bin 9a and LEV I cars	2
Bin 9b	2
Bin 10a	1
Bin 10b and Tier 1 cars	1
Bin 11	0

CHART 38–2

Air Pollution Score
Source: Courtesy of the Environmental Protection Agency (EPA).

	MINIMUM FUEL ECONOMY (MPG) COMBINED CITY-HIGHWAY LABEL VALUE				
SCORE	GASOLINE	DIESEL	E-85	LPG	CNG*
10	44	50	31	28	33
9	36	41	26	23	27
8	30	35	22	20	23
7	26	30	19	17	20
6	23	27	17	15	18
5	21	24	15	14	16
4	19	22	14	12	14
3	17	20	12	11	13
2	16	18	—	—	12
1	15	17	11	10	11
0	14	16	10	9	10

CHART 38–3

Greenhouse Gas Score

Source: Courtesy of the Environmental Protection Agency (EPA).

*CNG assumes a gallon equivalent of 121.5 cubic feet.

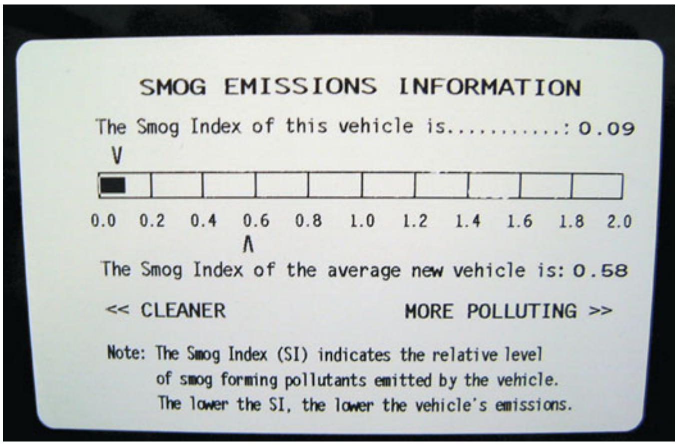


FIGURE 38–2 This label on a Toyota Camry hybrid shows the relative smog-producing emissions, but this does not include carbon dioxide (CO_2), which may increase global warming.

EUROPEAN STANDARDS

Europe has its own set of standards that vehicles must meet, which includes the following tiers:

- Euro I (1992–1995)
- Euro II (1995–1999)
- Euro III (1999–2005)
- Euro IV (2005–2008)
- Euro V (2008+)

Vehicle emission standards and technological advancements have successfully reduced pollution from cars and trucks by about 90% since the 1970s. Unfortunately, there currently are more vehicles on the road and they are being driven more miles each year, partially offsetting the environmental benefits of individual vehicle emissions reductions.

EXHAUST ANALYSIS TESTING

The Clean Air Act Amendments require enhanced Inspection and Maintenance (I/M) programs in areas of the country that have the worst air quality and the Northeast Ozone Transport region. The states must submit to the EPA a **State Implementation Plan (SIP)** for their programs. Each enhanced I/M program is required to include as a minimum the following items:

- Computerized emission analyzers
- Visual inspection of emission control items
- Minimum waiver limit (to be increased based on the inflation index)
- Remote on-road testing of one-half of 1% of the vehicle population
- Registration denial for vehicles not passing an I/M test
- Denial of waiver for vehicles that are under warranty or that have been tampered with
- Annual inspections
- OBD-II systems check for 1996 and newer vehicles

FEDERAL TEST PROCEDURE (FTP)

The **Federal Test Procedure (FTP)** is the test used to certify all new vehicles before they can be sold. Once a vehicle meets these standards, it is certified by the EPA for sale in the United States. The FTP test procedure is a loaded-mode test lasting for a total duration of 505 seconds and is designed to simulate an urban driving trip. A cold start-up representing a morning start and a hot start after a soak period is part of the test. In addition to this drive cycle, a vehicle must undergo evaporative testing. Evaporative emissions are determined using the **Sealed Housing for Evaporative Determination (SHED)** test, which measures the evaporative emissions from the vehicle after a heat-up period representing a vehicle sitting in the sun. In addition, the vehicle is driven and then tested during the hot soak period.

NOTE: A SHED is constructed entirely of stainless steel. The walls, floors, and ceiling, plus the door, are all constructed of stainless steel because it does not absorb hydrocarbons, which could offset test results.

The FTP is a much more stringent test of vehicle emissions than is any test type that uses equipment that measures percentages of exhaust gases. The federal emission standards for each model year vehicle are the same for that model regardless of what size engine the vehicle is equipped with. This is why larger V-8 engines often are equipped with more emission control devices than smaller four- and six-cylinder engines.

FIGURE 38–3 Photo of a sign taken at an emissions test facility.

I/M TEST PROGRAMS There are a variety of I/M testing programs that have been implemented by the various states. These programs may be centralized testing programs or decentralized testing programs. Each state is free to develop a testing program suitable to their needs as long as they can demonstrate to the EPA that their plan will achieve the attainment levels set by the EPA. This approach has led to a variety of different testing programs. ● **SEE FIGURE 38–3.**

VISUAL TAMPERING CHECKS Visual tampering checks may be part of an I/M testing program and usually include checking for the following items:

- Catalytic converter
- Fuel tank inlet restrictor
- Exhaust gas recirculation (EGR)
- Evaporative emission system
- Air-injection reaction system (AIR)
- Positive crankcase ventilation (PCV)

If any of these systems are missing, not connected, or tampered with, the vehicle will fail the emissions test and will have to be repaired/replaced by the vehicle owner before the vehicle can pass the emission test. Any cost associated with repairing or replacing these components may not be used toward the waiver amount required for the vehicle to receive a waiver.

ONE-SPEED AND TWO-SPEED IDLE TEST The one-speed and two-speed idle test measures the exhaust emissions from the tailpipe of the vehicle at idle and/or at 2500 RPM. This uses stand-alone exhaust gas sampling equipment that measures the emissions in percentages. Each state chooses the standards that the vehicle has to meet in order to pass the test. The advantage to using this type of testing is that the equipment is relatively cheap and allows states to have decentralized testing programs because many facilities can afford the necessary equipment required to perform this test.

FIGURE 38–4 A vehicle being tested during an enhanced emission test.

LOADED MODE TEST The loaded mode test uses a dynamometer that places a "single weight" load on the vehicle. The load applied to the vehicle varies with the speed of the vehicle. Typically, a four-cylinder vehicle speed would be 24 mph, a six-cylinder vehicle speed would be 30 mph, and an eight-cylinder vehicle speed would be 34 mph. Conventional stand-alone sampling equipment is used to measure HC and CO emissions. This type of test is classified as a Basic I/M test by the EPA. ● **SEE FIGURE 38–4.**

ACCELERATION SIMULATION MODE (ASM) The **ASM-type** of test uses a dynamometer that applies a heavy load on the vehicle at a steady-state speed. The load applied to the vehicle is based on the acceleration rate on the second simulated hill of the FTP. This acceleration rate is 3.3 mph/sec/sec (read as 3.3 mph per second per second, which is the unit of acceleration). There are different ASM tests used by different states.

The **ASM 50/15** test places a load of 50% on the vehicle at a steady 15 mph. This load represents 50% of the horsepower required to simulate the FTP acceleration rate of 3.3 mph/sec. This type of test produces relatively high levels of NO_x emissions; therefore, it is useful in detecting vehicles that are emitting excessive NO_x.

The **ASM 25/25** test places a 25% load on the vehicle while it is driven at a steady 25 mph. This represents 25% of the load required to simulate the FTP acceleration rate of 3.3 mph/sec. Because this applies a smaller load on the vehicle at a higher speed, it will produce a higher level of HC and CO emissions than the ASM 50/15. NO_x emissions will tend to be lower with this type of test.

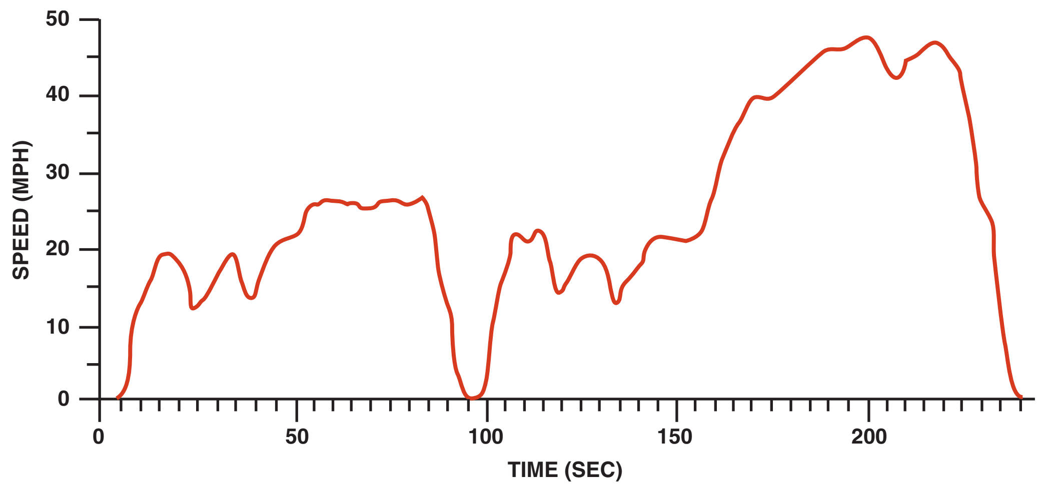


FIGURE 38–5 Trace showing the Inspection/Maintenance 240 test. The test duplicates an urban test loop around Los Angeles, California. The first "hump" in the curve represents the vehicle being accelerated to about 20 mph, then driving up a small hill to about 30 mph and coming to a stop at 94 seconds. Then, the vehicle accelerates while climbing a hill and speeding up to about 50 mph during this second phase of the test.

I/M 240 TEST The **I/M 240** test is the EPA's enhanced test. It is actually a portion of the 505-second FTP test used by the manufacturers to certify their new vehicles. The "240" stands for 240 seconds of drive time on a dynamometer. This is a loaded-mode transient test that uses constant volume sampling equipment to measure the exhaust emissions in mass just as is done during the FTP. The I/M 240 test simulates the first two hills of the FTP drive cycle. ● **FIGURE 38–5** shows the I/M 240 drive trace.

OBD-II TESTING In 1999, the EPA requested that states adopt OBD-II systems testing for 1996 and newer vehicles. The OBD-II system is designed to illuminate the MIL light and store trouble codes any time a malfunction exists that would cause the vehicle emissions to exceed 1 1/2 times the FTP limits. If the OBD-II system is working correctly, the system should be able to detect a vehicle failure that would cause emissions to increase to an unacceptable level. The EPA has determined that the OBD-II system should detect emission failures of a vehicle even before that vehicle would fail an emissions test of the type that most states are employing. Furthermore, the EPA has determined that, as the population of OBD-II-equipped vehicles increases and the population of older non-OBD-II-equipped vehicles decreases, tailpipe testing will no longer be necessary.

The OBD-II testing program consists of a computer that can scan the vehicle OBD-II system using the DLC connector. The technician first performs a visual check of the vehicle MIL light to determine if it is working correctly. Next, the computer is connected to the vehicle's DLC connector. The computer will scan the vehicle OBD-II system and determine if there are any codes stored that are commanding the MIL light on. In addition, it will scan the status of the readiness monitors and determine if they have all run and passed. If the readiness monitors have all run and passed, it indicates that the OBD-II system has tested all the components of the emission control system. An OBD-II vehicle would fail this OBD-II test if:

- The MIL light does not come on with the key on, engine off
- The MIL is commanded on
- A number (varies by state) of the readiness monitors have not been run

If none of these conditions are present, the vehicle will pass the emissions test.

REMOTE SENSING The EPA requires that, in high-enhanced areas, states perform on-the-road testing of vehicle emissions. The state must sample 0.5% of the vehicle population base in high-enhanced areas. This may be accomplished by using a remote sensing device. This type of sensing may be done through equipment that projects an infrared light through the exhaust stream of a passing vehicle. The reflected beam can then be analyzed to determine the pollutant levels coming from the vehicle. If a vehicle fails this type of test, the vehicle owner will receive notification in the mail that he or she must take the vehicle to a test facility to have the emissions tested.

RANDOM ROADSIDE TESTING Some states may implement random roadside testing that would usually involve visual checks of the emission control devices to detect tampering. Obviously, this method is not very popular as it can lead to traffic tie-ups and delays on the part of commuters.

Exhaust analysis is an excellent tool to use for the diagnosis of engine performance concerns. In areas of the country that require exhaust testing to be able to get license plates, exhaust analysis must be able to:

- Establish a baseline for failure diagnosis and service.
- Identify areas of engine performance that are and are not functioning correctly.
- Determine that the service and repair of the vehicle have been accomplished and are complete.

FIGURE 38–6 A partial stream sampling exhaust probe being used to measure exhaust gases in parts per million (PPM) or percent (%).

FREQUENTLY ASKED QUESTION

What Does NMHC Mean?

NMHC means **non-methane hydrocarbon** and it is the standard by which exhaust emission testing for hydrocarbons is evaluated. Methane is natural gas and can come from animals, animal waste, and other natural sources. By not measuring methane gas, all background sources are eliminated, giving better results as to the true amount of unburned hydrocarbons that are present in the exhaust stream.

EXHAUST ANALYSIS AND COMBUSTION EFFICIENCY

A popular method of engine analysis, as well as emission testing, involves the use of five-gas exhaust analysis equipment. ● **SEE FIGURE 38–6.** The five gases analyzed and their significance include:

HYDROCARBONS Hydrocarbons (HC) are unburned gasoline and are measured in parts per million (ppm). A correctly operating engine should burn (oxidize) almost all the gasoline; therefore, very little unburned gasoline should be present in the exhaust. Acceptable levels of HC are 50 PPM or less. High levels of HC could be due to excessive oil consumption caused by weak piston rings or worn valve guides. The most common cause of excessive HC emissions is a fault in the ignition system. Items that should be checked include:

- Spark plugs
- Spark plug wires
- Distributor cap and rotor (if the vehicle is so equipped)
- Ignition timing (if possible)
- Ignition coil

CARBON MONOXIDE Carbon monoxide (CO) is unstable and will easily combine with any oxygen to form stable carbon dioxide (CO_2). The fact that CO combines with oxygen is the reason that CO is a poisonous gas (in the lungs, it combines with oxygen to form CO_2 and deprives the brain of oxygen). CO levels of a properly operating engine should be less than 0.5%. High levels of CO can be caused by clogged or restricted crankcase ventilation devices such as the PCV valve, hose(s), and tubes. Other items that might cause excessive CO include:

- Clogged air filter
- Incorrect idle speed
- Too-high fuel-pump pressure
- Any other items that can cause a rich condition

CARBON DIOXIDE (CO_2) Carbon dioxide (CO_2) is the result of oxygen in the engine combining with the carbon of the gasoline. An acceptable level of CO_2 is between 12% and 15%. A high reading indicates an efficiently operating engine. If the CO_2 level is low, the mixture may be either too rich or too lean.

OXYGEN The next gas is oxygen (O_2). There is about 21% oxygen in the atmosphere, and most of this oxygen should be "used up" during the combustion process to oxidize all the hydrogen and carbon (hydrocarbons) in the gasoline. Levels of O_2 should be very low (about 0.5%). High levels of O_2, especially at idle, could be due to an exhaust system leak.

NOTE: Adding 10% alcohol to gasoline provides additional oxygen to the fuel and will result in lower levels of CO and higher levels of O_2 in the exhaust.

OXIDES OF NITROGEN (NO_x) An oxide of nitrogen (NO) is a colorless, tasteless, and odorless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen, nitrogen oxides (NO_2) are formed. NO_2 is reddish-brown and has an acid and pungent smell. NO and NO_2 are grouped together and referred to as NO_x, where x represents any number of oxygen atoms. NO_x, the symbol used to represent all oxides of nitrogen, is the fifth gas commonly tested using a five-gas analyzer. The exhaust gas recirculation (EGR) system is the major controlling device limiting the formation of NO_x.

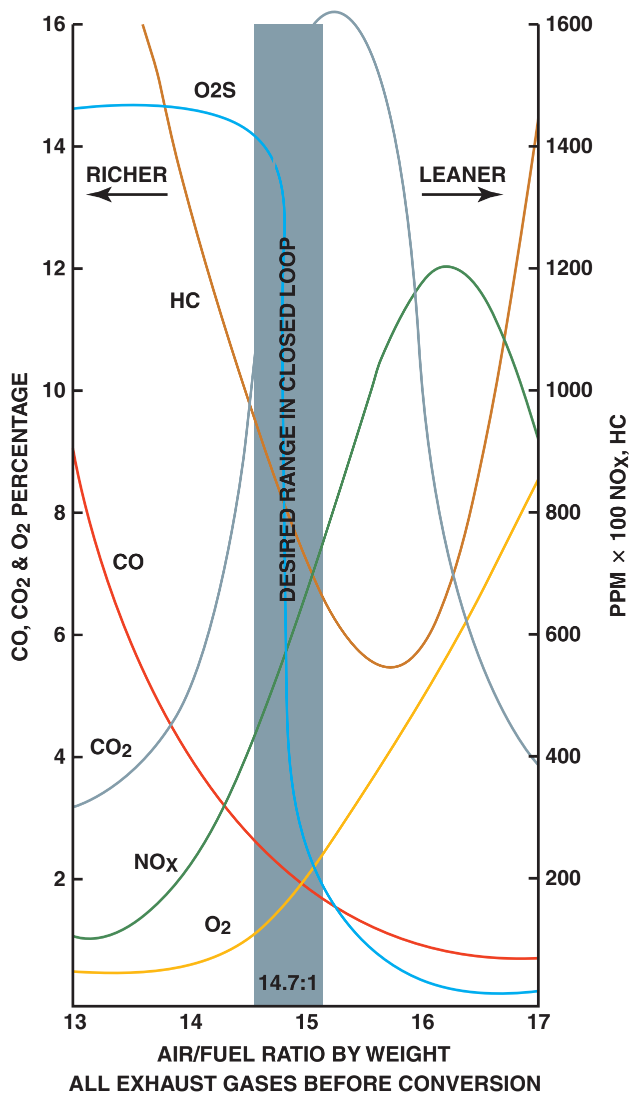


FIGURE 38–7 Exhaust emissions are very complex. When the air–fuel mixture becomes richer, some exhaust emissions are reduced, while others increase.

? FREQUENTLY ASKED QUESTION

How Can My Worn-Out, Old, High-Mileage Vehicle Pass an Exhaust Emission Test?

Age and mileage of a vehicle are generally not factors when it comes to passing an exhaust emission test. Regular maintenance is the most important factor for passing an enhanced Inspection and Maintenance (I/M) exhaust analysis test. Failure of the vehicle owner to replace broken accessory drive belts, leaking air pump tubes, defective spark plug wires, or a cracked exhaust manifold can lead to failure of other components such as the catalytic converter. Tests have shown that if the vehicle is properly cared for, even an engine that has 300,000 miles (483,000 km) can pass an exhaust emission test.

Acceptable exhaust emissions include:

	Without Catalytic Converter	With Catalytic Converter
HC	300 PPM or less	30 to 50 PPM or less
CO	3% or less	0.3% to 0.5% or less
O_2	0% to 2%	0% to 2%
CO_2	12% to 15% or higher	12% to 15% or higher
NO_x	Less than 100 PPM at idle and less than 1,000 PPM at WOT	Less than 100 PPM at idle and less than 1,000 PPM at WOT

● SEE FIGURE 38–7.

HC TOO HIGH

High hydrocarbon exhaust emissions are usually caused by an engine misfire. What burns the fuel in an engine? The ignition system ignites a spark at the spark plug to ignite the proper mixture inside the combustion chamber. If a spark plug does not ignite the mixture, the resulting unburned fuel is pushed out of the cylinder on the exhaust stroke by the piston through the exhaust valves and into the exhaust system. Therefore, if any of the following ignition components or adjustments are not correct, excessive HC emission is likely.

1. Defective or worn spark plugs
2. Defective or loose spark plug wires
3. Defective distributor cap and/or rotor
4. Incorrect ignition timing (either too far advanced or too far retarded)
5. A lean air–fuel mixture can also cause a misfire. This condition is referred to as a lean misfire. A lean air-fuel mixture can be caused by low fuel pump pressure, a clogged fuel filter or a restricted fuel injector.

NOTE: To make discussion easier in future reference to these items, this list of ignition components and check can be referred to as simply as "spark stuff."

CO TOO HIGH

Excessive carbon monoxide is an indication of too rich an air–fuel mixture. CO is the **rich indicator.** The higher the CO reading, the richer the air–fuel mixture. High concentrations of CO indicate that not enough oxygen was available for the amount of fuel. Common causes of high CO include:

- Too-high fuel-pump pressure
- Defective fuel-pressure regulator

> **TECH TIP**
>
> **CO Equals O_2**
>
> If the exhaust is rich, CO emissions will be higher than normal. If the exhaust is lean, O_2 emissions will be higher than normal. Therefore, if the CO reading is the same as the O_2 reading, then the engine is operating correctly. For example, if both CO and O_2 are 0.5% and the engine develops a vacuum leak, the O_2 will rise. If a fuel-pressure regulator were to malfunction, the resulting richer air–fuel mixture would increase CO emissions. Therefore, if both the rich indicator (CO) and the lean indicator (O_2) are equal, the engine is operating correctly.

- Clogged air filter or PCV valve

  NOTE: One technician remembers "CO" as meaning "clogged oxygen" and always looks for restricted airflow into the engine whenever high CO levels are detected.

- Defective injectors

MEASURING OXYGEN (O_2) AND CARBON DIOXIDE (CO_2)

Two gas exhaust analyzers (HC and CO) work well, but both HC and CO are consumed (converted) inside the catalytic converter. The amount of leftover oxygen coming out of the tailpipe is an indication of leanness. The higher the O_2 level, the leaner the exhaust. Oxygen therefore is the **lean indicator.** Acceptable levels of O_2 are 0% to 2%.

NOTE: A hole in the exhaust system can draw outside air (oxygen) into the exhaust system. Therefore, to be assured of an accurate reading, carefully check the exhaust system for leaks. Using a smoke machine is an easy method to locate leaks in the exhaust system.

Carbon dioxide (CO_2) is a measure of efficiency. The higher the level of CO_2 in the exhaust stream, the more efficiently the engine is operating. Levels of 12% to 15% are considered to be acceptable. Because CO_2 levels peak at an air–fuel mixture of 14.7:1, a lower level of CO_2 indicates either a too-rich or a too-lean condition. The CO_2 measurement by itself does not indicate which condition is present. For example:

$CO_2 = 8\%$ (This means efficiency is low and the air–fuel mixture is not correct.)

Look at O_2 and CO levels.

A high O_2 indicates lean and a high CO indicates rich.

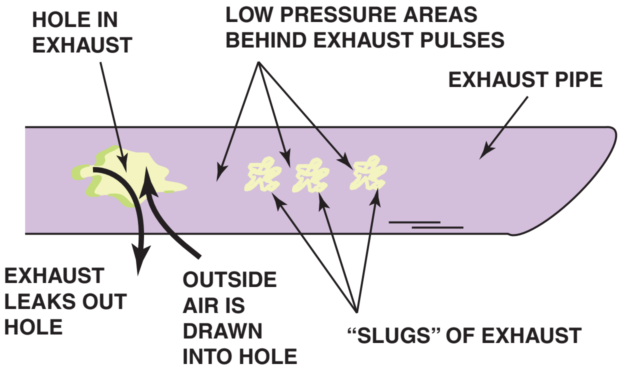


FIGURE 38–8 A hole in the exhaust system can cause outside air (containing oxygen) to be drawn into the exhaust system. This extra oxygen can be confusing to a service technician because the extra O_2 in the exhaust stream could be misinterpreted as a too-lean air–fuel mixture.

> **TECH TIP**
>
> **How to Find a Leak in the Exhaust System**
>
> A hole in the exhaust system can dilute the exhaust gases with additional oxygen (O_2). **SEE FIGURE 38–8.**
>
> This additional O_2 in the exhaust can lead the service technician to believe that the air–fuel mixture is too lean. To help identify an exhaust leak, perform an exhaust analysis at idle and at 2500 RPM (fast idle) and compare with the following:
>
> - If the O_2 is high at idle and at 2500 RPM, the mixture is lean at both idle and at 2500 RPM.
> - If the O_2 is low at idle and high at 2500 RPM, this usually means that the vehicle is equipped with a working AIR pump.
> - If the O_2 is high at idle, but okay at 2500 RPM, a hole in the exhaust or a small vacuum leak that is "covered up" at higher speed is indicated.

PHOTOCHEMICAL SMOG FORMATION

Oxides of nitrogen are formed by high temperature—over 2500°F (1370°C)—and/or pressures inside the combustion chamber. Oxides of nitrogen contribute to the formation of photochemical **smog** when sunlight reacts chemically with NO_x and unburned hydrocarbons (HC). Smog is a term derived by combining the words *smoke* and *fog*. Ground-level ozone is a constituent of smog. **Ozone** is an enriched oxygen molecule with three atoms of oxygen (O_3) instead of the normal two atoms of oxygen (O_2).

Ozone in the upper atmosphere is beneficial because it blocks out harmful ultraviolet rays that contribute to skin cancer. However, at ground level, this ozone (smog) is an irritant to the respiratory system.

TECH TIP

Your Nose Knows

Using the nose, a technician can often identify a major problem without having to connect the vehicle to an exhaust analyzer. For example,

- The strong smell of exhaust is due to excessive unburned hydrocarbon (HC) emissions. Look for an ignition system fault that could prevent the proper burning of the fuel. A vacuum leak could also cause a lean misfire and cause excessive HC exhaust emissions.
- If your eyes start to burn or water, suspect excessive oxides of nitrogen (NO_x) emissions. The oxides of nitrogen combine with the moisture in the eyes to form a mild solution of nitric acid. The acid formation causes the eyes to burn and water. Excessive NO_x exhaust emissions can be caused by:
  - A vacuum leak causing higher-than-normal combustion chamber temperatures
  - Overadvanced ignition timing causing higher-than-normal combustion chamber temperatures
  - Lack of proper amount of exhaust gas recirculation (EGR) (This is usually noticed above idle on most vehicles.)
- Dizzy feeling or headache. This is commonly caused by excessive carbon monoxide (CO) exhaust emissions. Get into fresh air as soon as possible. A probable cause of high levels of CO is an excessively rich air–fuel mixture.

TESTING FOR OXIDES OF NITROGEN

Because the formation of NO_x occurs mostly under load, the most efficient method to test for NO_x is to use a portable exhaust analyzer that can be carried in the vehicle while the vehicle is being driven under a variety of conditions.

SPECIFICATIONS FOR NO_x From experience, a maximum reading of 1,000 parts per million (PPM) of NO_x under loaded driving conditions will generally mean that the vehicle will pass an enhanced I/M roller test. A reading of over 100 PPM at idle should be considered excessive.

TECH TIP

Check for Dog Food?

A commonly experienced problem in many parts of the country involves squirrels or other animals placing dog food into the air intake ducts of vehicles. Dog food is often found packed tight in the ducts against the air filter. An air intake restriction reduces engine power and vehicle performance.

REAL WORLD FIX

The Case of the Retarded Exhaust Camshaft

A Toyota equipped with a double overhead camshaft (DOHC) inline six-cylinder engine failed the state-mandated enhanced exhaust emission test for NO_x. The engine ran perfectly without spark knocking (ping), which is usually a major reason for excessive NO_x emissions. The technician checked the following:

- The ignition timing, which was found to be set to specifications (if too far advanced, can cause excessive NO_x)
- The cylinders, which were decarbonized using top engine cleaner
- The EGR valve, which was inspected and the EGR passages cleaned

After all the items were completed, the vehicle was returned to the inspection station where the vehicle again failed for excessive NO_x emissions (better, but still over the maximum allowable limit).

After additional hours of troubleshooting, the technician decided to go back to basics and start over again. A check of the vehicle history with the owner indicated that the only previous work performed on the engine was a replacement timing belt over a year before. The technician discovered that the exhaust cam timing was retarded two teeth, resulting in late closing of the exhaust valve. The proper exhaust valve timing resulted in a slight amount of exhaust being retained in the cylinder. This extra exhaust was added to the amount supplied by the EGR valve and helped reduce NO_x emissions. After repositioning the timing belt, the vehicle passed the emissions test well within the limits.

Exhaust Gas Summary Chart

Gas	Cause and Correction
High HC	Engine misfire or incomplete burning of fuel caused by: 1. Ignition system fault 2. Lean misfire 3. Too low an engine temperature (thermostat)
High CO	Rich condition caused by: 1. Leaking fuel injectors or fuel-pressure regulator 2. Clogged air filter or PCV system 3. Excessive fuel pressure
High HC and CO	Excessively rich condition caused by: 1. All items included under high CO 2. Fouled spark plugs causing a misfire to occur 3. Possible nonoperating catalytic converter
High NO_x	Excessive combustion chamber temperature: 1. Nonoperating EGR valve 2. Clogged EGR passages 3. Engine operating temperature too high due to cooling system restriction, worn water pump impeller, or other faults in the cooling system 4. Lean air–fuel mixture 5. High compression caused by excessive carbon buildup in the cylinders

REAL WORLD FIX

O2S Shows Rich, but Pulse Width Is Low

A service technician was attempting to solve a driveability problem. The computer did not indicate any diagnostic trouble codes (DTCs). A check of the oxygen sensor voltage indicated a higher-than-normal reading almost all the time. The pulse width to the port injectors was lower than normal. The lower-than-normal pulse width indicates that the computer is attempting to reduce fuel flow into the engine by decreasing the amount of on-time for all the injectors.

What could cause a rich mixture if the injectors were being commanded to deliver a lean mixture? Finally the technician shut off the engine and took a careful look at the entire fuel-injection system. Although the vacuum hose was removed from the fuel-pressure regulator, fuel was found dripping from the vacuum hose. The problem was a defective fuel-pressure regulator that allowed an uncontrolled amount of fuel to be drawn by the intake manifold vacuum into the cylinders. While the computer tried to reduce fuel by reducing the pulse width signal to the injectors, the extra fuel being drawn directly from the fuel rail caused the engine to operate with too rich an air–fuel mixture.

SUMMARY

1. Excessive hydrocarbon (HC) exhaust emissions are created by a lack of proper combustion such as a fault in the ignition system, too lean an air–fuel mixture, or too-cold engine operation.
2. Excessive carbon monoxide (CO) exhaust emissions are usually created by a rich air–fuel mixture.
3. Excessive oxides of nitrogen (NO_x) exhaust emissions are usually created by excessive heat or pressure in the combustion chamber or a lack of the proper amount of exhaust gas recirculation (EGR).
4. Carbon dioxide (CO_2) levels indicate efficiency. The higher the CO_2, the more efficient the engine operation.
5. Oxygen (O_2) indicates leanness. The higher the O_2, the leaner the air–fuel mixture.
6. A vehicle should be driven about 20 miles, especially during cold weather, to allow the engine to be fully warm before an enhanced emissions test.

REVIEW QUESTIONS

1. List the five exhaust gases and their maximum allowable readings for a fuel-injected vehicle equipped with a catalytic converter.
2. List two causes of a rich exhaust.
3. List two causes of a lean exhaust.
4. List those items that should be checked if a vehicle fails an exhaust test for excessive NO_x emissions.

CHAPTER QUIZ

1. Technician A says that high HC emission levels are often caused by a fault in the ignition system. Technician B says that high CO_2 emissions are usually caused by a richer-than-normal air–fuel mixture. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. HC and CO are high and CO_2 and O_2 are low. This could be caused by a _____________.
   a. Rich mixture
   b. Lean mixture
   c. Defective ignition component
   d. Clogged EGR passage
3. Which gas is generally considered to be the rich indicator? (The higher the level of this gas, the richer the air–fuel mixture.)
   a. HC
   b. CO
   c. CO_2
   d. O_2
4. Which gas is generally considered to be the lean indicator? (The higher the level of this gas, the leaner the air–fuel mixture.)
   a. HC
   b. CO
   c. CO_2
   d. O_2
5. Which exhaust gas indicates efficiency? (The higher the level of this gas, the more efficient the engine operates.)
   a. HC
   b. CO
   c. CO_2
   d. O_2
6. All of the gases are measured in percentages except _____________.
   a. HC
   b. CO
   c. CO_2
   d. O_2
7. After the following exhaust emissions were measured, how was the engine operating?
   HC = 766 PPM CO_2 = 8.2% CO = 4.6% O_2 = 0.1%
   a. Too rich
   b. Too lean
8. Technician A says that carbon inside the engine can cause excessive NO_X to form. Technician B says that excessive NO_X could be caused by a cooling system fault causing the engine to operate too hot. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A clogged EGR passage could cause excessive _____________ exhaust emissions.
   a. HC
   b. CO
   c. NO_X
   d. CO_2
10. An ignition fault could cause excessive _____________ exhaust emissions.
    a. HC
    b. CO
    c. NO_X
    d. CO_2

chapter
39

EMISSION CONTROL DEVICES OPERATION AND DIAGNOSIS

OBJECTIVES: After studying Chapter 39, the reader will be able to: • Prepare for the ASE Engine Performance (A8) certification test content area "D" (Emission Control Systems). • Describe the purpose and function of the exhaust gas recirculation (EGR) system. • Explain methods for diagnosing and testing for faults in the exhaust gas recirculation system. • Describe the purpose and function of the positive crankcase ventilation (PCV) and the secondary air-injection (SAI) reaction systems. • Explain methods for diagnosing and testing faults in the PCV and SAI systems. • Describe the purpose and function of the catalytic converter. • Explain the method for diagnosing and testing the catalytic converter. • Describe the purpose and function of the evaporative emission control system. • Discuss how the evaporative emission control system is tested under OBD-II regulations. • Explain methods for diagnosing and testing faults in the evaporative emission control system.

KEY TERMS: Adsorption 574 • AIR 565 • Blowby 562 • Canister purge (CANP) 576 • Catalyst 568 • Catalytic converter 568 • Cerium 569 • Check valves 566 • Digital EGR 558 • DPFE sensor 559 • EGR 556 • EVP 558 • EVRV 560 • Fuel tank pressure (FTP) 579 • HO2S 569 • Inert 556 • Infrared thermometer (pyrometer) 571 • Leak detection pump (LDP) 577 • Light-off temperature 569 • Linear EGR 558 • LOC 569 • Mini converter 569 • Negative backpressure 557 • NOx 556 • OSC 569 • Palladium 569 • PCV 562 • PFE 558 • Platinum 569 • Positive backpressure 557 • Preconverter 569 • Pup converter 569 • Rhodium 569 • SAI 565 • Smog 555 • Smog pump 565 • Tap test 570 • Thermactor pump 565 • TWC 565 • Washcoat 568

INTRODUCTION

Most of the major advances in engines are a direct result of the need to improve fuel economy and reduce exhaust emissions. The engine changes needed to meet the latest emission standards include:

- More efficient combustion chambers
- Low friction engine components such as low tension piston rings, roller camshaft followers (rockers), and roller lifters
- More precise ignition timing with coil-on-plug ignition systems, which have the ability to change ignition timing on individual cylinders as needed to achieve the highest possible efficiency
- Closer engine tolerances to reduce unburned fuel emissions and to improve power output
- Variable valve timing systems used to increase engine power and reduce exhaust emissions

It has been said that engine changes are due to the need to reduce three things.

1. Emissions
2. Emissions
3. Emissions

SMOG

DEFINITION AND TERMINOLOGY The common term used to describe air pollution is **smog,** a word that combines two words: *smoke* and *fog*. Smog is formed in the atmosphere when sunlight combines with unburned fuel (hydrocarbons, or HC) and oxides of nitrogen (NOx) produced during the combustion process inside the cylinders of an engine. Carbon monoxide (CO) is a poisonous gas. Smog is ozone (O_3), a strong irritant to the lungs and eyes. Ozone is located two places.

1. Upper-atmospheric ozone is desirable because it blocks out harmful ultraviolet rays from the sun.
2. Ground-level ozone is considered to be unhealthy smog.

Emissions that are controlled include:

- **HC (unburned hydrocarbons).** Excessive HC emissions (unburned fuel) are controlled by the evaporative system (charcoal canister), the positive crankcase ventilation (PCV) system, the secondary air-injection (SAI) system, and the catalytic converter.
- **CO (carbon monoxide).** Excessive CO emissions are controlled by the positive crankcase ventilation (PCV) system, the secondary air-injection (SAI) system, and the catalytic converter.

FIGURE 39–1 Notice the red-brown haze which is often over many major cities. This haze is the result of oxides or nitrogen in the atmosphere.

- **NOx (oxides of nitrogen).** Excessive NOx emissions are controlled by the exhaust gas recirculation (EGR) system and the catalytic converter. An oxide of nitrogen (NO) is a colorless, tasteless, and odorless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen, nitrogen oxides (NO_2) are formed, which appear as red-brown emissions. Both No and NO_2 together are labeled NO_x. ● **SEE FIGURE 39–1.**

EXHAUST GAS RECIRCULATION SYSTEMS

INTRODUCTION **Exhaust gas recirculation (EGR)** is an emission control system that lowers the amount of **nitrogen oxides (NOx)** formed during combustion. In the presence of sunlight, NOx reacts with hydrocarbons in the atmosphere to form ozone (O_3) or photochemical smog, an air pollutant.

NOx FORMATION Nitrogen (N_2) and oxygen (O_2) molecules are separated into individual atoms of nitrogen and oxygen during the combustion process. These molecules then bond to form NOx (NO, NO_2). When combustion flame front temperatures exceed 2,500°F (1,370°C), NOx is formed inside the cylinders which is then discharged into the atmosphere from the tailpipe.

CONTROLLING NOx To handle the NOx generated above 2,500°F (1,370°C), the most efficient method to meet NOx emissions without significantly affecting engine performance, fuel economy, and other exhaust emissions is to use exhaust gas recirculation (EGR). The EGR system routes small quantities, usually between 6% and 10%, of exhaust gas into the intake manifold.

Here, the exhaust gas mixes with and takes the place of some of the intake charge. This leaves less room for the intake charge to enter the combustion chamber. The recirculated exhaust gas is **inert** (chemically inactive) and does not enter into the combustion process. The result is a lower peak combustion temperature. When the combustion temperature is lowered, the production of oxides of nitrogen is reduced.

The EGR system has some means of interconnecting the exhaust and intake manifolds. ● **SEE FIGURES 39–2 AND 39–3.**

The EGR valve controls the flow of exhaust gases through the interconnecting passages.

- On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve. The exhaust gas is sent from the EGR valve to openings in the manifold.
- On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve. This tube is often designed to be long so that the exhaust gas is cooled before it enters the EGR valve.

EGR SYSTEM OPERATION Since small amounts of exhaust are all that is needed to lower peak combustion temperatures, the orifice that the exhaust passes through is small.

EGR is usually *not* required during the following conditions because the combustion temperatures are low.

- Idle speed
- When the engine is cold
- At wide-open throttle (WOT) (Not allowing EGR allows the engine to provide extra power when demanded. While the NOx formation is high during these times, the overall effect of not using EGR during wide-open throttle conditions is minor.)

The level of NOx emission changes according to engine speed, temperature, and load.

EGR BENEFITS In addition to lowering NOx levels, the EGR system also helps control detonation. Detonation, also called spark knock or ping, occurs when high pressure and heat cause the air-fuel mixture to ignite. This uncontrolled combustion can severely damage the engine.

Using the EGR system allows for greater ignition timing advance and for the advance to occur sooner without detonation problems, which increases power and efficiency.

POSITIVE AND NEGATIVE BACKPRESSURE EGR VALVES Some vacuum-operated EGR valves used on older engines are designed with a small valve inside that

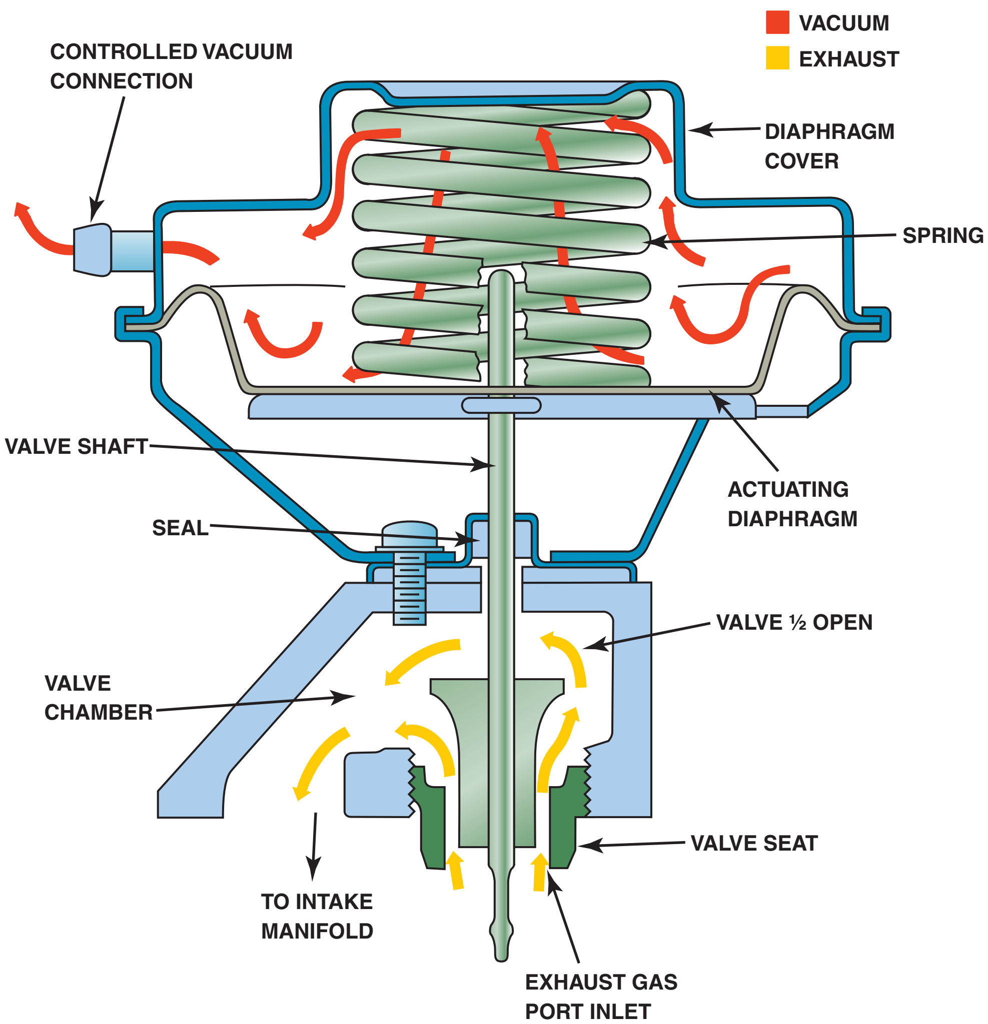


FIGURE 39–2 When the EGR valve opens, the exhaust gases flow through the valve and into passages in the intake manifold.

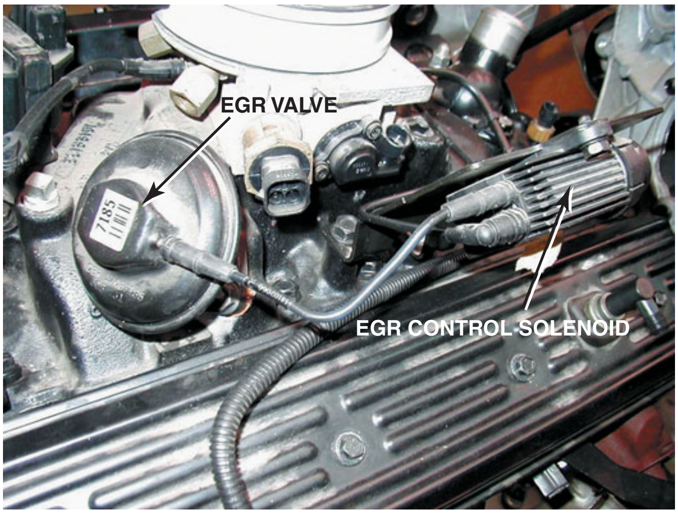


FIGURE 39–3 A vacuum-operated EGR valve. The vacuum to the EGR valve is computer controlled by the EGR valve control solenoid.

bleeds off any applied vacuum and prevents the valve from opening.

- **Positive backpressure.** These types of EGR valves require a positive backpressure in the exhaust system. At low engine speeds and light engine loads, the EGR system is not needed, and the backpressure in it is also low. Without sufficient backpressure, the EGR valve does not open even though vacuum may be present at the EGR valve.
- **Negative backpressure.** On each exhaust stroke, the engine emits an exhaust "pulse." Each pulse represents a positive pressure. Behind each pulse is a small area of low pressure. Some EGR valves react to this low-pressure area by closing a small internal valve, which allows the EGR valve to be opened by vacuum.

The following conditions must occur before a backpressure-type vacuum-controlled EGR will operate.

1. Vacuum must be applied to the EGR valve itself. The vacuum source can be ported vacuum (above the throttle plate) or manifold vacuum (below the throttle plate) and by the computer through a solenoid valve.
2. Exhaust backpressure must be present to close an internal valve inside the EGR to allow the vacuum to move the diaphragm.

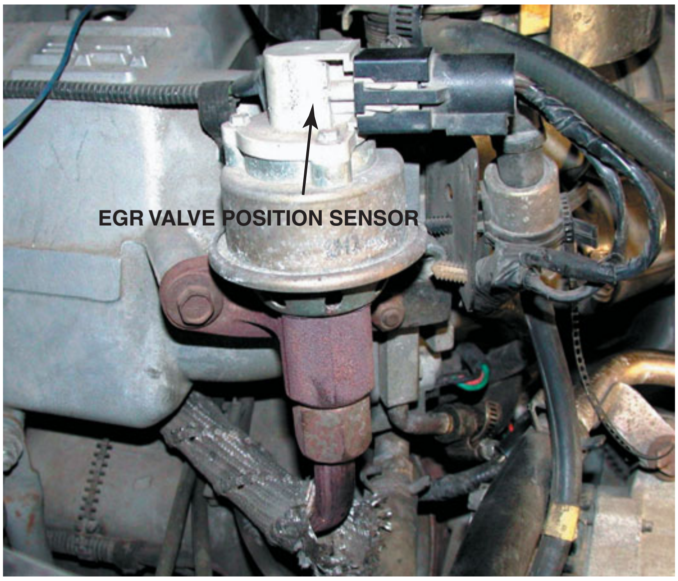


FIGURE 39–4 An EGR valve position sensor on top of an EGR valve.

NOTE: Installing a high-performance exhaust system could prevent a backpressure vacuum-operated EGR valve from opening. If this occurs, excessive combustion chamber temperature leads to severe spark knock, piston damage, or a blown head gasket.

COMPUTER-CONTROLLED EGR SYSTEMS Many computer-controlled EGR systems have one or more solenoids controlling the EGR vacuum. The computer controls a solenoid to shut off vacuum to the EGR valve at cold engine temperatures, idle speed, and wide-open throttle operation. If two solenoids are used, one acts as an off-on control of supply vacuum, while the second solenoid vents vacuum when EGR flow is not desired or needs to be reduced. The second solenoid is used to control a vacuum air bleed, allowing atmospheric pressure in to modulate EGR flow according to vehicle operating conditions.

EGR VALVE POSITION SENSORS Most computer-controlled EGR systems use a sensor to indicate EGR operation. Onboard diagnostics generation-II (OBD-II) EGR system monitors require an EGR sensor to verify that the valve opened. A linear potentiometer on the top of the EGR valve stem indicates valve position to the computer. This is called an **EGR valve position (EVP)** sensor. Some later-model Ford EGR systems, however, use a feedback signal provided by an EGR exhaust backpressure sensor that converts the exhaust backpressure to a voltage signal. This sensor is called a **pressure feedback EGR (PFE)** sensor.

On some EGR systems, the top of the valve contains a vacuum regulator and EGR pintle-position sensor in one assembly sealed inside a nonremovable plastic cover. The pintle-position sensor provides a voltage output to the PCM, which increases as the duty cycle increases, allowing the PCM to monitor valve operation. ● **SEE FIGURE 39–4.**

FIGURE 39–5 Digital EGR valve.

TECH TIP

Find the Root Cause

Excessive backpressure, such as that caused by a partially clogged exhaust system, could cause the plastic sensors on the EGR valve to melt. Always check for a restricted exhaust whenever replacing a failed EGR valve sensor.

DIGITAL EGR VALVES GM introduced a **digital EGR** valve design on some engines. Unlike vacuum-operated EGR valves, the digital EGR valve consists of three solenoids controlled by the powertrain control module (PCM). Each solenoid controls a different size orifice in the base—small, medium, and large. The PCM controls the ground circuit of each of the solenoids individually. It can produce any of seven different flow rates, using the solenoids to open the three valves in different combinations. The digital EGR valve offers precise control, and using a swivel pintle design helps prevent carbon deposit problems. ● **SEE FIGURE 39–5.**

LINEAR EGR Most General Motors and many other vehicles use a **linear EGR** that contains a pulse-width modulated solenoid to precisely regulate exhaust gas flow and a feedback potentiometer that signals the computer regarding the actual position of the valve. ● **SEE FIGURES 39–6 AND 39–7.**

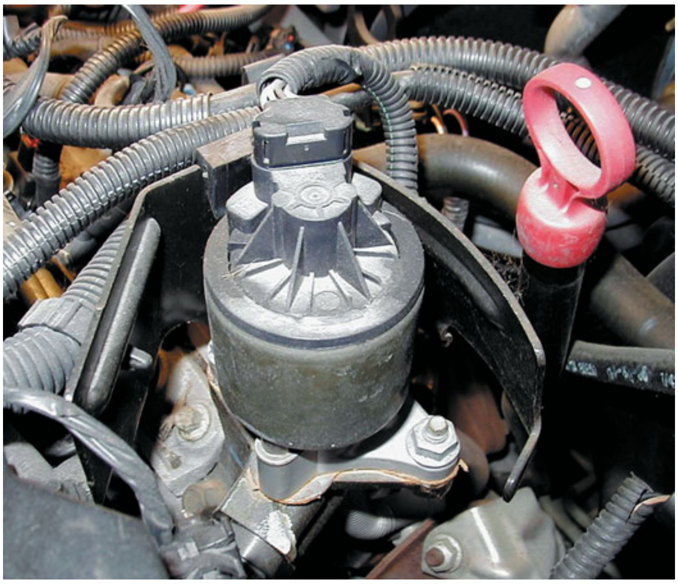


FIGURE 39–6 A General Motors linear EGR valve.

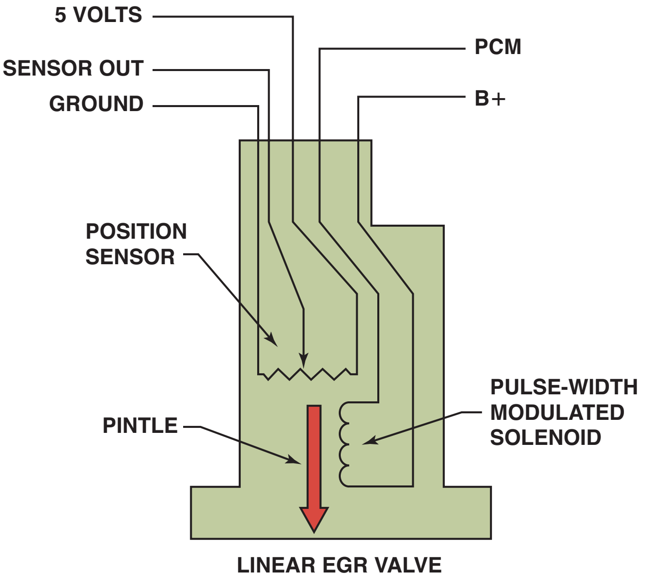


FIGURE 39–7 The EGR valve pintle is pulse-width modulated and a three-wire potentiometer provides pintle-position information back to the PCM.

OBD-II EGR MONITORING STRATEGIES

PURPOSE AND FUNCTION In 1996, the U.S. EPA began requiring OBD-II systems in all passenger cars and most light-duty trucks. These systems include emissions system monitors that alert the driver and the technician if an emissions system is malfunctioning. The OBD-II system performs this test by opening and closing the EGR valve. The PCM monitors an EGR function sensor for a change in signal voltage. If the EGR system fails, a diagnostic trouble code (DTC) is set. If the system fails two consecutive times, the malfunction indicator light (MIL) is lit.

MONITORING STRATEGIES EGR monitoring strategies include the following:

- Some vehicle manufacturers, such as Chrysler, monitor the difference in the exhaust oxygen sensor's voltage activity as the EGR valve opens and closes. Oxygen in the exhaust decreases when the EGR valve is open and increases when the EGR valve is closed. The PCM sets a DTC if the sensor signal does not change.
- Most Fords use an EGR monitor test sensor called a **delta pressure feedback EGR (DPFE) sensor.** This sensor measures the pressure differential between two sides of a metered orifice positioned just below the EGR valve's exhaust side. Pressure between the orifice and the EGR valve decreases when the EGR opens because it becomes exposed to the lower pressure in the intake. The DPFE sensor recognizes this pressure drop, compares it to the relatively higher pressure on the exhaust side of the orifice, and signals the value of the pressure difference to the PCM. ● **SEE FIGURE 39–8.**
- Many vehicle manufacturers use the manifold absolute pressure (MAP) sensor as the EGR monitor on some applications. After meeting the enable criteria (operating condition requirements), the EGR monitor is run. The PCM monitors the MAP sensor while it commands the EGR valve to open. The MAP sensor signal should change in response to the sudden change in manifold pressure or the fuel trim changes created by a change in the oxygen sensor voltage. If the signal value falls outside the acceptable value in the look-up table, a DTC sets. If the EGR fails on two consecutive trips, the PCM lights the MIL. ● **SEE FIGURE 39–9.**

DIAGNOSING A DEFECTIVE EGR SYSTEM

SYMPTOMS If the EGR valve is not opening or the flow of the exhaust gas is restricted, then the following symptoms are likely.

- Detonation (spark knock or ping) during acceleration or during cruise (steady-speed driving)
- Excessive oxides of nitrogen (NOx) exhaust emissions

If the EGR valve is stuck open or partially open, then the following symptoms are likely.

- Rough idle or frequent stalling
- Poor performance/low power, especially at low engine speed

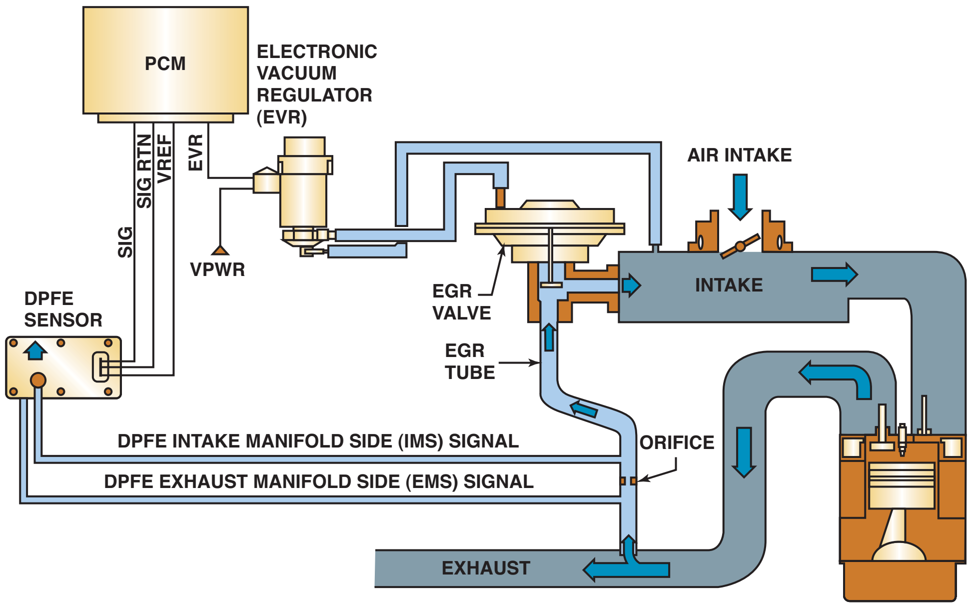


FIGURE 39–8 A DPFE sensor and related components.

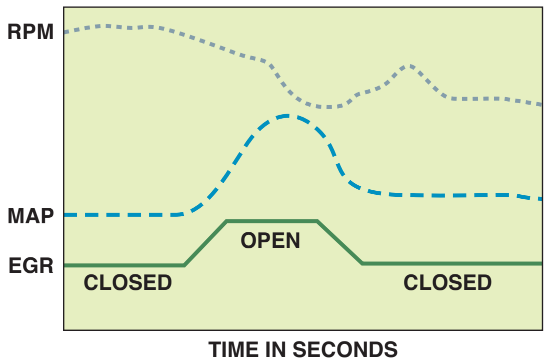


FIGURE 39–9 An OBD-II active test. The PCM opens the EGR valve and then monitors the MAP sensor and/or engine speed (RPM) to verify that it meets acceptable values.

TECH TIP

Watch Out for Carbon Balls!

Exhaust gas recirculation (EGR) valves can get stuck partially open by a chunk of carbon. The EGR valve or solenoid will test as defective. When the valve (or solenoid) is removed, small chunks or balls of carbon often fall into the exhaust manifold passage. When the replacement valve is installed, the carbon balls can be drawn into the new valve again, causing the engine to idle roughly or stall.

To help prevent this problem, start the engine with the EGR valve or solenoid removed. Any balls or chunks of carbon will be blown out of the passage by the exhaust. Stop the engine and install the replacement EGR valve or solenoid.

REAL WORLD FIX

The Blazer Story

The owner of a Chevrolet Blazer equipped with a 4.3 liter V-6 engine complained that the engine would stumble and hesitate at times. Everything seemed to be functioning correctly, except that the service technician discovered a weak vacuum going to the EGR valve at idle. This vehicle was equipped with an EGR valve-control solenoid, called an **electronic vacuum regulator valve (EVRV)** by General Motors Corporation. The computer pulses the solenoid to control the vacuum that regulates the operation of the EGR valve. The technician checked the service manual for details on how the system worked. The technician discovered that vacuum should be present at the EGR valve only when the gear selector indicates a drive gear (drive, low, reverse). Because the technician discovered the vacuum at the solenoid to be leaking, the solenoid was obviously defective and required replacement. After replacement of the solenoid (EVRV), the hesitation problem was solved.

NOTE: The technician also discovered in the service manual that blower-type exhaust hoses should not be connected to the tailpipe on any vehicle while performing an inspection of the EGR system. The vacuum created by the system could cause false EGR valve operation to occur.

EGR TESTING PROCEDURES

The first step in almost any diagnosis is to perform a thorough visual inspection. To check for proper operation of a vacuum-operated EGR valve, follow these steps.

STEP 1 **Check the vacuum diaphragm of the EGR valve to see if it can hold vacuum.** Because many EGR valves require exhaust backpressure to function correctly, the engine should be running at a fast idle during this test. Always follow the specified testing procedures.

STEP 2 **Apply vacuum from a hand-operated vacuum pump and check for proper operation.** The valve itself should move when vacuum is applied, and the engine operation should be affected. The EGR valve should be able to hold the vacuum that was applied. If the vacuum drops off, then the valve is likely to be defective.

STEP 3 **Monitor engine vacuum drop.** Connect a vacuum gauge to an intake manifold vacuum source and monitor the engine vacuum at idle (should be 17 to 21 in. Hg at sea level). Raise the speed of the engine to 2500 RPM and note the vacuum reading (should be 17 to 21 in. Hg or higher).

Activate the EGR valve using a scan tool or vacuum pump, if vacuum controlled, and observe the vacuum gauge. The results are as follows:

- The vacuum should drop 6 to 8 in. Hg.
- If the vacuum drops less than 6 to 8 in. Hg, the valve or the EGR passages are clogged.

Results

- If the EGR valve is able to hold vacuum, but the engine is not affected when the valve is opened, then the exhaust passage(s) must be checked for restriction.

> **TECH TIP**
>
> **The Snake Trick**
>
> The EGR passages on many intake manifolds become clogged with carbon, which reduces the flow of exhaust and the amount of exhaust gases in the cylinders. This reduction can cause spark knock (detonation) and increased emissions of oxides of nitrogen (NOx) (especially important in areas with enhanced exhaust emissions testing).
>
> To quickly and easily remove carbon from exhaust passages, cut an approximately 1 ft (30 cm) length from stranded wire, such as garage door guide wire or an old speedometer cable. Flare the end and place the end of the wire into the passage. Set your drill on reverse, turn it on, and the wire will pull its way through the passage, cleaning the carbon as it goes, just like a snake in a drain pipe. Some vehicles, such as Hondas, require that plugs be drilled out to gain access to the EGR passages, as shown in ● **FIGURE 39–10.**

FIGURE 39–10 Removing the EGR passage plugs from the intake manifold on a Honda.

See the Tech Tip, "The Snake Trick." If the EGR valve will not hold vacuum, the valve itself is likely to be defective and require replacement.

EGR-RELATED OBD-II DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0400	Exhaust gas recirculation flow problems	• EGR valve • EGR valve hose or electrical connection • Defective PCM
P0401	Exhaust gas recirculation flow insufficient	• EGR valve • Clogged EGR ports or passages
P0402	Exhaust gas recirculation flow excessive	• Stuck-open EGR valve • Vacuum hose(s) misrouted • Electrical wiring shorted

CRANKCASE VENTILATION

PURPOSE AND FUNCTION

The problem of crankcase ventilation has existed since the beginning of the automobile, because no piston ring, new or old, can provide a perfect seal between the piston and the cylinder wall. When an engine is running, the pressure of combustion forces the piston downward. This same pressure also forces gases and unburned

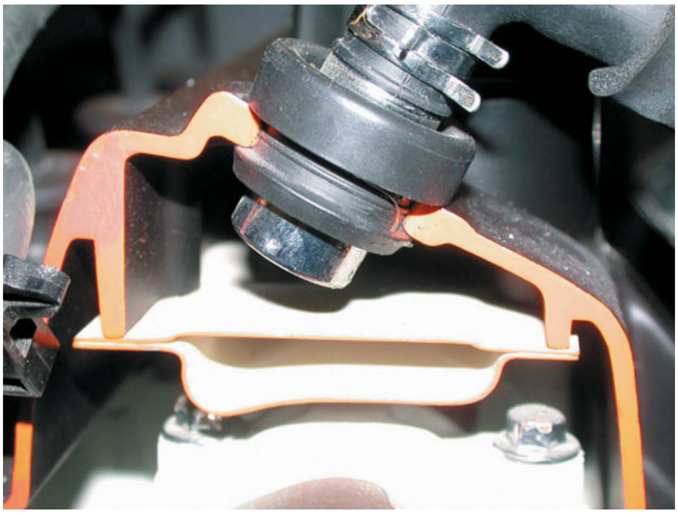


FIGURE 39–11 A PCV valve in a cutaway valve cover, showing the baffles that prevent liquid oil from being drawn into the intake manifold.

fuel from the combustion chamber, past the piston rings, and into the crankcase. **Blowby** is the term used to describe when combustion gases are forced past the piston rings and into the crankcase.

These combustion by-products, particularly unburned hydrocarbons (HC) caused by blowby, must be ventilated from the crankcase. However, the crankcase cannot be vented directly to the atmosphere, because the hydrocarbon vapors add to air pollution. **Positive crankcase ventilation (PCV)** systems were developed to ventilate the crankcase and recirculate the vapors to the engine's induction system so they can be burned in the cylinders. PCV systems help reduce HC and CO emissions.

All systems use the following:

1. PCV valve, calibrated orifice, or orifice and separator
2. PCV inlet air filter plus all connecting hoses

● **SEE FIGURE 39–11.**

An oil/vapor or oil/water separator is used in some systems instead of a valve or orifice, particularly with turbocharged and fuel-injected engines. The oil/vapor separator lets oil condense and drain back into the crankcase. The oil/water separator accumulates moisture and prevents it from freezing during cold engine starts.

The air for the PCV system is drawn after the air cleaner filter, which acts as a PCV filter.

NOTE: Some older designs drew from the dirty side of the air cleaner, where a separate crankcase ventilation filter was used.

PCV VALVES

The PCV valve in most systems is a one-way valve containing a spring-operated plunger that controls valve flow rate. ● **SEE FIGURE 39–12.**

Flow rate is established for each engine and a valve for a different engine should not be substituted. The flow rate is

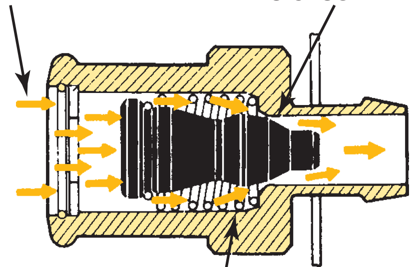


FIGURE 39–12 Spring force, crankcase pressure, and intake manifold vacuum work together to regulate the flow rate through the PCV valve.

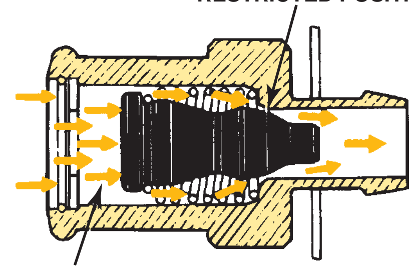


FIGURE 39–13 Air flows through the PCV valve during idle, cruising, and light-load conditions.

determined by the size of the plunger and the holes inside the valve. PCV valves usually are located in the valve cover or intake manifold.

The PCV valve regulates airflow through the crankcase under all driving conditions and speeds. When manifold vacuum is high (at idle, cruising, and light-load operation), the PCV valve restricts the airflow to maintain a balanced air-fuel ratio. ● **SEE FIGURE 39–13.**

It also prevents high intake manifold vacuum from pulling oil out of the crankcase and into the intake manifold. Under high speed or heavy loads, the valve opens and allows maximum airflow. ● **SEE FIGURE 39–14.**

If the engine backfires, the valve will close instantly to prevent a crankcase explosion. ● **SEE FIGURE 39–15.**

ORIFICE-CONTROLLED SYSTEMS

The closed PCV system used on some 4-cylinder engines contains a calibrated orifice instead of a PCV valve. The orifice may be

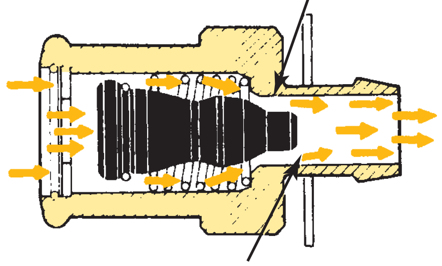


FIGURE 39–14 Air flows through the PCV valve during acceleration and when the engine is under a heavy load.

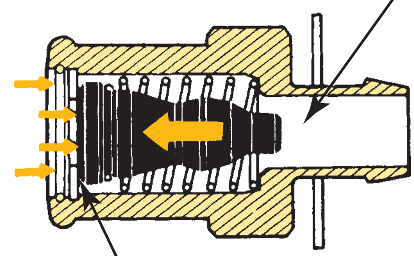


FIGURE 39–15 PCV valve operation in the event of a backfire.

located in the valve cover or intake manifold, or in a hose connected between the valve cover, air cleaner, and intake manifold.

While most orifice flow control systems work the same as a PCV valve system, they may not use fresh air scavenging of the crankcase. Crankcase vapors are drawn into the intake manifold in calibrated amounts depending on manifold pressure and the orifice size. If vapor availability is low, as during idle, air is drawn in with the vapors. During off-idle operation, excess vapors are sent to the air cleaner.

At idle, PCV flow is controlled by a 0.05 in. (1.3 mm) orifice. As the engine moves off idle, ported vacuum pulls a spring-loaded valve off of its seat, allowing PCV flow to pass through a 0.09 in. (2.3 mm) orifice.

SEPARATOR SYSTEMS Turbocharged and many fuel-injected engines use an oil/vapor or oil/water separator and a calibrated orifice instead of a PCV valve. In the most common applications, the air intake throttle body acts as the source for crankcase ventilation vacuum and a calibrated orifice acts as the metering device.

REAL WORLD FIX

The Whistling Engine

An older vehicle was being diagnosed for a whistling sound whenever the engine was running, especially at idle. It was finally discovered that the breather in the valve cover was plugged and caused high vacuum in the crankcase. The engine was sucking air from what was likely the rear main seal lip, making the "whistle" noise. After replacing the breather and PCV, the noise stopped.

TECH TIP

Check for Oil Leaks with the Engine Off

The owner of an older vehicle equipped with a V-6 engine complained to his technician that he smelled burning oil, but only *after* shutting off the engine. The technician found that the rocker cover gaskets were leaking. But why did the owner only notice the smell of hot oil when the engine was shut off? Because of the positive crankcase ventilation (PCV) system, engine vacuum tends to draw oil away from gasket surfaces. But when the engine stops, engine vacuum disappears and the oil remaining in the upper regions of the engine will tend to flow down and out through any opening. Therefore, a good technician should check an engine for oil leaks not only with the engine running but also shortly after shutdown.

PCV SYSTEM DIAGNOSIS

SYMPTOMS If the PCV valve or orifice is not clogged, intake air flows freely and the PCV system functions properly. Engine design includes the air and vapor flow as a calibrated part of the air-fuel mixture. In fact, some engines receive as much as 30% of the idle air through the PCV system. For this reason, a flow problem in the PCV system results in driveability problems.

A blocked or plugged PCV system can cause:

- Rough or unstable idle
- Excessive oil consumption
- Oil in the air filter housing
- Oil leaks due to excessive crankcase pressure

Before expensive engine repairs are attempted, check the condition of the PCV system.

PCV SYSTEM PERFORMANCE CHECK A properly operating positive crankcase ventilation system should be able to draw vapors from the crankcase and into the intake manifold. If the pipes, hoses, and PCV valve itself are not restricted, vacuum is applied to the crankcase. A slight vacuum is created in the crankcase (usually less than 1 in. Hg if measured at the dipstick) and is also applied to other areas of the engine. Oil drainback holes provide a path for oil to drain back into the oil pan. These holes also allow crankcase vacuum to be applied under the rocker covers and in the valley area of most V-type engines. There are several methods that can be used to test a PCV system.

RATTLE TEST The rattle test is performed by simply removing the PCV valve and shaking it in your hand.

- If the PCV valve does *not* rattle, it is definitely defective and must be replaced.
- If the PCV valve *does* rattle, it does not necessarily mean that the PCV valve is good. All PCV valves contain springs that can become weaker with age and with heating and cooling cycles. Replace any PCV valve with the *exact* replacement according to the vehicle manufacturer's recommended intervals, usually every three years or 36,000 miles (60,000 km).

REAL WORLD FIX

The Oil Burning Chevrolet Astro Van

An automotive instructor was driving a Chevrolet Astro van to Fairbanks, Alaska, in January. It was cold, about −32°F (−36°C). As he pulled into Fairbanks and stopped at a traffic light, he smelled burning oil. He thought it was the vehicle ahead of him as it was an older vehicle and did not look like it was in good condition. However, when he stopped at the hotel he still smelled burning oil. He looked under the van and discovered a large pool of oil. After checking the oil and finding very little left, he called a local shop and was told to bring it in. The technician looked over the situation and said, "You need to put some cardboard across the grill to stop the PCV valve from freezing up." Apparently the PCV valve froze, which then caused the normal blowby gases to force several quarts out the dipstick tube. After he installed the cardboard, he did not have any further problems.

CAUTION: Do not cover the radiator when driving unless under severe cold conditions and carefully watch the coolant temperature to avoid overheating the engine.

THE 3 × 5 CARD TEST Remove the oil-fill cap (where oil is added to the engine) and start the engine.

NOTE: Use care on some overhead camshaft engines. With the engine running, oil may be sprayed from the open oil-fill opening.

Hold a 3 × 5 card over the opening (a dollar bill or any other piece of paper can be used for this test).

- If the PCV system, including the valve and hoses, is functioning correctly, the card should be held down on the oil-fill opening by the slight vacuum inside the crankcase.
- If the card will not stay, carefully inspect the PCV valve, hose(s), and manifold vacuum port for carbon buildup (restriction). Clean or replace as necessary.

NOTE: On some 4-cylinder engines, the 3 × 5 card may vibrate on the oil-fill opening when the engine is running at idle speed. This is normal because of the time intervals between intake strokes on a 4-cylinder engine.

SNAP-BACK TEST The proper operation of the PCV valve can be checked by placing a finger over the inlet hole in the valve when the engine is running and removing the finger rapidly. Repeat several times. The valve should "snap back." If the valve does not snap back, replace the valve.

CRANKCASE VACUUM TEST Sometimes the PCV system can be checked by testing for a weak vacuum at the oil dipstick tube using an inches-of-water manometer or gauge, as follows:

STEP 1 Remove the oil-fill cap or vent PCV opening and cover the opening.

STEP 2 Remove the oil dipstick (oil level indicator).

STEP 3 Connect a water manometer or gauge to the dipstick tube.

STEP 4 Start the engine and observe the gauge at idle and at 2500 RPM.

● **SEE FIGURE 39–16.**

The gauge should show some vacuum, especially at 2500 RPM. If not, carefully inspect the PCV system for blockages or other faults.

PCV MONITOR Starting with 2004 and newer vehicles, all vehicle PCMs monitor the PCV system for proper operation as part of the OBD-II system. The PCV monitor will fail if the PCM detects an opening between the crankcase and the PCV valve or between the PCV valve and the intake manifold. ● **SEE FIGURE 39–17.**

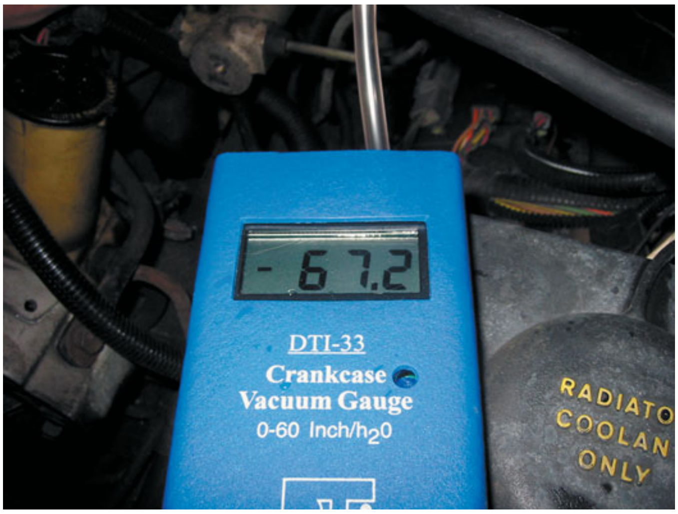


FIGURE 39–16 Using a gauge that measures vacuum in units of inches of water to test the vacuum at the dipstick tube, being sure that the PCV system is capable of drawing a vacuum on the crankcase. Note that 28 in. of water equals 1 PSI, or about 2 in. of mercury (in. Hg) of vacuum.

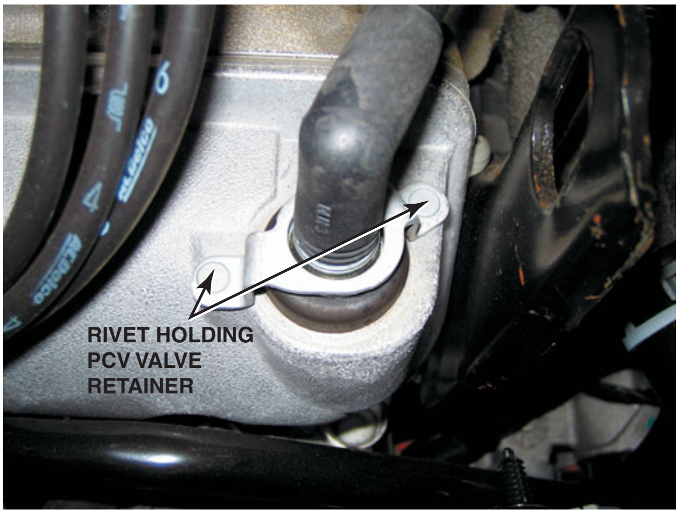


FIGURE 39–17 Most PCV valves used on newer vehicles are secured with fasteners, which makes it more difficult to disconnect and therefore less likely to increase emissions.

? FREQUENTLY ASKED QUESTION

Why Are There Wires at the PCV Valve?

Ford uses an electric heater to prevent ice from forming inside the PCV valve causing blockage. Water is a by-product of combustion and resulting moisture can freeze when the outside air temperature is low. General Motors and others clip a heater hose to the PCV hose to provide the heat needed to prevent an ice blockage.

PCV-RELATED DIAGNOSTIC TROUBLE CODE

Diagnostic Trouble Code	Description	Possible Causes
P0101	MAF or airflow circuit range problem	• Defective PCV valve, hose/ connections, or MAF circuit fault
P0505	Idle control system problem	• Defective PCV valve or hose/ connections

SECONDARY AIR-INJECTION SYSTEM

PURPOSE AND FUNCTION The **secondary air-injection (SAI)** system provides the air necessary for the oxidizing process either at the exhaust manifold or inside the catalytic converter.

NOTE: This system is commonly called AIR, meaning air-injection reaction. Therefore, an AIR pump does pump air.

PARTS AND OPERATION The SAI pump, also called an AIR pump, a **smog pump,** or a **thermactor pump,** is mounted at the front of the engine and can be driven by a belt from the crankshaft pulley. It pulls fresh air in through an external filter and pumps the air under slight pressure to each exhaust port through connecting hoses or a manifold. The typical SAI system includes the following components.

- A belt-driven pump with inlet air filter (older models) (**SEE FIGURE 39–18.**)
- An electronic air pump (newer models)
- One or more air distribution manifolds and nozzles
- One or more exhaust check valves
- Connecting hoses for air distribution
- Air management valves and solenoids on all newer applications

With the introduction of NOx reduction converters (also called dual-bed, **three-way converters,** or **TWC**), the output of the SAI pump is sent to the center of the converter where the extra air can help oxidize unburned hydrocarbons (HC), carbon monoxide (CO) into water vapor (H_2O), and carbon dioxide (CO_2).

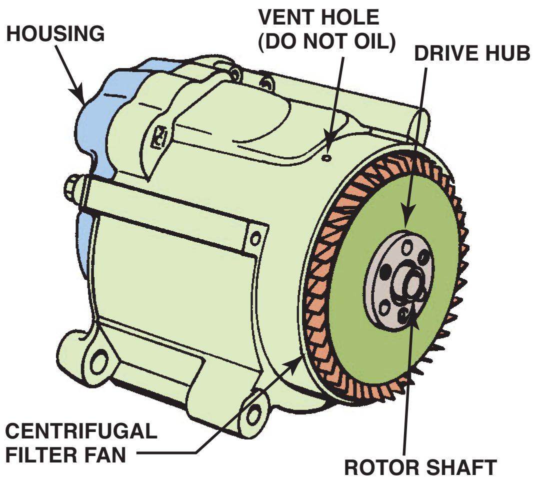


FIGURE 39–18 A typical belt-driven AIR pump. Air enters through the revolving fins behind the drive pulley. The fins act as an air filter because dirt is heavier than air and therefore the dirt is deflected off of the fins at the same time air is being drawn into the pump.

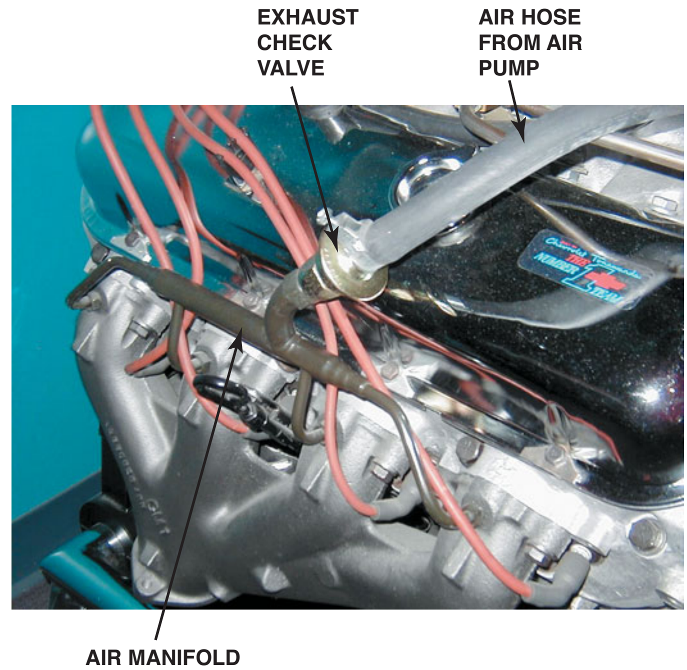


FIGURE 39–19 The external air manifold and exhaust check valve on a restored muscle car engine.

The computer controls the airflow from the pump by switching on and off various solenoid valves.

AIR DISTRIBUTION MANIFOLDS AND NOZZLES The secondary air-injection system sends air from the pump to a nozzle installed near each exhaust port in the cylinder head. This provides equal air injection for the exhaust from each cylinder and makes it available at a point in the system where exhaust gases are the hottest.

Air is delivered to the exhaust system in one of two ways.

1. An external air manifold, or manifolds, distributes the air through injection tubes with stainless steel nozzles. The nozzles are threaded into the cylinder heads or exhaust manifolds close to each exhaust valve. This method is used primarily with smaller engines.
2. An internal air manifold distributes the air to the exhaust ports near each exhaust valve through passages cast in the cylinder head or the exhaust manifold. This method is used mainly with larger engines.

EXHAUST CHECK VALVES All air-injection systems use one or more one-way check valves to protect the air pump and other components from reverse exhaust flow. A **check valve** contains a spring-type metallic disc or reed that closes under exhaust backpressure. Check valves are located between the air manifold and the switching valve(s). If exhaust pressure exceeds injection pressure, or if the air pump fails, the check valve spring closes the valve to prevent reverse exhaust flow. ● **SEE FIGURE 39–19.**

NOTE: These check valves commonly fail, resulting in excessive exhaust emissions (CO especially). When the check valve fails, hot exhaust can travel up to and destroy the switching valve(s) and air pump itself.

BELT-DRIVEN AIR PUMPS The belt-driven air pump uses a centrifugal filter just behind the drive pulley. As the pump rotates, underhood air is drawn into the pump and slightly compressed. The system uses either vacuum- or solenoid-controlled diverter valves to air directed to the following:

- Exhaust manifold when the engine is cold to help oxidize carbon monoxide (CO) and unburned hydrocarbons (HC) into carbon dioxide (CO_2) and water vapor (H_2O)
- Catalytic converter on many models to help provide the extra oxygen needed for the efficient conversion of CO and HC into CO_2 and H_2O
- Air cleaner during deceleration or wide-open throttle (WOT) engine operation

  ● **SEE FIGURE 39–20.**

ELECTRIC MOTOR-DRIVEN AIR PUMPS The electric motor-driven air pump is generally used only during cold engine operation and is computer controlled. The secondary air-injection (SAI) system helps reduce hydrocarbon (HC) and carbon monoxide (CO). It also helps to warm the three-way catalytic converters quickly on engine start-up so conversion of exhaust gases may occur sooner.

- The SAI pump solenoids are controlled by the PCM. The PCM turns on the SAI pump by providing the ground to complete the circuit which energizes the SAI pump solenoid relay. When air to the exhaust ports is desired, the PCM energizes the relay in order to turn on the solenoid and the SAI pump. ● **SEE FIGURE 39–21.**

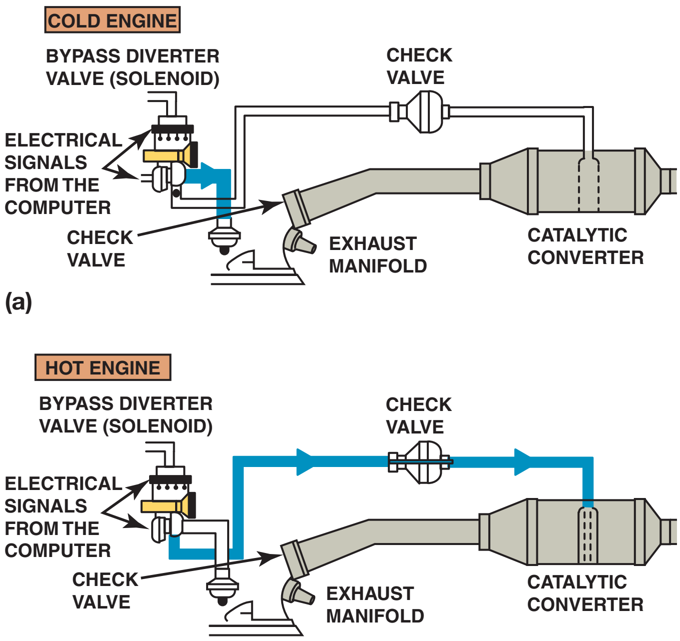


FIGURE 39–20 (a) When the engine is cold and before the oxygen sensor is hot enough to achieve closed loop, the airflow from the air pump is directed to the exhaust manifold(s) through the one-way check valves which keep the exhaust gases from entering the switching solenoids and the pump itself. (b) When the engine achieves closed loop, the air is directed to the catalytic converter.

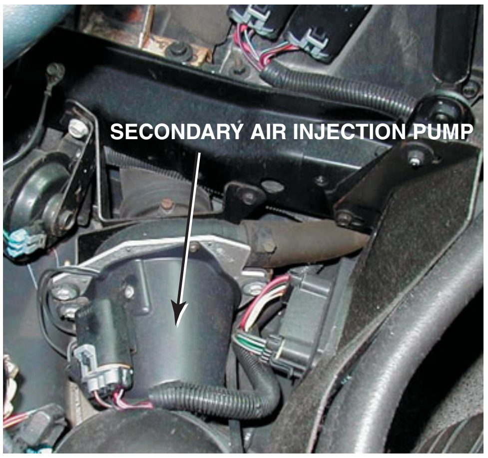


FIGURE 39–21 A typical electric motor-driven SAI pump. This unit is on a Chevrolet Corvette and only works when the engine is cold.

- The PCM turns on the SAI pump during start-up any time the engine coolant temperature is above 32°F (0°C). A typical electric SAI pump operates for a maximum of four minutes, or until the system enters closed-loop operation.

ENGINE OPERATION	NORMAL OPERATION OF A TYPICAL SAI SYSTEM
Cold engine (open-loop operation)	Air is diverted to the exhaust manifold(s) or cylinder head.
Warm engine (closed-loop operation)	Air is diverted to the catalytic converter.
Deceleration	Air is diverted to the air cleaner assembly.
Wide-open throttle	Air is diverted to the air cleaner assembly.

CHART 39–1

Typical SAI system operation showing the location of the airflow from the pump.

SECONDARY AIR-INJECTION SYSTEM DIAGNOSIS

SYMPTOMS The air pump system should be inspected if an exhaust emissions test failure occurs. In severe cases, the exhaust will enter the air cleaner assembly, resulting in a horribly running engine because the extra exhaust displaces the oxygen needed for proper combustion. With the engine running, check for normal operation. ● **SEE CHART 39–1.**

VISUAL INSPECTION Carefully inspect all secondary air-injection (SAI) systems, including:

- Any hoses or pipes that have holes and leak air or exhaust, which require replacement.
- Check valve(s), when a pump has become inoperative.
- Exhaust gases that may have gotten past the check valve and damaged the pump (Look for signs of overheated areas upstream from the check valves. In severe cases, the exhaust can enter the air cleaner assembly and destroy the air filter and greatly reduce engine power.)
- Drive belt on an engine-driven pump, for wear and proper tension (If the belt is worn or damaged, check that the AIR pump rotates.)

FOUR-GAS EXHAUST ANALYSIS An SAI system can be easily tested using an exhaust gas analyzer and the following steps.

STEP 1 Start the engine and allow it to run until normal operating temperature is achieved.

STEP 2 Connect the analyzer probe to the tailpipe and observe the exhaust readings for hydrocarbons (HC) and carbon monoxide (CO).

STEP 3 Using the appropriate pinch-off pliers, shut off the airflow from the SAI system. Observe the HC and CO readings. If the SAI system is working correctly, the HC and CO should increase when the SAI system is shut off.

STEP 4 Record the O_2 reading with the SAI system still inoperative. Unclamp the pliers and watch the O_2 readings. If the system is functioning correctly, the O_2 level should increase by 1% to 4%.

SAI-RELATED DIAGNOSTIC TROUBLE CODE

Diagnostic Trouble Code	Description	Possible Causes
P0410	SAI solenoid circuit fault	• Defective SAI solenoid • Loose or corroded electrical connections • Loose, missing, or defective rubber hose(s)

CATALYTIC CONVERTERS

PURPOSE AND FUNCTION

A **catalytic converter** is an after treatment device used to reduce exhaust emissions outside of the engine. The catalytic converter uses a **catalyst,** which is a chemical that helps start a chemical reaction but does not enter into the chemical reaction.

- The catalyst materials on the surface of the material inside the converter help create a chemical reaction.
- The chemical reaction changes harmful exhaust emissions into nonharmful exhaust emissions.
- The converter, therefore, converts harmful exhaust gases into water vapor (H_2O) and carbon dioxide (CO_2).

This device is installed in the exhaust system between the exhaust manifold and the muffler, and usually is positioned beneath the passenger compartment. The location of the converter is important, since as much of the exhaust heat as possible must be retained for effective operation. The nearer it is to the engine, the better. ● **SEE FIGURE 39–22.**

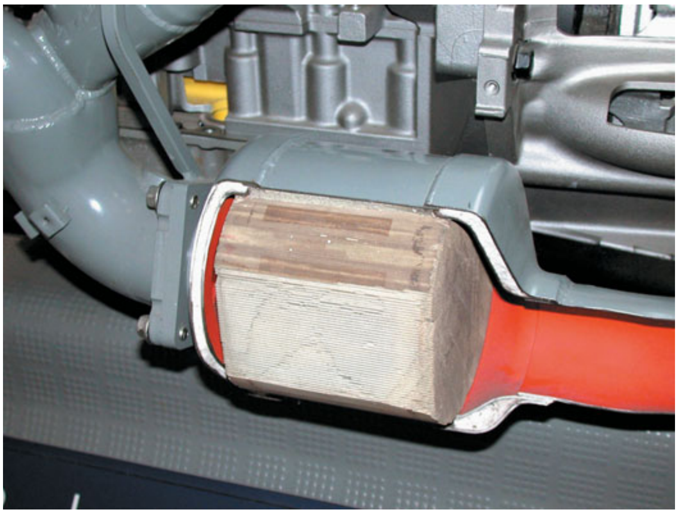


FIGURE 39–22 Most catalytic converters are located as close to the exhaust manifold as possible, as seen in this display of a Chevrolet Corvette.

CATALYTIC CONVERTER CONSTRUCTION

Most catalytic converters are constructed of a ceramic material in a honeycomb shape with square openings for the exhaust gases.

- There are approximately 400 openings per square inch (62 openings per square centimeter) and the wall thickness is about 0.006 in. (1.5 mm).

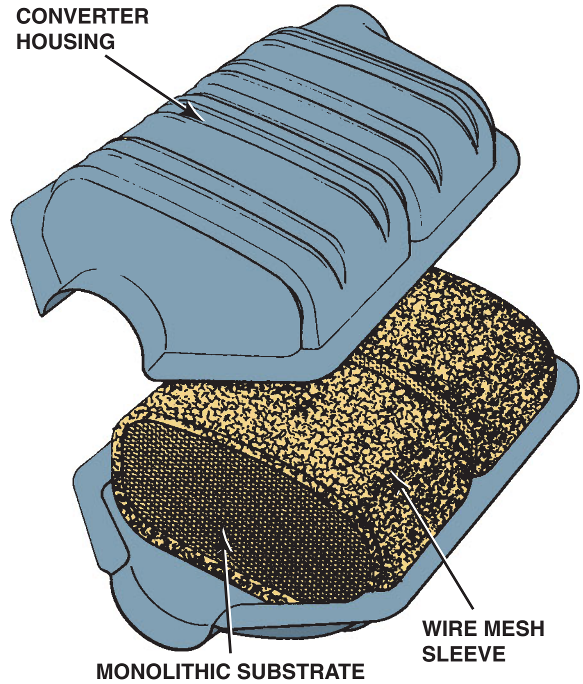


FIGURE 39–23 A typical catalytic converter with a monolithic substrate.

- The substrate is then coated with a porous aluminum material called the **washcoat,** which makes the surface rough.
- The catalytic materials are then applied on top of the washcoat. The substrate is contained within a round or oval shell made by welding together two stamped pieces of stainless steel. ● **SEE FIGURE 39–23.**

The ceramic substrate in monolithic converters is not restrictive; however, the converter can be physically broken if exposed to shock or severe jolts. Monolithic converters can be serviced only as a unit.

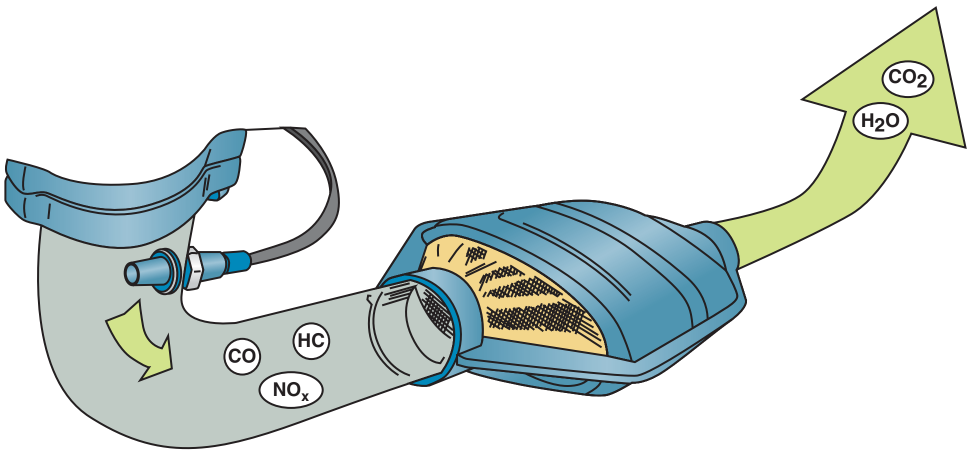


FIGURE 39–24 The three-way catalytic converter first separates the NOx into nitrogen and oxygen and then converts the HC and CO into harmless water (H_2O) and carbon dioxide (CO_2). The nitrogen (N) passes through the converter and exits the tailpipe and enters the atmosphere which is about 78% nitrogen.

An exhaust pipe is connected to the manifold or header to carry gases through a catalytic converter and then to the muffler or silencer. V-type engines can use dual converters or route the exhaust into one catalytic converter by using a Y-exhaust pipe.

CATALYTIC CONVERTER OPERATION The converter substrate contains small amounts of **rhodium, palladium,** and **platinum.** These elements act as catalysts, which, as mentioned, start a chemical reaction without becoming part of, or being consumed in, the process. In a three-way catalytic converter (TWC), all three exhaust emissions (NOx, HC, and CO) are converted to carbon dioxide (CO_2) and water (H_2O). As the exhaust gas passes through the catalyst, oxides of nitrogen (NOx) are chemically reduced (that is, nitrogen and oxygen are separated) in the first section of the catalytic converter. In the second section of the catalytic converter, most of the hydrocarbons and carbon monoxide remaining in the exhaust gas are oxidized to form harmless carbon dioxide (CO_2) and water vapor (H_2O). ● **SEE FIGURE 39–24.**

Since the early 1990s, many converters also contain **cerium,** an element that can store oxygen. The purpose of the cerium is to provide oxygen to the oxidation bed of the converter when the exhaust is rich and lacks enough oxygen for proper oxidation. When the exhaust is lean, the cerium absorbs the extra oxygen. For the most efficient operation, the converter should have a 14.7:1 air-fuel ratio but can use a mixture that varies slightly.

- A rich exhaust is required for reduction—stripping the oxygen (O_2) from the nitrogen in NOx.
- A lean exhaust is required to provide the oxygen necessary to oxidize HC and CO (combining oxygen with HC and CO to form H_2O and CO_2).

If the catalytic converter is not functioning correctly, check that the air-fuel mixture being supplied to the engine is correct and that the ignition system is free of defects.

CONVERTER LIGHT-OFF TEMPERATURE The catalytic converter does not work when cold, and it must be heated to its **light-off temperature** of close to 500°F (260°C) before it starts working at 50% effectiveness. When fully effective, the converter reaches a temperature range of 900°F to 1,600°F (482°C to 871°C). In spite of the intense heat, however, catalytic reactions do not generate a flame associated with a simple burning reaction. Because of the extreme heat (almost as hot as combustion chamber temperatures), a converter remains hot long after the engine is shut off. Most vehicles use a series of heat shields to protect the passenger compartment and other parts of the chassis from excessive heat. Vehicles have been known to start fires because of the hot converter causing tall grass or dry leaves beneath the just-parked vehicle to ignite, especially if the engine is idling. This is most likely to occur if the heat shields have been removed from the converter.

CONVERTER USAGE A catalytic converter must be located as close as possible to the exhaust manifold to work effectively. The farther back the converter is positioned in the exhaust system, the more the exhaust gases cool before they reach the converter. Since positioning in the exhaust system affects the oxidation process, cars that use only an oxidation converter generally locate it underneath the front of the passenger compartment.

Some vehicles have used a small, quick heating oxidation converter called a **preconverter,** a **pup converter,** or a **mini converter** that connects directly to the exhaust manifold outlet. These have a small catalyst surface area close to the engine that heats up rapidly to start the oxidation process more quickly during cold engine warm-up. For this reason, they were often called **light-off converters (LOCs).** The larger main converter, under the passenger compartment, completes the oxidation reaction started in the LOC.

OBD-II CATALYTIC CONVERTER PERFORMANCE With OBD-II equipped vehicles, catalytic converter performance is monitored by a **heated oxygen sensor (HO_2S),** both before and after the converter. The converters used on these vehicles have what is known as **oxygen storage capacity (OSC).** This OSC is due mostly to the cerium coating in the catalyst rather than the precious metals used. When the three-way converter (TWC) is operating as it should, the postconverter HO_2S is far less

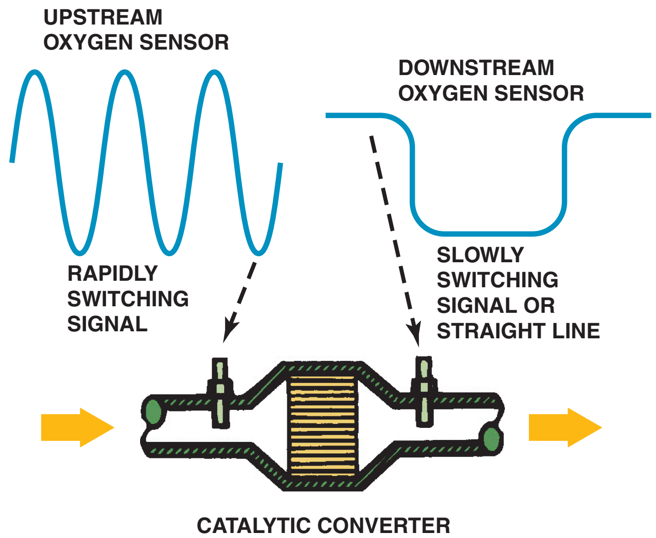


FIGURE 39–25 The OBD-II catalytic converter monitor compares the signals of the upstream and downstream HO2S to determine converter efficiency.

active than the preconverter sensor. The converter stores, then releases, the oxygen during normal reduction and oxidation of the exhaust gases, smoothing out the variations in O_2 being released.

Where a cycling sensor voltage output is expected before the converter, because of the converter action, the postconverter HO_2S should read a steady signal without much fluctuation. ● **SEE FIGURE 39–25.**

CONVERTER-DAMAGING CONDITIONS Since converters have no moving parts, they require no periodic service. Under federal law, catalyst effectiveness is warranted for 80,000 miles or eight years.

The three main causes of premature converter failure are as follows:

- **Contamination.** Substances that can destroy the converter include exhaust that contains excess engine oil, antifreeze, sulfur (from poor fuel), and various other chemical substances.
- **Excessive temperatures.** Although a converter operates at high temperature, it can be destroyed by excessive temperatures. This most often occurs either when too much unburned fuel enters the converter, or with excessively lean mixtures. Excessive temperatures may be caused by long idling periods on some vehicles, since more heat develops at those times than when driving at normal highway speeds. Severe high temperatures can cause the converter to melt down, leading to the internal parts breaking apart and either clogging the converter or moving downstream to plug the muffler. In either case, the restricted exhaust flow severely reduces engine power.
- **Improper air-fuel mixtures.** Rich mixtures or raw fuel in the exhaust can be caused by engine misfiring, or an excessively rich air-fuel mixture resulting from a defective engine coolant temperature sensor or defective fuel injectors. Lean mixtures are commonly caused by intake manifold leaks. When either of these circumstances occurs, the converter can become a catalytic furnace, causing the previously described damage.

? FREQUENTLY ASKED QUESTION

Can a Catalytic Converter Be Defective Without Being Clogged?

Yes. Catalytic converters can fail by being chemically damaged or poisoned without being mechanically clogged. Therefore, the catalytic converter should not only be tested for physical damage (clogging) by performing a backpressure or vacuum test and a rattle test, but also for temperature rise, usually with a pyrometer or propane test, to check the efficiency of the converter.

To avoid excessive catalyst temperatures and the possibility of fuel vapors reaching the converter, follow these rules.

1. Do not use fuel additives or cleaners that are not converter safe.
2. Do not crank an engine for more than 40 seconds when it is flooded or misfiring.
3. Do not turn off the ignition switch when the vehicle is in motion.
4. Do not disconnect a spark plug wire for more than 30 seconds.
5. Repair engine problems such as dieseling, misfiring, or stumbling as soon as possible.

DIAGNOSING CATALYTIC CONVERTERS

THE TAP TEST The simple **tap test** involves tapping (not pounding) on the catalytic converter using a rubber mallet. If the substrate inside the converter is broken, the converter will rattle when hit. If the converter rattles, a replacement converter is required.

TESTING BACKPRESSURE WITH A PRESSURE GAUGE Exhaust system backpressure can be measured directly by installing a pressure gauge in an exhaust opening. This can be accomplished in one of the following ways.

1. To test backpressure, remove the inside of an old, discarded oxygen sensor and thread in an adapter to convert it to a vacuum or pressure gauge.

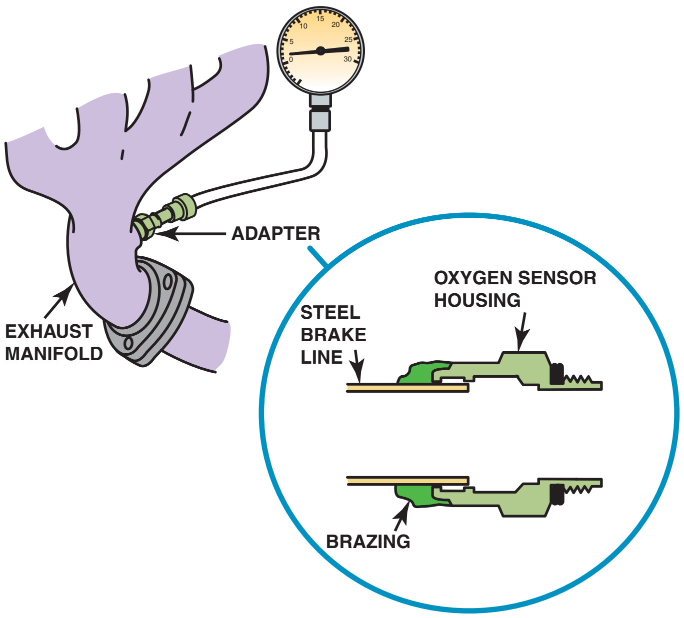


FIGURE 39–26 A back pressure tool can be made by using an oxygen sensor housing and epoxy or braze to hold the tube to the housing.

NOTE: An adapter can be easily made by inserting a metal tube or pipe into an old oxygen sensor housing. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing or it can be glued with epoxy. An 18 mm compression gauge adapter can also be adapted to fit into the oxygen sensor opening. ● SEE FIGURE 39–26.

2. To test the exhaust backpressure at the exhaust gas recirculation (EGR) valve, remove the EGR valve and fabricate a plate equipped with a fitting for a pressure gauge.
3. To test at the secondary air-injection (SAI) check valve, remove the check valve from the exhaust tubes leading to the exhaust manifold. Use a rubber cone with a tube inside to seal against the exhaust tube. Connect the tube to a pressure gauge.

At idle, the maximum backpressure should be less than 1.5 PSI (10 kPa), and it should be less than 2.5 PSI (15 kPa) at 2,500 RPM. Pressure readings higher than these indicate that the exhaust system is restricted and further testing will be needed to determine the location of the restriction.

TESTING FOR BACKPRESSURE USING A VACUUM GAUGE An exhaust restriction can be tested indirectly by checking the intake manifold vacuum with the engine operating at a fast idle speed (about 2,500 RPM). If the exhaust is restricted, some exhaust can pass through and the effect may not be noticeable when the engine is at idle speed. However, when the engine is operating at a higher speed, the exhaust gases can build up behind the restriction and eventually will be unable to leave the combustion chamber. When some of the exhaust is left behind at the end of the exhaust stroke, the resulting pressure in the combustion chamber reduces engine vacuum. To test for an exhaust restriction using a vacuum gauge, perform the following steps.

STEP 1 Attach a vacuum gauge to an intake manifold vacuum source.

STEP 2 Start the engine. Record the engine manifold vacuum reading. The engine vacuum should read 17 to 21 in. Hg when the engine is at idle speed.

STEP 3 Increase the engine speed to 2500 RPM and hold that speed for 60 seconds while looking at the vacuum gauge.

Results

- If the vacuum reading is equal to or higher than the vacuum reading when the engine was at idle speed, the exhaust system is *not* restricted.
- If the vacuum reading is lower than the vacuum reading when the engine was at idle speed, then the exhaust is restricted. Further testing will be needed to determine the location of the restriction.

TESTING A CATALYTIC CONVERTER FOR TEMPERATURE RISE A properly working catalytic converter should be able to reduce NOx exhaust emissions into nitrogen (N) and oxygen (O_2) and oxidize unburned hydrocarbon (HC) and carbon monoxide (CO) into harmless carbon dioxide (CO_2) and water vapor (H_2O). During these chemical processes, the catalytic converter should increase in temperature at least 10% if the converter is working properly. To test the converter, operate the engine at 2,500 RPM for at least two minutes to fully warm up the converter. Measure the inlet and the outlet temperatures using an **infrared thermometer (pyrometer),** as shown in ● **FIGURE 39–27.**

NOTE: If the engine is extremely efficient, the converter may not have any excessive unburned hydrocarbons or carbon monoxide to convert! In this case, a spark plug wire could be grounded out using a vacuum hose and a test light to create some unburned hydrocarbon in the exhaust. Do not ground out a cylinder for longer than 10 seconds or the excessive amount of unburned hydrocarbon could overheat and damage the converter.

CATALYTIC CONVERTER EFFICIENCY TESTS The efficiency of a catalytic converter can be determined using an exhaust gas analyzer.

- **Oxygen level test.** With the engine warm and in closed loop, check the oxygen (O_2) and carbon monoxide (CO) levels. A good converter should be able to oxidize the extra hydrocarbons caused by the rapid acceleration.
  - If O_2 is zero, go to the snap-throttle test.
  - If O_2 is greater than zero, check the CO level.
  - If CO is greater than zero, the converter is *not* functioning correctly.

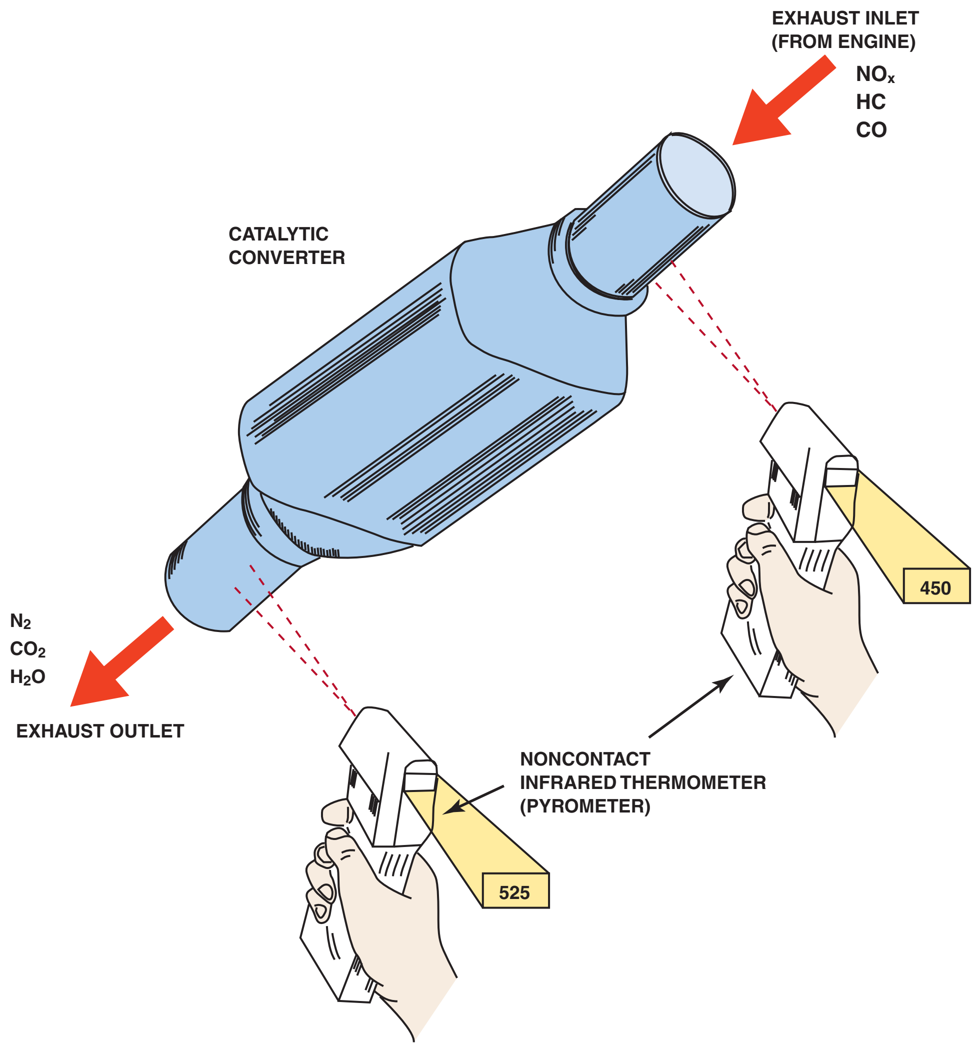


FIGURE 39–27 The temperature of the outlet should be at least 10% hotter than the temperature of the inlet. If a converter is not working, the inlet temperature will be hotter than the outlet temperature.

- **Snap-throttle test.** With the engine warm and in closed loop, snap the throttle to wide open (WOT) in park or neutral and observe the oxygen reading.
  - The O_2 reading should not exceed 1.2%; if it does, the converter is *not* working.
  - If the O_2 rises to 1.2%, the converter may have low efficiency.
  - If the O_2 remains below 1.2%, then the converter is okay.

TECH TIP

Aftermarket Catalytic Converters

Some replacement aftermarket (nonfactory) catalytic converters do not contain the same amount of cerium as the original part. Cerium is the element that is used in catalytic converters to store oxygen. As a result of the lack of cerium, the correlation between the oxygen storage and the conversion efficiency may be affected enough to set a false diagnostic trouble code (P0422).

NOTE: If an aftermarket converter is being installed, be sure that the distance between the rear of the catalyst block is the same distance from the rear oxygen sensor as the factory converter to be assured of proper operation. Always follow the instructions that come with the replacement converter. **SEE FIGURE 39–28.**

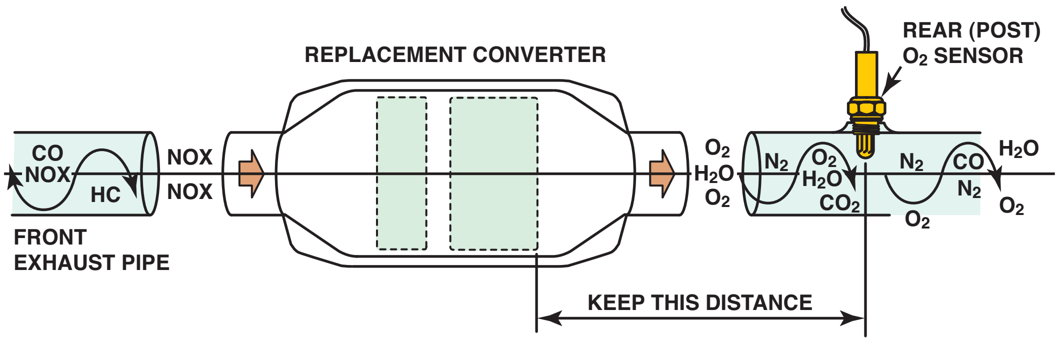


FIGURE 39–28 Whenever replacing a catalytic converter with a universal unit, first measure the distance between the rear brick and the center of the rear oxygen sensor. Be sure that the replacement unit is installed to the same dimension.

TECH TIP

Catalytic Converters Are Murdered

Catalytic converters start a chemical reaction but do not enter into the chemical reaction. Therefore, catalytic converters do not wear out and they do not die of old age. If a catalytic converter is found to be defective (nonfunctioning or clogged), look for the *root* cause. Remember this:

"Catalytic converters do not commit suicide—they're murdered."

Items that should be checked when a defective catalytic converter is discovered include all components of the ignition and fuel systems. Excessive unburned fuel can cause the catalytic converter to overheat and fail. The oxygen sensor must be working and fluctuating from 0.5 to 5 Hz (times per second) to provide the necessary air-fuel mixture variations for maximum catalytic converter efficiency.

CATALYTIC CONVERTER REPLACEMENT GUIDELINES

Because a catalytic converter is a major exhaust gas emission control device, the Environmental Protection Agency (EPA) has strict guidelines for its replacement, including:

- If a converter is replaced on a vehicle with less than 80,000 miles or eight years, depending on the year of the vehicle, an original equipment catalytic converter *must* be used as a replacement.
- The replacement converter must be of the same design as the original. If the original had an air pump fitting, so must the replacement.
- The old converter must be kept for possible inspection by the authorities for 60 days.
- A form must be completed and signed by both the vehicle owner and a representative from the service facility. This form must state the cause of the converter failure and must remain on file for two years.

CATALYTIC CONVERTER-RELATED DIAGNOSTIC TROUBLE CODE

Diagnostic Trouble Code	Description	Possible Causes
P0422	Catalytic converter efficiency failure	**1.** Engine mechanical fault **2.** Exhaust leaks **3.** Fuel contaminants, such as engine oil, coolant, or sulfur

EVAPORATIVE EMISSION CONTROL SYSTEM

PURPOSE AND FUNCTION The purpose of the evaporative (EVAP) emission control system is to trap and hold gasoline vapors, also called volatile organic compounds, or VOCs. The evaporative control system includes the charcoal canister, hoses, and valves. These vapors are routed into a charcoal canister, then into the intake airflow where they are burned in the engine instead of being released into the atmosphere.

COMMON COMPONENTS The fuel tank filler caps used on vehicles with modern EVAP systems are a special design. Most EVAP fuel tank filler caps have pressure-vacuum relief built into them. When pressure or vacuum exceeds a calibrated value, the valve opens. Once the pressure or vacuum has been relieved, the valve closes. If a sealed cap is used on an EVAP system that

FIGURE 39–29 A capless system from a Ford Flex does not use a replaceable cap; instead, it has a spring-loaded closure.

? FREQUENTLY ASKED QUESTION

When Filling My Fuel Tank, Why Should I Stop When the Pump Clicks Off?

Every fuel tank has an upper volume chamber that allows for expansion of the fuel when hot. The volume of the chamber is between 10% and 20% of the volume of the tank. For example, if a fuel tank had a capacity of 20 gallons, the expansion chamber volume would be from 2 to 4 gallons. A hose is attached at the top of the chamber and vented to the charcoal canister. If extra fuel is forced into this expansion volume, liquid gasoline can be drawn into the charcoal canister. This liquid fuel can saturate the canister and create an overly rich air-fuel mixture when the canister purge valve is opened during normal vehicle operation. This extra-rich air-fuel mixture can cause the vehicle to fail an exhaust emissions test, reduce fuel economy, and possibly damage the catalytic converter. To avoid problems, simply add fuel to the next dime's worth after the nozzle clicks off. This will ensure that the tank is full, yet not overfilled.

requires a pressure-vacuum relief design, a vacuum lock may develop in the fuel system, or the fuel tank may be damaged by fuel expansion or contraction. ● **SEE FIGURE 39–29.**

EVAPORATIVE CONTROL SYSTEM OPERATION The canister is located under the hood or underneath the vehicle, and is filled with activated charcoal granules that can hold up to one-third of their own weight in fuel vapors. ● **SEE FIGURE 39–30.**

NOTE: Some vehicles with large or dual fuel tanks may have dual canisters.

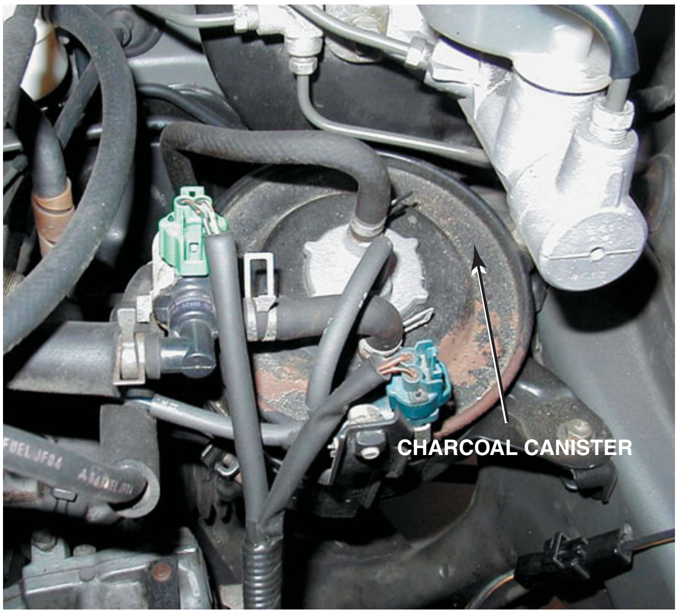


FIGURE 39–30 A charcoal canister can be located under the hood or underneath the vehicle.

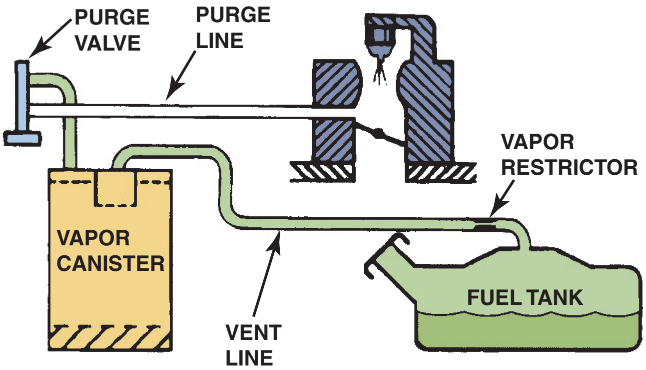


FIGURE 39–31 The evaporative emission control system includes all of the lines, hoses, and valves, plus the charcoal canister.

Activated charcoal is an effective vapor trap because of its great surface area. Each gram of activated charcoal has a surface area of 1,100 m^2 (more than a quarter acre). Typical canisters hold either 300 or 625 grams of charcoal *with a surface area equivalent to 80 or 165 football fields.* By a process called **adsorption,** the fuel vapor molecules adhere to the carbon surface. This attaching force is not strong, so the system purges the vapor molecules quite simply by sending a fresh airflow through the charcoal.

- **Vapor purging.** During engine operation, stored vapors are drawn from the canister into the engine through a hose connected to the throttle body or the air cleaner. This "purging" process mixes HC vapors from the canister with the existing air-fuel charge. ● **SEE FIGURES 39–31 AND 39–32.**

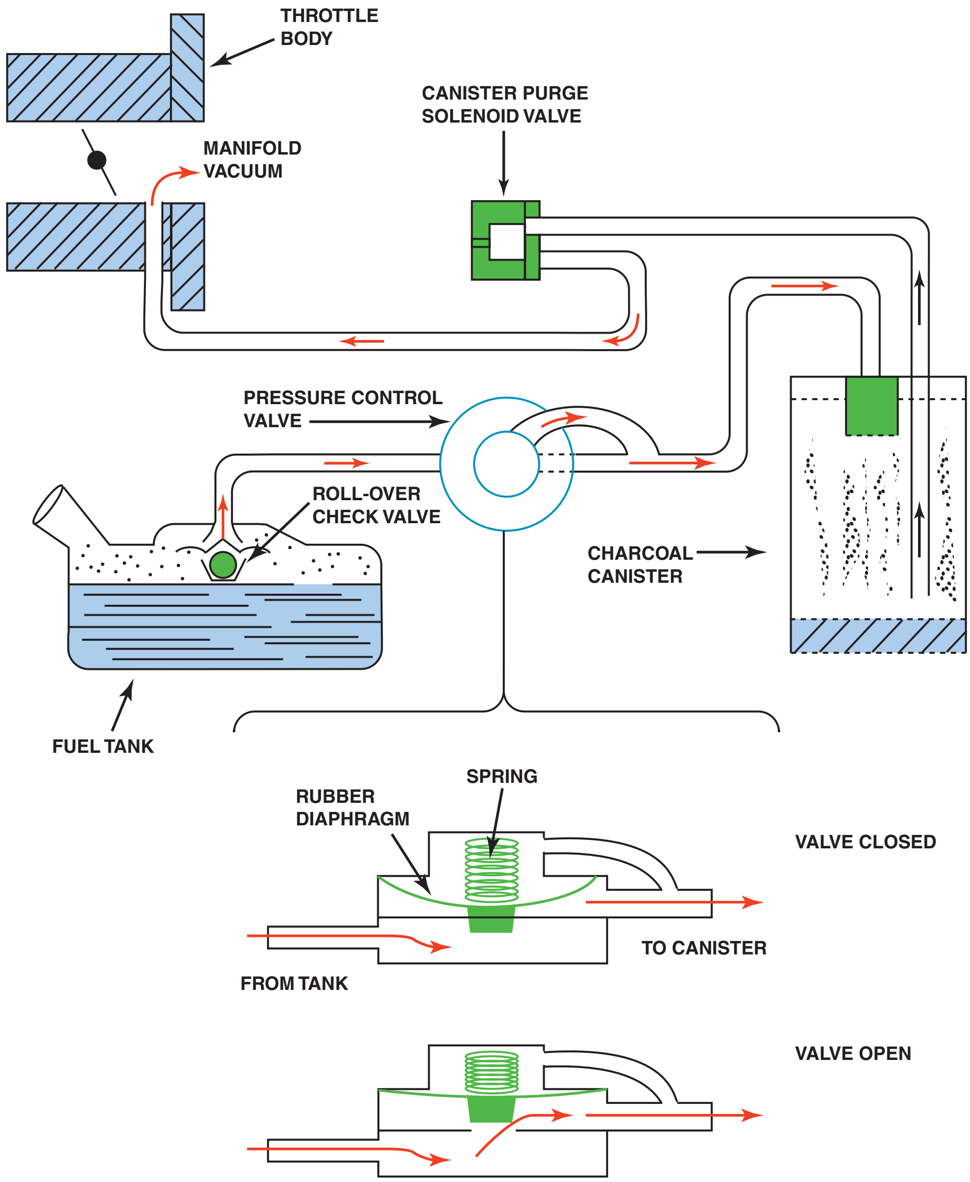


FIGURE 39–32 A typical evaporative emission control system. Note that when the computer turns on the canister purge solenoid valve, manifold vacuum draws any stored vapors from the canister into the engine. Manifold vacuum also is applied to the pressure control valve. When this valve opens, fumes from the fuel tank are drawn into the charcoal canister and eventually into the engine. When the solenoid valve is turned off (or the engine stops and there is no manifold vacuum), the pressure control valve is spring-loaded shut to keep vapors inside the fuel tank from escaping to the atmosphere.

- **Computer-controlled purge.** The PCM controls when the canister purges on most engines. This is done by an electric vacuum solenoid, and one or more purge valves. Under normal conditions, most engine control systems permit purging only during closed-loop operation at cruising speeds. During other engine operation conditions, such as open-loop mode, idle, deceleration, or wide-open throttle, the PCM prevents canister purging.

Pressures can build inside the fuel system and are usually measured in units of inches of water (in. H_2O) (28 in. of water equals 1 PSI). Some scan tools display other units of measure for the EVAP system that make understanding the system difficult. ● **SEE CHART 39–2** for the conversion among PSI, in. Hg., and in. H_2O.

Pressure buildup in the EVAP system can be caused by:

- Fuel evaporation rates (volatility)
- Gas tank size (fuel surface area and volume)
- Fuel level (liquid versus vapor)
- Fuel slosh (driving conditions)
- Hot temperatures (ambient, in-tank, close to the tank)
- Returned fuel from the rail

PSI	INCHES HG	INCHES H_2O
14.7	29.93	407.19
1.0	2.036	27.7
0.9	1.8	24.93
0.8	1.63	22.16
0.7	1.43	19.39
0.6	1.22	16.62
0.5	1.018	13.85
0.4	0.814	11.08
0.3	0.611	8.31
0.2	0.407	5.54
0.1	0.204	2.77
0.09	0.183	2.49
0.08	0.163	2.22
0.07	0.143	1.94
0.06	0.122	1.66
0.05	0.102	1.385

CHART 39–2 PRESSURE CONVERSIONS

NOTE: Pressure conversions.
1 PSI = 28 in. H_2O
1/4 PSI = 7 in. H_2O

NONENHANCED EVAPORATIVE CONTROL SYSTEMS

Prior to 1996, evaporative systems were referred to as nonenhanced evaporative (EVAP) control systems. This term refers to evaporative systems that had limited diagnostic capabilities. While they are often PCM controlled, their diagnostic capability is usually limited to their ability to detect if purge has occurred. Many systems have a diagnostic switch that could sense if purge is occurring and set a code if no purge is detected. This system does not check for leaks. On some vehicles, the PCM also has the capability of monitoring the integrity of the purge solenoid and circuit. These systems' limitations are their ability to check the integrity of the evaporative system on the vehicle. They could not detect leaks or missing or loose gas caps that could lead to excessive evaporative emissions from the vehicle. Nonenhanced evaporative systems use either a canister purge solenoid or a vapor management valve to control purge vapor.

ENHANCED EVAPORATIVE CONTROL SYSTEM

BACKGROUND Beginning in 1996, with OBD-II vehicles, manufacturers were required to install systems that are able to detect both purge flow and evaporative system leakage.

- The systems on models produced between 1996 and 2000 must be able to detect a leak as small as 0.04 in. diameter.
- Beginning in the model year 2000, the enhanced systems started a phase-in of 0.02 in. diameter leak detection.
- All vehicles built after 1995 have enhanced evaporative systems that have the ability to detect purge flow and system leakage. If either of these two functions fails, the system is required to set a diagnostic trouble code (DTC) and turn on the MIL light to warn the driver of the failure.

CANISTER VENT VALVE The canister vent valve is a *normally open* valve and is only closed when commanded by the PCM during testing of the system. The vent valve is only closed during testing by the PCM as part of the mandated OBD-II standards. The vent solenoid is located under the vehicle in most cases and is exposed to the environment, making this valve subject to rust and corrosion.

CANISTER PURGE VALVE The purge valve, also called the **canister purge (CANP)** solenoid is *normally closed* and is pulsed open by the PCM during purging. The purge valve is connected to the intake manifold vacuum and this line is used to draw gasoline vapors from the charcoal canister into the engine when the purge valve is commanded open. Most purge valves are pulsed on and off to better control the amount of fumes being drawn into the intake manifold.

TECH TIP

Problems After Refueling? Check the Purge Valve.

The purge valve is normally closed and open only when the PCM is commanding the system to purge. If the purge solenoid were to become stuck in the open position, gasoline fumes would be allowed to flow directly from the gas tank to the intake manifold. When refueling, this would result in a lot of fumes being forced into the intake manifold; and as a result, would cause a hard-to-start condition after refueling. This would also result in a rich exhaust (likely black) when first starting the engine after refueling. Although the purge solenoid is usually located under the hood of most vehicles and less subject to rust and corrosion, as with the vent valve, it can still fail.

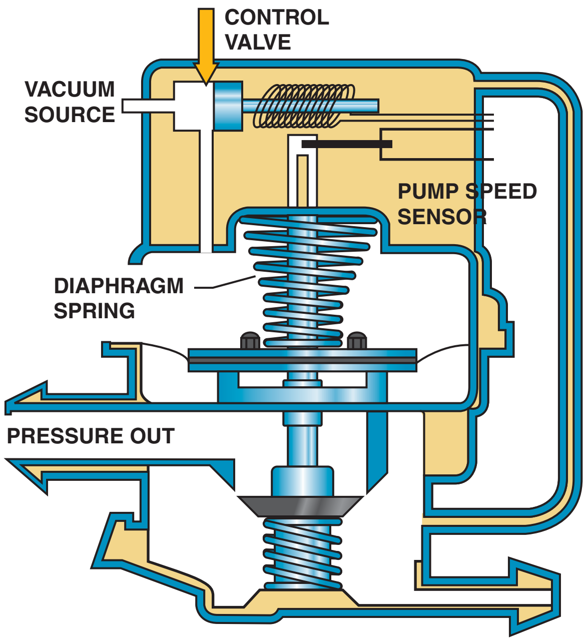


FIGURE 39–33 A leak detection pump (LDP) used on some Chrysler vehicles to pressurize (slightly) the fuel system to check for leaks.

FIGURE 39–34 A restricted fuel fill pipe shown on a vehicle with the interior removed.

LEAK DETECTION PUMP SYSTEM

PURPOSE AND FUNCTION Many vehicles use a **leak detection pump (LDP)** as part of the evaporative control system diagnosis equipment. ● **SEE FIGURE 39–33.**

OPERATION The system works to test for leaks as follows:

- The purge solenoid is normally closed.
- The vent valve in the LDP is normally open. Filtered fresh air is drawn through the LDP to the canister.
- The LDP uses a spring attached to a diaphragm to apply pressure (7.5 in. H_2O) to the fuel tank.
- The PCM monitors the LDP switch that is triggered if the pressure drops in the fuel tank.
- The time between LDP solenoid off and LDP switch close is called the pump period. This time period is inversely proportional to the size of the leak. The shorter the pump period, the larger the leak. The longer the pump period, the smaller the leak.

  EVAP large leak (greater than 0.08 in.): less than 0.9 second

  EVAP medium leak (0.04 to 0.08 in.): 0.9 to 1.2 seconds

  EVAP small leak (0.02 to 0.04 in.): 1.2 to 6 seconds

ONBOARD REFUELING VAPOR RECOVERY

PURPOSE AND FUNCTION The onboard refueling vapor recovery (ORVR) system was first introduced on some 1998 vehicles. Previously designed EVAP systems allowed fuel vapor to escape to the atmosphere during refueling.

OPERATION The primary feature of most ORVR systems is the restricted tank filler tube, which is about 1 in. (25 mm) in diameter. This reduced size filler tube creates an aspiration effect, which tends to draw outside air into the filler tube. During refueling, the fuel tank is vented to the charcoal canister, which captures the gas fumes; and with air flowing into the filler tube, no vapors can escape to the atmosphere. ● **SEE FIGURE 39–34.**

STATE INSPECTION EVAP TESTS

In some states, a periodic inspection and test of the fuel system are mandated along with a dynamometer test. The emissions inspection includes tests on the vehicle before and during the dynamometer test. Before the running test, the fuel tank and cap, fuel lines, canister, and other fuel system components must be inspected and tested to ensure that they are not leaking gasoline vapors into the atmosphere.

- First, the fuel tank cap is tested to ensure that it is sealing properly and holds pressure within specs.
- Next, the cap is installed on the vehicle, and using a special adapter, the EVAP system is pressurized to approximately 0.5 PSI and monitored for two minutes.
- Pressure in the tank and lines should not drop below approximately 0.3 PSI.

If the cap or system leaks, hydrocarbon emissions are likely being released, and the vehicle fails the test. If the system leaks, an ultrasonic leak detector may be used to find the leak.

Finally, with the engine warmed up and running at a moderate speed, the canister purge line is tested for adequate flow using a special flow meter inserted into the system. In one example, if the flow from the canister to the intake system when the system is activated is at least 1 liter per minute, then the vehicle passes the canister purge test.

DIAGNOSING THE EVAP SYSTEM

SYMPTOMS Before vehicle emissions testing began in many parts of the country, little service work was done on the evaporative emission system. Common engine-performance problems that can be caused by a fault in this system include:

- **Poor fuel economy.** A leak in a vacuum-valve diaphragm can result in engine vacuum drawing in a constant flow of gasoline vapors from the fuel tank. This usually results in a drop in fuel economy of 2 to 4 miles per gallon (mpg). Use a hand-operated vacuum pump to check that the vacuum diaphragm can hold vacuum.
- **Poor performance.** A vacuum leak in the manifold or ported vacuum section of vacuum hose in the system can cause the engine to run rough. Age, heat, and time all contribute to the deterioration of rubber hoses.

Enhanced exhaust emissions (I/M-240) testing tests the evaporative emission system. A leak in the system is tested by pressurizing the entire fuel system to a level below 1 lb/in.^{2} or 1 PSI (about 14 in. H_2O). The system is typically pressurized with nitrogen, a nonflammable gas that makes up 78% of our atmosphere. The pressure in the system is then shut off and monitored. If the pressure drops below a set standard, then the vehicle fails the test. This test determines if there is a leak in the system.

HINT: To help pass the evaporative section of an enhanced emissions test, arrive at the test site with less than one-half tank of fuel. This means that the rest of the volume of the fuel tank is filled with air. It takes longer for the pressure to drop from a small leak when the volume of the air is greater compared to when the tank is full and the volume of air remaining in the tank is small.

FIGURE 39–35 Some vehicles will display a message if an evaporative control system leak is detected that could be the result of a loose gas cap.

FIGURE 39–36 To test for a leak, this tester was set to the 0.020 in. hole and turned on. The ball rose in the scale on the left and the red arrow was moved to that location. When testing the system for leaks, if the ball rises higher than the arrow, then the leak is larger than 0.02 in. If the ball does not rise to the level of the arrow, the leak is smaller than 0.02 in.

LOCATING LEAKS IN THE SYSTEM Leaks in the evaporative emission control system will cause the malfunction check gas cap indication lamp to light on some vehicles. ● **SEE FIGURE 39–35.**

A leak will also cause a gas smell, which would be most noticeable if the vehicle were parked in an enclosed garage. The first step is to determine if there is a leak in the system by setting the EVAP tester to rate the system, either a 0.04 in. or a 0.02 in. hole size leak. ● **SEE FIGURE 39–36.**

FIGURE 39–37 This unit is applying smoke to the fuel tank through an adapter and the leak was easily found to be the gas cap seal.

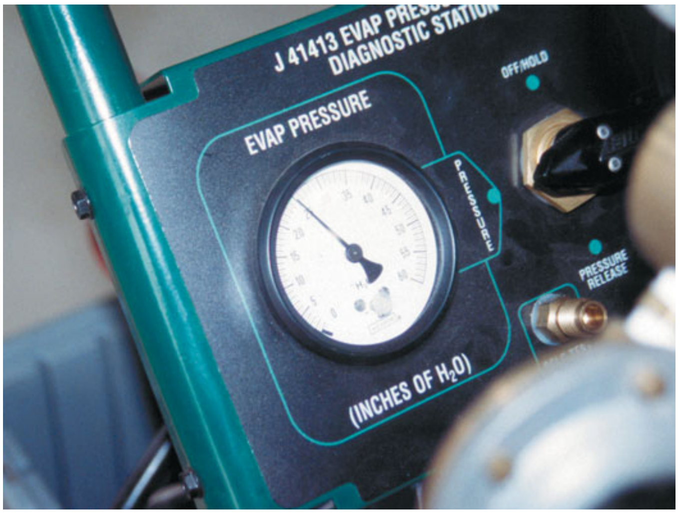


FIGURE 39–38 An emission tester that uses nitrogen to pressurize the fuel system.

After it has been determined that a leak exists and that it is larger than specified, then there are two methods that can be used to check for leaks in the evaporative system.

- **Smoke machine testing.** The most efficient method of leak detection is to introduce smoke under low pressure from a machine specifically designed for this purpose. ● **SEE FIGURE 39–37.**
- **Nitrogen gas pressurization.** This method uses nitrogen gas under a very low pressure (lower than 1 PSI) in the fuel system. The service technician then listens for the escaping air, using amplified headphones. ● **SEE FIGURE 39–38.**

EVAPORATIVE SYSTEM MONITOR

OBD-II REQUIREMENTS OBD-II computer programs not only detect faults, but also *periodically test various systems* and alert the driver before emissions-related components are harmed by system faults.

- Serious faults cause a blinking malfunction indicator lamp (MIL) or even an engine shutdown.
- Less serious faults may simply store a code but not illuminate the MIL.

The OBD-II requirements did not affect fuel system design. However, one new component, a fuel evaporative canister purge line pressure sensor, was added for monitoring purge line pressure during tests. The OBD-II requirements state that vehicle fuel systems are to be routinely tested *while underway* by the PCM.

All OBD-II vehicles perform a canister purge system pressure test, as commanded by the PCM. While the vehicle is being driven, the vapor line between the canister and the purge valve is monitored for pressure changes.

- When the canister purge solenoid is open, the line should be under a vacuum since vapors must be drawn from the canister into the intake system. However, when the purge solenoid is closed, there should be no vacuum in the line. The pressure sensor detects if a vacuum is present, and the information is compared to the command given to the solenoid.
- If, during the canister purge cycle, no vacuum exists in the canister purge line, a code is set indicating a possible fault, which could be caused by an inoperative or clogged solenoid or a blocked or leaking canister purge fuel line. Likewise, if vacuum exists when no command for purge is given, a stuck solenoid is evident, and a code is set. The EVAP system monitor tests for purge volume and leaks.

A typical EVAP monitor first closes off the system to atmospheric pressure and opens the purge valve during cruise operation. A **fuel tank pressure (FTP)** sensor then monitors the rate with which vacuum increases in the system. The monitor uses this information to determine the purge volume flow rate. To test for leaks, the EVAP monitor closes the purge valve, creating a completely closed system. The fuel tank pressure sensor then monitors the leak-down rate. If the rate exceeds PCM-stored values, a leak greater than or equal to the OBD-II standard of 0.04 in. (1 mm) or 0.02 in. (0.5 mm) exists. After two consecutive failed trips testing either purge volume or the presence of a leak, the PCM lights the MIL and sets a DTC.

The fuel tank pressure sensor is similar to the MAP sensor, and instead of monitoring intake manifold absolute pressure, it is used to monitor fuel tank pressure. ● **SEE FIGURE 39–39.**

FIGURE 39–39 The fuel tank pressure sensor looks like a MAP sensor and is usually located on top of the fuel pump module (white unit).

FIGURE 39–40 This Toyota cap has a warning. The check engine light will come on if not tightened until one click.

TECH TIP

Always Tighten the Cap Correctly

Many diagnostic trouble codes (DTCs) are set because the gas cap has not been properly installed. To be sure that a screw-type gas cap is properly sealed, it may need to be tightened until it clicks three times. The clicking is a ratchet device and the clicking does not harm the cap. Therefore, if a P0440 or similar DTC is set, check the cap. ● **SEE FIGURE 39–40.**

ENGINE-OFF NATURAL VACUUM System integrity (leakage) can also be checked after the engine is shut off. The premise is that a warm evaporative system will cool down after the engine is shut off and the vehicle is stable. A slight vacuum will be created in the gas tank during this cooling period. If a specific level of vacuum is reached and maintained, the system is said to have integrity (no leakage).

TYPICAL EVAP MONITOR

The PCM will run the EVAP monitor when the following enable criteria are met.

- Cold start
- Barometric pressure (BARO) greater than 70 kPa (20.7 in. Hg or 10.2 PSI)
- Intake air temperature (IAT) between 39°F and 86°F at engine start-up

TECH TIP

Keep the Fuel Tank Properly Filled

Most evaporative system monitors will not run unless the fuel level is between 15% and 85%. In other words, if a driver always runs with close to an empty tank or always tries to keep the tank full, the EVAP monitor may not run. ● **SEE FIGURE 39–41.**

- Engine coolant temperature (ECT) between 39°F and 86°F at engine start-up
- ECT and IAT within 39°F of each other at engine start-up
- Fuel level within 15% to 85%
- Throttle position (TP) sensor between 9% and 35%

RUNNING THE EVAP MONITOR There are three tests that are performed during a typical EVAP monitor. A DTC is assigned to each test.

1. **Weak vacuum test (P0440—large leak).** This test identifies gross leaks. During the monitor, the vent solenoid is closed and the purge solenoid is duty cycled. The fuel tank pressure (FTP) should indicate a vacuum of approximately 6 to 10 in. H_2O.
2. **Small leak test (P0442—small leak).** After the large leak test passes, the PCM checks for a small leak by keeping the vent solenoid closed and closing the purge solenoid. The system is now sealed. The PCM measures the change in FTP voltage over time.
3. **Excess vacuum test (P0446).** This test checks for vent path restrictions. With the vent solenoid open and purge commanded, the PCM should not see excessive vacuum in the EVAP system. Typical EVAP system vacuum with the vent solenoid open is about 5 to 6 in. H_2O.

FIGURE 39–41 The fuel level must be between 15% and 85% before the EVAP monitor will run on most vehicles.

EVAP SYSTEM-RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0440	Evaporative system fault	• Loose gas cap • Defective EVAP vent • Cracked charcoal canister • EVAP vent or purge vapor line problems
P0442	Small leak detected	• Loose gas cap • Defective EVAP vent or purge solenoid • EVAP vent or purge line problems
P0446	EVAP canister vent blocked	• EVAP vent or purge solenoid electrical problems • Restricted EVAP canister vent line

SUMMARY

1. Recirculating 6% to 10% inert exhaust gases back into the intake system by the EGR system reduces peak temperature inside the combustion chamber and reduces NOx exhaust emissions.
2. EGR is usually not needed at idle, at wide-open throttle, or when the engine is cold.
3. Many EGR systems use a feedback potentiometer to signal the PCM the position of the EGR valve pintle.
4. OBD-II requires that the flow rate be tested and then is achieved by opening the EGR valve and observing the reaction of the MAP sensor.
5. Positive crankcase ventilation (PCV) systems use a valve or a fixed orifice to control and direct the fumes from the crankcase back into the intake system.
6. A PCV valve regulates the flow of fumes depending on engine vacuum and seals the crankcase vent in the event of a backfire.
7. As much as 30% of the air needed by the engine at idle speed flows through the PCV system.
8. The secondary air-injection (SAI) system forces air at low pressure into the exhaust to reduce CO and HC exhaust emissions.
9. A catalytic converter is an aftertreatment device that reduces exhaust emissions outside of the engine. A catalyst is an element that starts a chemical reaction but is not consumed in the process.
10. The catalyst material used in a catalytic converter includes rhodium, palladium, and platinum.
11. The OBD-II system monitor compares the relative activity of a rear oxygen sensor to the precatalytic oxygen sensor to determine catalytic converter efficiency.
12. The purpose of the evaporative (EVAP) emission control system is to reduce the release of volatile organic compounds (VOCs) into the atmosphere.
13. A carbon (charcoal) canister is used to trap and hold gasoline vapors until they can be purged and run into the engine to be burned.
14. OBD-II regulation requires that the evaporative emission control system be checked for leakage and proper purge flow rates.
15. External leaks can best be located by pressurizing the fuel system with low-pressure smoke.

REVIEW QUESTIONS

1. How does the use of exhaust gas recirculation reduce NOx exhaust emission?
2. How does the DPFE sensor work?
3. What exhaust emissions does the PCV valve and SAI system control?
4. How does a catalytic converter reduce NOx to nitrogen and oxygen?
5. How does the computer monitor catalytic converter performance?

CHAPTER QUIZ

1. Two technicians are discussing clogged EGR passages. Technician A says clogged EGR passages can cause excessive NOx exhaust emission. Technician B says that clogged EGR passages can cause the engine to ping (spark knock or detonation). Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. An EGR valve that is partially stuck open would *most likely* cause what condition?
   - **a.** Rough idle/stalling
   - **b.** Excessive NOx exhaust emissions
   - **c.** Ping (spark knock or detonation)
   - **d.** Missing at highway speed
3. How much air flows through the PCV system when the engine is at idle speed?
   - **a.** 1% to 3%
   - **b.** 5% to 10%
   - **c.** 10% to 20%
   - **d.** Up to 30%
4. Technician A says that if a PCV valve rattles, then it is okay and does not need to be replaced. Technician B says that if a PCV valve does not rattle, it should be replaced. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. The switching valves on the AIR pump have failed several times. Technician A says that a defective exhaust check valve could be the cause. Technician B says that a leaking exhaust system at the muffler could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Two technicians are discussing testing a catalytic converter. Technician A says that a vacuum gauge can be used and observed to see if the vacuum drops with the engine at 2,500 RPM for 60 seconds. Technician B says that a pressure gauge can be used to check for backpressure. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. At about what temperature does oxygen combine with the nitrogen in the air to form NOx?
   - **a.** 500°F (260°C)
   - **b.** 750°F (400°C)
   - **c.** 1,500°F (815°C)
   - **d.** 2,500°F (1,370°C)
8. A P0401 is being discussed. Technician A says that a stuck-closed EGR valve could be the cause. Technician B says that clogged EGR ports could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Which EVAP valve(s) is(are) normally closed?
   - **a.** Canister purge valve
   - **b.** Canister vent valve
   - **c.** Both canister purge and canister vent valves
   - **d.** Neither canister purge nor canister vent valve
10. Before an evaporative emission monitor will run, the fuel level must be where?
    - **a.** At least 75% full
    - **b.** Over 25%
    - **c.** Between 15% and 85%
    - **d.** The level of the fuel in the tank is not needed to run the monitor test

chapter 40

SCAN TOOLS AND ENGINE PERFORMANCE DIAGNOSIS

OBJECTIVES: After studying Chapter 40, the reader will be able to: • Prepare for the ASE computerized engine controls diagnosis (A8) certification test content area "E". • List the steps of the diagnostic process. • Describe the simple preliminary tests that should be performed at the start of the diagnostic process. • List six items to check as part of a thorough visual inspection. • Explain the troubleshooting procedures to follow if a diagnostic trouble code has been set. • Explain the troubleshooting procedures to follow if no diagnostic trouble code has been set. • Discuss the type of scan tools that are used to assess vehicle components. • Describe the methods that can be used to reprogram (reflash) a vehicle computer.

KEY TERMS: Data link connector (DLC) 588 • Drive cycle 600 • Flash code retrieval 591 • Key-on—engine off test (KOEO) 592 • Key-on—engine running test (KOER) 592 • Paper test 586 • Pending code 587 • Self-test automatic readout (STAR) 592 • Smoke machine 586 • Technical service bulletin (TSB) 587 • Trip 596

THE EIGHT-STEP DIAGNOSTIC PROCEDURE

It is important that all automotive service technicians know how to diagnose and troubleshoot engine computer systems. The diagnostic process is a strategy that eliminates known-good components or systems in order to find the root cause of automotive engine performance problems. All vehicle manufacturers recommend a diagnostic procedure, and the plan suggested in this chapter combines most of the features of these plans plus additional steps developed over years of real-world problem solving.

Many different things can cause an engine performance problem or concern. The service technician has to narrow the possibilities to find the cause of the problem and correct it. A funnel is a way of visualizing a diagnostic procedure. ● **SEE FIGURE 40–1.** At the wide top are the symptoms of the problem; the funnel narrows as possible causes are eliminated until the root cause is found and corrected at the bottom of the funnel.

All problem diagnosis deals with symptoms that could be the result of many different causes. The wide range of possible solutions must be narrowed to the most likely and these must eventually be further narrowed to the actual cause. The following section describes eight steps the service technician can take to narrow the possibilities to one cause.

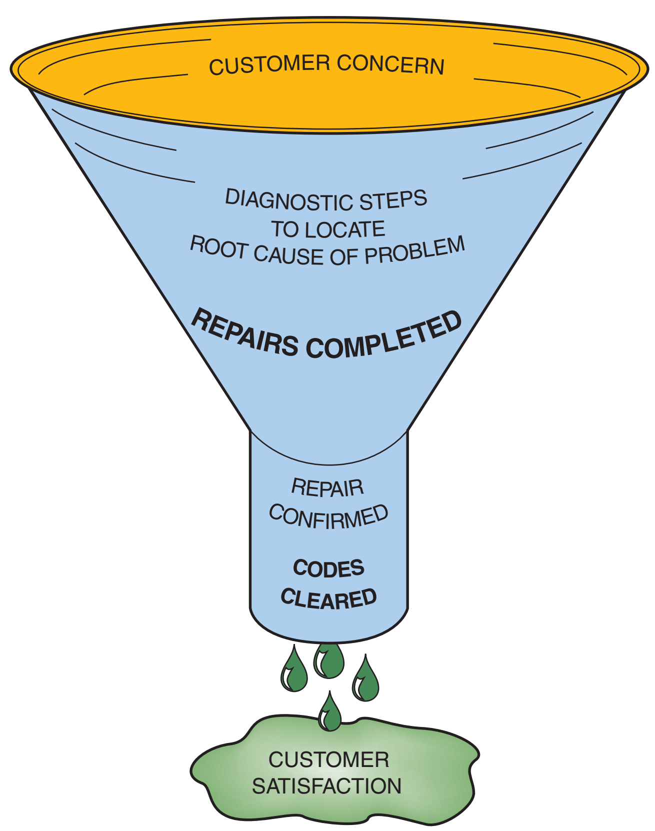


FIGURE 40–1 A funnel is one way to visualize the diagnostic process. The purpose is to narrow the possible causes of a concern until the root cause is determined and corrected.

STEP 1 VERIFY THE PROBLEM (CONCERN)

Before a minute is spent on diagnosis, be certain that a problem exists. If the problem cannot be verified, it cannot be solved or tested to verify that the repair was complete. ● **SEE FIGURE 40–2.**

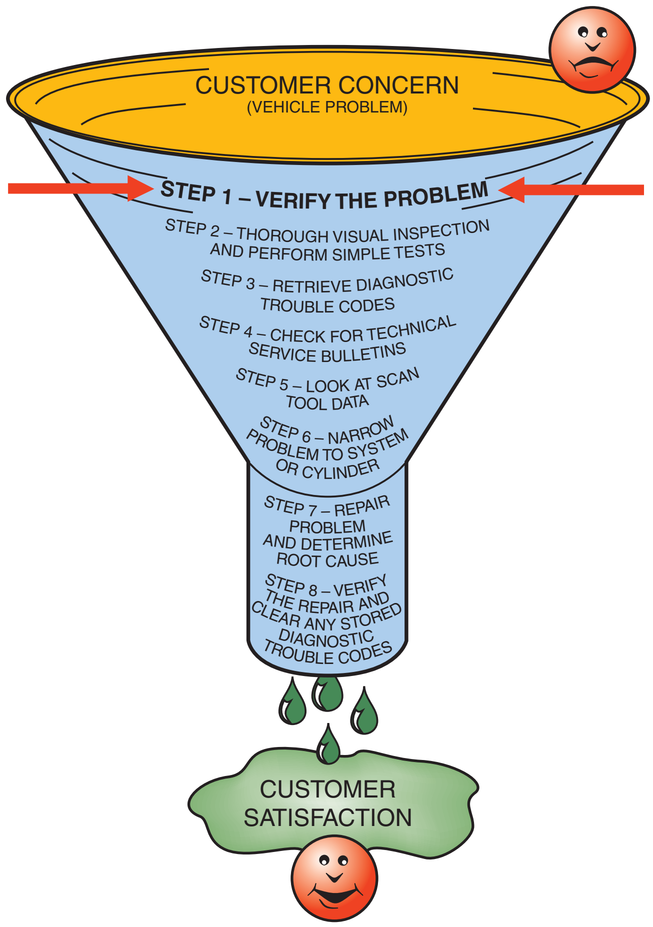


FIGURE 40–2 Step #1 is to verify the customer concern or problem. If the problem cannot be verified, then the repair cannot be verified.

The driver of the vehicle knows much about the vehicle and how it is driven. *Before* diagnosis, always ask the following questions:

- Is the malfunction indicator light (check engine) on?
- What was the temperature outside?
- Was the engine warm or cold?
- Was the problem during starting, acceleration, cruise, or some other condition?
- How far had the vehicle been driven?
- Were any dash warning lights on? If so, which one(s)?
- Has there been any service or repair work performed on the vehicle lately?

NOTE: This last question is very important. Many engine performance faults are often the result of something being knocked loose or a hose falling off during repair work. Knowing that the vehicle was just serviced before the problem began may be an indicator as to where to look for the solution to a problem.

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed. A sample form that customers could fill out with details of the problem is shown in ● **FIGURE 40–3.**

NOTE: Because drivers differ, it is sometimes the best policy to take the customer on the test drive to verify the concern.

TECH TIP

"Original Equipment" Is Not a Four-Letter Word

To many service technicians, an original-equipment part is considered to be only marginal and to get the really "good stuff" an aftermarket (renewal market) part has to be purchased. However, many problems can be traced to the use of an aftermarket part that has failed early in its service life. Technicians who work at dealerships usually begin their diagnosis with an aftermarket part identified during a visual inspection. It has been their experience that simply replacing the aftermarket part with the factory original-equipment (OE) part often solves the problem.

Original equipment parts are *required* to pass quality and durability standards and tests at a level not required of aftermarket parts. The technician should be aware that the presence of a new part does not necessarily mean that the part is good.

STEP 2 PERFORM A THOROUGH VISUAL INSPECTION AND BASIC TESTS The visual inspection is the most important aspect of diagnosis! Most experts agree that between 10% and 30% of all engine performance problems can be found simply by performing a *thorough* visual inspection. The inspection should include the following:

- **Check for obvious problems (basics, basics, basics).**
  Fuel leaks
  Vacuum hoses that are disconnected or split
  Corroded connectors
  Unusual noises, smoke, or smell
  Check the air cleaner and air duct (squirrels and other small animals can build nests or store dog food in them). ● **SEE FIGURE 40–4.**
- **Check everything that does and does not work.** This step involves turning things on and observing that everything is working properly.
- **Look for evidence of previous repairs.** Any time work is performed on a vehicle, there is always a risk that something will be disturbed, knocked off, or left disconnected.
- **Check oil level and condition.** Another area for visual inspection is oil level and condition.
  Oil level. Oil should be to the proper level.
  Oil condition. Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present

ENGINE PERFORMANCE DIAGNOSIS WORKSHEET

(To Be Filled Out By the Vehicle Owner)

Name: ______________________ Mileage: ____________ Date: ____________

Make: ____________ Model: ____________ Year: ____________ Engine: ____________

(Please Circle All That Apply in All Categories)	
Describe Problem:	
When Did the Problem First Occur?	• Just Started • Last Week • Last Month • Other ____________
List Previous Repairs in the Last 6 Months:	
Starting Problems	• Will Not Crank • Cranks, but Will Not Start • Starts, but Takes a Long Time
Engine Quits or Stalls	• Right after Starting • When Put into Gear • During Steady Speed Driving • Right after Vehicle Comes to a Stop • While Idling • During Acceleration • When Parking
Poor Idling Conditions	• Is Too Slow at All Times • Is Too Fast • Intermittently Too Fast or Too Slow • Is Rough or Uneven • Fluctuates Up and Down
Poor Running Conditions	• Runs Rough • Lacks Power • Bucks and Jerks • Poor Fuel Economy • Hesitates or Stumbles on Acceleration • Backfires • Misfires or Cuts Out • Engine Knocks, Pings, Rattles • Surges • Dieseling or Run-On
Auto. Transmission Problems	• Improper Shifting (Early/Late) • Changes Gear Incorrectly • Vehicle Does Not Move when in Gear • Jerks or Bucks
Usually Occurs	• Morning • Afternoon • Anytime
Engine Temperature	• Cold • Warm • Hot
Driving Conditions During Occurrence	• Short—Less Than 2 Miles • 2–10 Miles • Long—More Than 10 Miles • Stop and Go • While Turning • While Braking • At Gear Engagement • With A/C Operating • With Headlights On • During Acceleration • During Deceleration • Mostly Downhill • Mostly Uphill • Mostly Level • Mostly Curvy • Rough Road
Driving Habits	• Mostly City Driving • Highway • Park Vehicle Inside • Park Vehicle Outside **Drive Per Day:** • Less Than 10 Miles • 10–50 • More Than 50
Gasoline Used	**Fuel Octane:** • 87 • 89 • 91 • More Than 91 **Brand:** ____________
Temperature when Problem Occurs	• 32–55° F • Below Freezing (32° F) • Above 55° F
Check Engine Light/ Dash Warning Light	• Light on Sometimes • Light on Always • Light Never On
Smells	• "Hot" • Gasoline • Oil Burning • Electrical
Noises	• Rattle • Knock • Squeak • Other

FIGURE 40–3 A form that the customer should fill out if there is a driveablilty concern to help the service technician more quickly find the root cause.

FIGURE 40–4 This is what was found when removing an air filter from a vehicle that had a lack-of-power concern. Obviously the nuts were deposited by squirrels or some other animal, blocking a lot of the airflow into the engine.

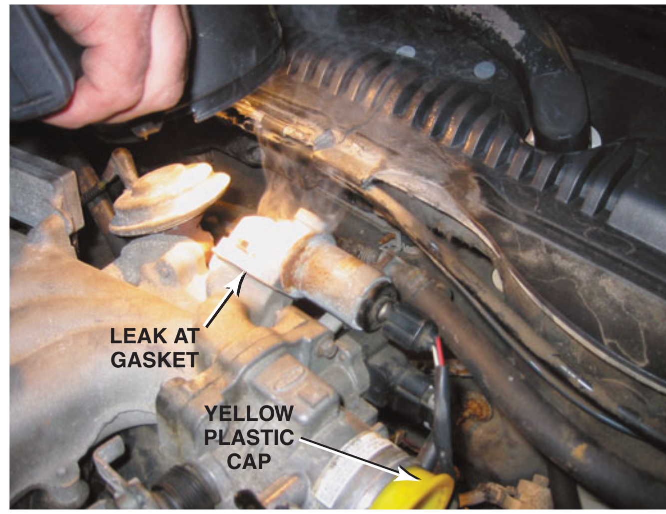


FIGURE 40–5 Using a bright light makes seeing where the smoke is coming from easier. In this case, smoke was added to the intake manifold with the inlet blocked with a yellow plastic cap and smoke was seen escaping past a gasket at the idle air control.

TECH TIP

Smoke Machine Testing

Vacuum (air) leaks can cause a variety of driveability problems and are often difficult to locate. One good method is to use a machine that generates a stream of smoke. Connecting the outlet of the **smoke machine** to the hose that was removed from the vacuum brake booster allows smoke to enter the intake manifold. Any vacuum leaks will be spotted by observing smoke coming out of the leak. **SEE FIGURE 40–5.**

in the engine oil. Drip some engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, coolant (water) is present in the oil. Check for grittiness by rubbing the oil between your fingers.

NOTE: Gasoline in the oil will cause the engine to run rich by drawing fuel through the positive crankcase ventilation (PCV) system.

- **Check coolant level and condition.** Many mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

NOTE: Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately, which can cause severe burns because the coolant expands explosively upward and outward from the radiator opening.

- **Use the paper test.** A sound engine should produce even and steady exhaust flow at the tailpipe when running. For the paper test, hold a piece of paper (even a dollar bill works) or a 3-by-5-inch card within 1 inch (2.5 centimeters) of the tailpipe with the engine running at idle. The paper should blow evenly away from the end of the tailpipe without "puffing" or being drawn inward toward the end of the tailpipe. If the paper is at times drawn *toward* the tailpipe, the valves in one or more cylinders could be burned. Other reasons why the paper might be drawn toward the tailpipe include the following:
  1. The engine could be misfiring because of a lean condition that could occur normally when the engine is cold.
  2. Pulsing of the paper toward the tailpipe could also be caused by a hole in the exhaust system. If exhaust escapes through a hole in the exhaust system, air could be drawn—in the intervals between the exhaust puffs—from the tailpipe to the hole in the exhaust, causing the paper to be drawn toward the tailpipe.
- **Ensure adequate fuel level.** Make certain that the fuel tank is at least one-fourth to one-half full; if the fuel level is low it is possible that any water or alcohol at the bottom of the fuel tank is more concentrated and can be drawn into the fuel system.
- **Check the battery voltage.** The voltage of the battery should be at least 12.4 volts and the charging voltage (engine running) should be 13.5 to 15.0 volts at 2,000 RPM. Low battery voltage can cause a variety of problems including reduced fuel economy and incorrect (usually too high) idle speed. Higher-than-normal battery voltage can also cause the PCM problems and could cause damage to electronic modules.
- **Check the spark using a spark tester.** Remove one spark plug wire and attach the removed plug wire to the spark tester. Attach the grounding clip of the spark tester to a good clean engine ground, start or crank the engine,

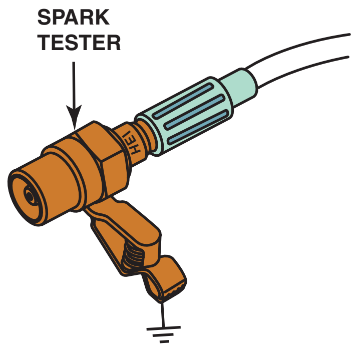


FIGURE 40–6 A spark tester connected to a spark plug wire or coil output. A typical spark tester will only fire if at least 25,000 volts is available from the coil, making a spark tester a very useful tool. Do not use one that just lights when a spark is present, because they do not require more than about 2,000 volts to light.

and observe the spark tester. ● **SEE FIGURE 40–6.** The spark at the spark tester should be steady and consistent. If an intermittent spark occurs, then this condition should be treated as a no-spark condition. If this test does not show satisfactory spark, carefully inspect and test all components of the primary and secondary ignition systems.

NOTE: Do not use a standard spark plug to check for proper ignition system voltage. An electronic ignition spark tester is designed to force the spark to jump about 0.75 inch (19 mm). This amount of gap requires between 25,000 and 30,000 volts (25 to 30 kV) at atmospheric pressure, which is enough voltage to ensure that a spark can occur under compression inside an engine.

- **Check the fuel-pump pressure.** Checking the fuel-pump pressure is relatively easy on many port-fuel-injected engines. Often the cause of intermittent engine performance is due to a weak electric fuel pump or clogged fuel filter. Checking fuel pump pressure early in the diagnostic process eliminates low fuel pressure as a possibility.

STEP 3 RETRIEVE THE DIAGNOSTIC TROUBLE CODES (DTCs)

If a diagnostic trouble code (DTC) is present in the computer memory, it may be signaled by illuminating a malfunction indicator lamp (MIL), commonly labeled "check engine" or "service engine soon." ● **SEE FIGURE 40–7.** Any code(s) that is displayed on a scan tool when the MIL is *not* on is called a **pending code**. Because the MIL is not on, this indicates that the fault has not repeated to cause the PCM to turn on the MIL. Although this pending code is helpful to the technician to know that a fault has, in the past, been detected, further testing will be needed to find the root cause of the problem.

STEP 4 CHECK FOR TECHNICAL SERVICE BULLETINS (TSBs)

Check for corrections or repair procedures in **technical service bulletins (TSBs)** that match the symptoms. ● **SEE FIGURE 40–8.** According to studies performed by automobile manufacturers, as many as 30% of vehicles can be repaired

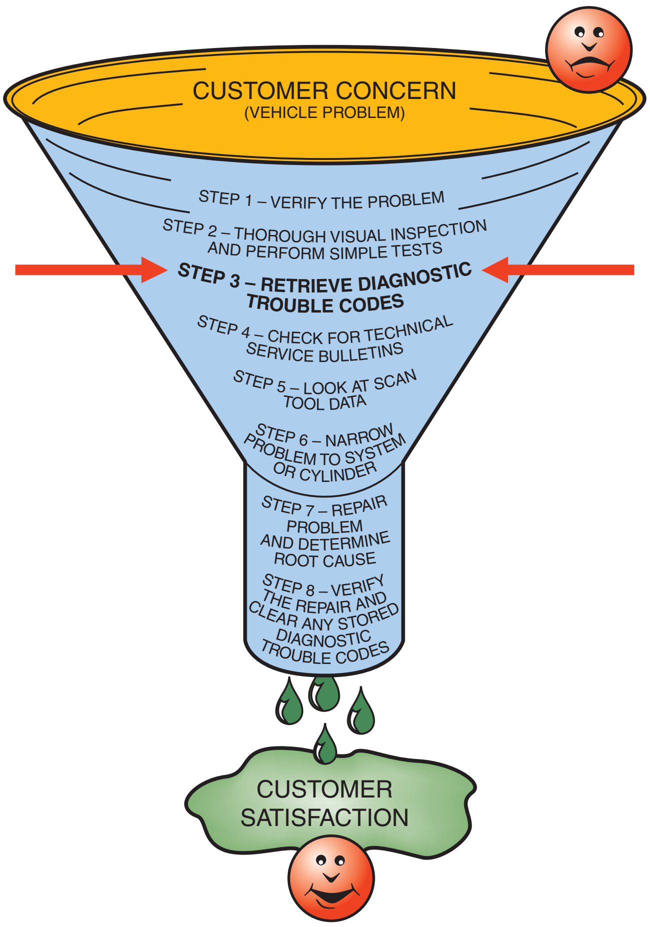


FIGURE 40–7 Step 3 in the diagnostic process is to retrieve any stored diagnostic trouble codes.

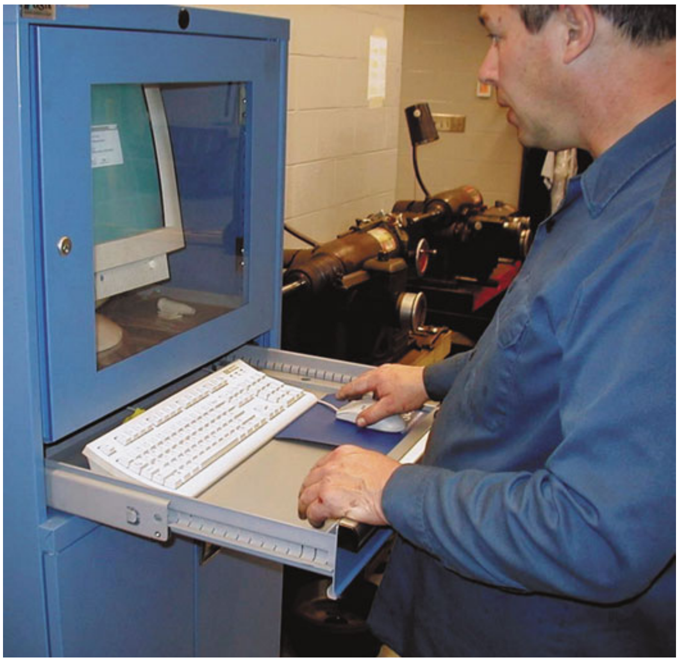


FIGURE 40–8 After checking for stored diagnostic trouble codes (DTCs), the wise technician checks service information for any technical service bulletins that may relate to the vehicle being serviced.

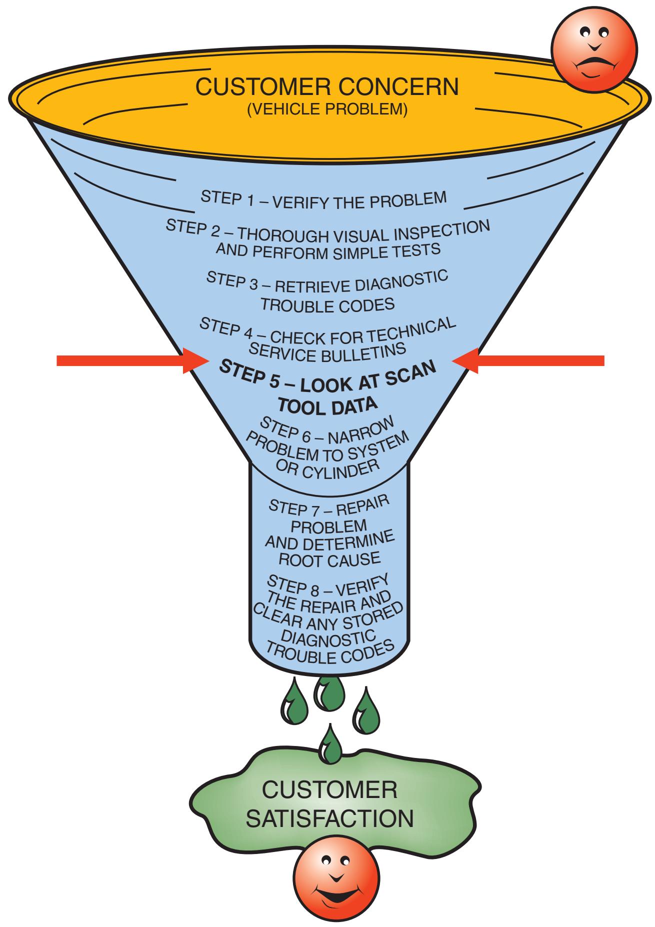


FIGURE 40–9 Looking carefully at the scan tool data is very helpful in locating the source of a problem.

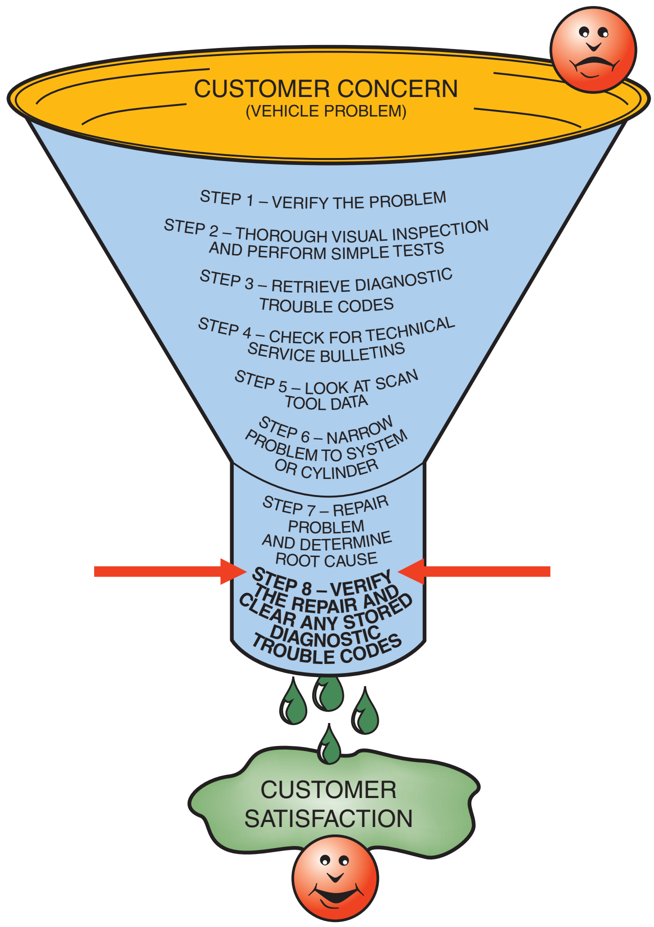


FIGURE 40–10 Step 8 is very important. Be sure that the customer's concern has been corrected.

following the information, suggestions, or replacement parts found in a service bulletin. DTCs must be known before searching for service bulletins, because bulletins often include information on solving problems that involve a stored diagnostic trouble code.

STEP 5 LOOK CAREFULLY AT SCAN TOOL DATA Vehicle manufacturers have been giving the technician more and more data on a scan tool connected to the **data link connector (DLC).** ● **SEE FIGURE 40–9.** Beginning technicians are often observed scrolling through scan data without a real clue about what they are looking for. When asked, they usually reply that they are looking for something unusual, as if the screen will flash a big message "LOOK HERE—THIS IS NOT CORRECT." That statement does not appear on scan tool displays. The best way to look at scan data is in a definite sequence and with specific, selected bits of data that can tell the most about the operation of the engine, such as the following:

- Engine coolant temperature (ECT) is the same as intake air temperature (IAT) after the vehicle sits for several hours.
- Idle air control (IAC) valve is being commanded to an acceptable range.
- Oxygen sensor (O_2S) is operating properly:

1. Readings below 200 mV at times
2. Readings above 800 mV at times
3. Rapid transitions between rich and lean

STEP 6 NARROW THE PROBLEM TO A SYSTEM OR CYLINDER Narrowing the focus to a system or individual cylinder is the hardest part of the entire diagnostic process.

- Perform a cylinder power balance test.
- If a weak cylinder is detected, perform a compression and a cylinder leakage test to determine the probable cause.

STEP 7 REPAIR THE PROBLEM AND DETERMINE THE ROOT CAUSE The repair or part replacement must be performed following vehicle manufacturer's recommendations and be certain that the root cause of the problem has been found. Also follow the manufacturer's recommended repair procedures and methods.

STEP 8 VERIFY THE REPAIR AND CLEAR ANY STORED DTCs ● **SEE FIGURE 40–10.**

- Test drive to verify that the original problem (concern) is fixed.
- Verify that no additional problems have occurred during the repair process.
- Check for and then clear all diagnostic trouble codes. (This step ensures that the computer will not make any changes based on a stored DTC, but should not be performed if the

TECH TIP

One Test Is Worth 1,000 "Expert" Opinions

Whenever any vehicle has an engine performance or driveability concern, certain people always say:

"Sounds like it's a bad injector."
"I'll bet you it's a bad computer."
"I had a problem just like yours yesterday and it was a bad EGR valve."

Regardless of the skills and talents of those people, it is still more accurate to perform tests on the vehicle than to rely on feelings or opinions of others who have not even seen the vehicle. Even your own opinion should not sway your thinking. Follow a plan, perform tests, and the test results will lead to the root cause.

vehicle is going to be tested for emissions because all of the monitors will need to be run and pass.)

- Return the vehicle to the customer and double-check the following:
  1. The vehicle is clean.
  2. The radio is turned off.
  3. The clock is set to the right time and the radio stations have been restored if the battery was disconnected during the repair procedure.

SCAN TOOLS

Scan tools are the workhorse for any diagnostic work on all vehicles. Scan tools can be divided into two basic groups:

1. **Factory scan tools.** These are the scan tools required by all dealers that sell and service the brand of vehicle. Examples of factory scan tools include:
   - **General Motors**—Tech 2. ● **SEE FIGURE 40–11.**
   - **Ford**—New Generation Star (NGS) and IDS (Integrated Diagnostic Software).
   - **Chrysler**—DRB-III or Star Scan (CAN-equipped vehicles)
   - **Honda**—HDS or Master Tech
   - **Toyota**—Master Tech

   All factory scan tools are designed to provide bidirectional capability which allows the service technician the opportunity to operate components using the scan tool thereby confirming that the component is able to work when commanded. Also all factory scan tools are capable of displaying all factory parameters.
2. **Aftermarket scan tools.** These scan tools are designed to function on more than one brand of vehicle. Examples of aftermarket scan tools include:
   - **Snap-on** (various models including the MT2500 and Modis)
   - **OTC** (various models including Pegasus, Genisys and Task Master)
   - **AutoEnginuity** and other programs that use a laptop or handheld computer for the display

FIGURE 40–11 A TECH 2 scan tool is the factory scan tool used on General Motors vehicles.

FIGURE 40–12 Some scan tools use pocket PCs which make it very convenient to use.

While many aftermarket scan tools can display most if not all of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults. ● **SEE FIGURE 40–12.**

RETRIEVAL OF DIAGNOSTIC INFORMATION

To retrieve diagnostic information from the Powertrain Control Module (PCM), a scan tool is needed. If a factory or factory-level scan tool is used, then all of the data can be retrieved. If a global (generic) only type scan tool is used, only the emissions-related data can be retrieved. To retrieve diagnostic information from the PCM, use the following steps:

STEP 1 Locate and gain access to the data link connector (DLC).

STEP 2 Connect the scan tool to the DLC and establish communication.

NOTE: If no communication is established, follow the vehicle manufacturer's specified instructions.

STEP 3 Follow the on-screen instructions of the scan tool to correctly identify the vehicle.

STEP 4 Observe the scan data, as well as any diagnostic trouble codes.

STEP 5 Follow vehicle manufacturer's instructions if any DTCs are stored. If no DTCs are stored, compare all sensor values with a factory acceptable range chart to see if any sensor values are out-of-range.

Parameter Identification (PID)

Scan Tool Parameter	Units Displayed	Typical Data Value
Engine Idling/Radiator Hose Hot/Closed Throttle/ Park or Neutral/Closed Loop/Accessories Off/ Brake Pedal Released		
3X Crank Sensor	RPM	Varies
24X Crank Sensor	RPM	Varies
Actual EGR Position	Percent	0
BARO	kPa/Volts	65–110 kPa/ 3.5–4.5 Volts
CMP Sensor Signal Present	Yes/No	Yes
Commanded Fuel Pump	On/Off	On
Cycles of Misfire Data	Counts	0–99
Desired EGR Position	Percent	0
ECT	°C/°F	Varies
EGR Duty Cycle	Percent	0
Engine Run Time	Hr: Min: Sec	Varies
EVAP Canister Purge	Percent	Low and Varying
EVAP Fault History	No Fault/ Excess Vacuum/ Purge Valve Leak/ Small Leak/ Weak Vacuum	No Fault
Fuel Tank Pressure	Inches of H_2O/ Volts	Varies
HO_2S Sensor 1	Ready/Not Ready	Ready
HO_2S Sensor 1	Millivolts	0–1,000 and Varying
HO_2S Sensor 2	Millivolts	0–1,000 and Varying
HO_2S X Counts	Counts	Varies
IAC Position	Counts	15–25 preferred
IAT	°C/°F	Varies
Knock Retard	Degrees	0
Long Term FT	Percent	0–10
MAF	Grams per second	3–7
MAF Frequency	Hz	1,200–3,000 (depends on altitude and engine load)
MAP	kPa/Volts	20–48 kPa/ 0.75–2 Volts (depends on altitude)
Misfire Current Cyl. 1–10	Counts	0
Misfire History Cyl. 1–10	Counts	0
Short Term FT	Percent	0–10
Start Up ECT	°C/°F	Varies
Start Up IAT	°C/°F	Varies
Total Misfire Current Count	Counts	0
Total Misfire Failures	Counts	0
Total Misfire Passes	Counts	0
TP Angle	Percent	0
TP Sensor	Volts	0.20–0.74
Vehicle Speed	MPH/Km/h	0

Note: Viewing the PID screen on the scanner is useful in determining if a problem is occurring at the present time

TROUBLESHOOTING USING DIAGNOSTIC TROUBLE CODES

Pinning down causes of the actual problem can be accomplished by trying to set the opposite code. For example, if a code indicates an open throttle position (TP) sensor (high resistance), clear the code and create a shorted (low-resistance) condition. This can be accomplished by using a jumper wire and connecting the signal terminal to the 5-volt reference terminal. This should set a diagnostic trouble code.

- **If the opposite code sets,** this indicates that the wiring and connector for the sensor is okay and the sensor itself is defective (open).

- **If the same code sets,** this indicates that the wiring or electrical connection is open (has high resistance) and is the cause of the setting of the DTC.

METHODS FOR CLEARING DIAGNOSTIC TROUBLE CODES Clearing diagnostic trouble codes from a vehicle computer sometimes needs to be performed. There are three methods that can be used to clear stored diagnostic trouble codes.

CAUTION: Clearing diagnostic trouble codes (DTCs) also will clear all of the noncontinuous monitors.

- **Clearing codes—Method 1.** The preferred method of clearing codes is by using a scan tool. This is the method recommended by most vehicle manufacturers if the procedure can be performed on the vehicle. The computer of some vehicles cannot be cleared with a scan tool.
- **Clearing codes—Method 2.** If a scan tool is not available or a scan tool cannot be used on the vehicle being serviced, the power to the computer can be disconnected.
  1. Disconnect the fusible link (if so equipped) that feeds the computer.
  2. Disconnect the fuse or fuses that feed the computer.

  NOTE: The fuse may not be labeled as a computer fuse. For example, many Toyotas can be cleared by disconnecting the fuel-injection fuse. Some vehicles require that two fuses be disconnected to clear any stored codes.
- **Clearing codes—Method 3.** If the other two methods cannot be used, the negative battery cable can be disconnected to clear stored diagnostic trouble codes.

NOTE: Because of the adaptive learning capacity of the computer, a vehicle may fail an exhaust emissions test if the vehicle is not driven enough to allow the computer to run all of the monitors.

CAUTION: By disconnecting the battery, the radio presets and clock information will be lost. They should be reset before returning the vehicle to the customer. If the radio has a security code, the code must be entered before the radio will function. Before disconnecting the battery, always check with the vehicle owner to be sure that the code is available.

FLASH CODE RETRIEVAL ON OBD-I GENERAL MOTORS VEHICLES

The GM system uses a "check engine" or "check engine soon" MIL to notify the driver of possible system failure. Under the dash (on most GM vehicles) is a data link connector (DLC) previously called an assembly line communications link (ALCL) or assembly line diagnostic link (ALDL).

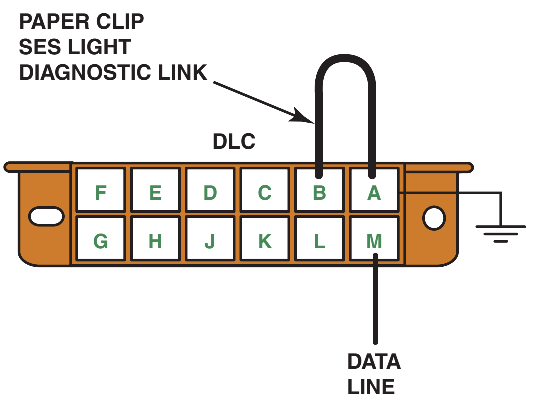


FIGURE 40–13 To retrieve flash codes from an OBD-I General Motors vehicle, without a scan tool, connect terminals A and B with the ignition on–engine off. The M terminal is used to retrieve data from the sensors to a scan tool.

TECH TIP

Do Not Lie to a Scan Tool!

Because computer calibration may vary from year to year, using the incorrect year for the vehicle while using a scan tool can cause the data retrieved to be incorrect or inaccurate.

Most General Motors diagnostic trouble codes can be retrieved by using a metal tool and contacting terminals A and B of the 12-pin DLC. ● **SEE FIGURE 40–13.** This method is called **flash code retrieval** because the MIL will flash to indicate diagnostic trouble codes. The steps are as follows:

1. Turn the ignition switch to on (engine off). The "check engine" light or "service engine soon" light should be on. If the amber malfunction indicator light (MIL) is not on, a problem exists within the light circuit.
2. Connect terminals A and B at the DLC.
3. Observe the MIL. A code 12 (one flash, then a pause, then two flashes) reveals that there is no engine speed indication to the computer. Because the engine is not running, this simply indicates that the computer diagnostic system is working correctly.

   NOTE: Refer to service manual diagnostic procedures if the MIL is on and does not flash a code 12 when terminals A and B are connected.
4. After code 12 is displayed three times, the MIL will flash any other stored DTCs in numeric order starting with the lowest-number code. If only code 12 is displayed another three times, the computer has not detected any other faults.

NOTE: Trouble codes can vary according to year, make, model, and engine. Always consult the service literature or service manual for the exact vehicle being serviced. Check service information for the meaning and recommended steps to follow if a diagnostic trouble code is retrieved.

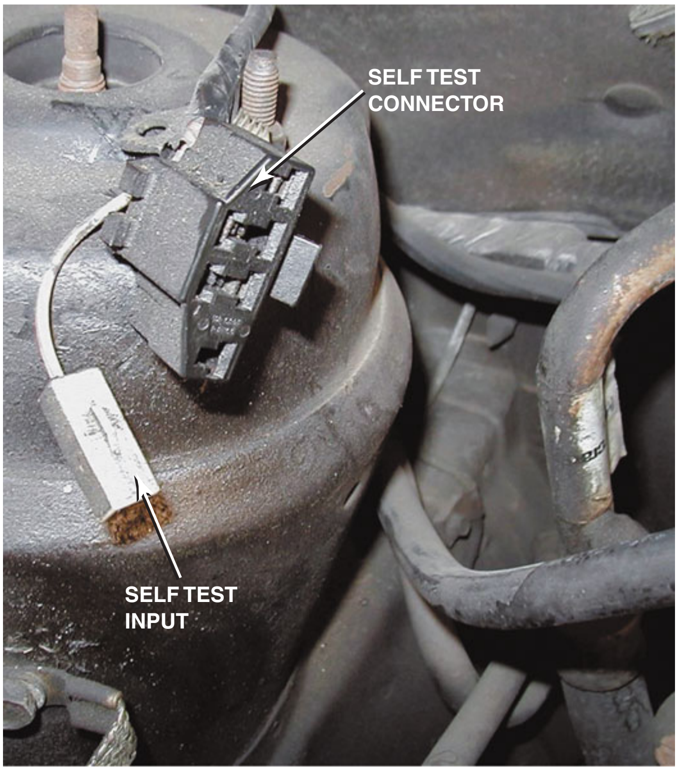


FIGURE 40–14 A Ford OBD-I self-test connector. The location of this connector can vary with model and year of vehicle.

TECH TIP

Put a Wire in the Attic and a Light in the Basement!

Retrieving DTCs from a Ford using low-cost test equipment is easier when you remember the following: "*Put a wire in the attic and a light in the basement.*"

After warming the engine to operating temperature, perform these simple steps:

1. Locate the data link connector (DLC) under the hood. Connect a jumper wire from the single-wire pigtail called the self-test input to terminal #2 at the top (attic) of the connector.
2. To read DTCs, connect a standard 12-volt test light (not a self-powered continuity light) to the positive battery terminal and the lower (basement) terminal (#4) of the DLC. ● **SEE FIGURE 40–15.** Turn the ignition to on (engine off). The DTCs will be displayed by means of the flashes of the test light.

To clear stored Ford DTCs, simply disconnect the jumper wire from the self-test input while the codes are being flashed. This interruption is the signal to the computer to clear any stored DTCs.

RETRIEVING FORD DIAGNOSTIC CODES

The best tool to use during troubleshooting of a Ford vehicle is a **self-test automatic readout (STAR)** tester, new generation STAR (NGS), WDS (Worldwide Diagnostic System), or another scan tool with Ford capabilities. If a STAR tester or scan tool is not available, a needle (analog) type of voltmeter can be used for all OBD-I (prior to 1996) systems. See the Tech Tip "Put a Wire in the Attic and a Light in the Basement!" to obtain flash codes. The test connector is usually located under the hood on the driver's side. ● **SEE FIGURE 40–14.**

KEY ON–ENGINE OFF TEST (ON-DEMAND CODES OR HARD FAULTS) With the ignition key on (engine off), watch the voltmeter pulses, which should appear within 5 to 30 seconds. (Ignore any initial surge of voltage when the ignition is turned on.)

The computer will send a two-digit code that will cause the voltmeter to pulse or move from left to right. For example, if the voltmeter needle pulses two times, then pauses for 2 seconds, and then pulses three times, the code is 23. There is normally a 4-second pause between codes.

SEPARATOR PULSE. After all the codes have been reported, the computer will pause for about 6 to 9 seconds, then cause the voltmeter needle to pulse once, and then pause for another 6 to 9 seconds. This is the normal separation between current trouble codes and continuous memory codes (for intermittent problems). Code 11 is the normal pass code, which means that no fault has been stored in memory. Therefore, normal operation of the diagnostic procedure using a voltmeter should indicate the following if no codes are set: 1 pulse (2-second pause), 1 pulse (6- to 9-second pause), 1 pulse (6- to 9-second pause), 1 pulse (2-second pause), and finally, 1 pulse. These last two pulses that are separated by a 2-second interval represent a code 11, which is the code used between current and intermittent trouble codes.

CONTINUOUS MEMORY CODES (SOFT CODES) Continuous memory codes are set based on information stored while the vehicle was in normal operation. These codes represent an intermittent problem and should only be used for diagnosis if the **KOEO** test results in code 11 (no faults detected). Therefore, any codes displayed after the separation pulse represent failures that have been detected but may no longer be present.

KEY ON–ENGINE RUNNING (KOER) TEST During the **KOER** self-test, the sensors are checked by the computer under actual operating conditions and the output devices (actuators) are operated and checked for expected results. Start the engine and raise the speed to 2500 to 3000 RPM to warm the oxygen sensor within 20 seconds of starting. Hold a steady high engine

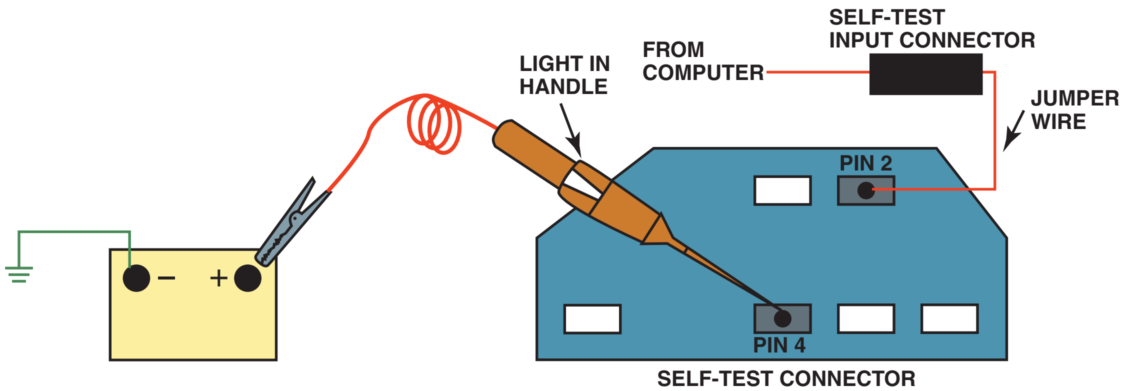


FIGURE 40–15 To retrieve Ford DTCs using a test light and a jumper wire, turn the ignition switch on (engine off) and make the connections shown. The test light will blink out the diagnostic trouble codes.

speed until the initial pulses appear (2 pulses for a four-cylinder engine, 3 pulses for a six-cylinder, and 4 pulses for an eight-cylinder). These codes are used to verify the proper processor (computer) is in the vehicle and that the self-test has been entered. Continue to hold a high engine speed until the code pulses begin (10 to 14 seconds).

STEERING, BRAKE, AND OVERDRIVE SWITCH TEST

To test the power steering pressure switch, the technician must turn the steering wheel one-half turn after the ID code has been displayed. The brake pedal and the overdrive cancel switch must also be cycled after the ID code to allow the system to detect a change of state of these switches.

DYNAMIC RESPONSE CHECK. The dynamic response test checks the throttle position (TP) mass air flow (MAF) and manifold absolute pressure (MAP) sensors during a brief wide-open throttle (WOT) test performed by the technician. The signal for the technician to depress the throttle briefly to wide open is a single pulse or a code 10 on a STAR tester.

If any hard (on-demand) faults appear, these should be repaired first and then any soft (continuous) codes next. Use the factory "pinpoint tests" to trace the problem. Refer to service information for a description of Ford-specific alphanumeric DTCs.

FLASH CODE RETRIEVAL ON CHRYSLER VEHICLES

To put the computer into the self-diagnostic mode, the ignition switch must be turned on and off three times within a 5-second period (on-off-on-off-on). The computer will flash a series of fault codes. Older Chrysler brand products flash the "check engine" lamp on the dash.

FIGURE 40–16 A typical OBD-II data link connector (DLC). The location varies with make and model and may even be covered, but a tool is not needed to gain access. Check service information for the exact location if needed.

NOTE: Unlike other manufacturers, most Chrysler brand vehicles equipped with OBD II will display the P-codes on the odometer display by cycling the ignition key as previously performed on older vehicles.

OBD-II DIAGNOSIS

Starting with the 1996 model year, all vehicles sold in the United States must use the same type of 16-pin data link connector (DLC) and must monitor emission-related components. ● **SEE FIGURE 40–16.**

RETRIEVING OBD-II CODES

A scan tool is required to retrieve diagnostic trouble codes from most OBD-II vehicles. Every OBD-II scan tool will be able to read all generic Society of Automotive Engineers (SAE) DTCs from any vehicle.

Fuel and Air Metering System

P0100 Mass or Volume Airflow Circuit Problem
P0101 Mass or Volume Airflow Circuit Range or Performance Problem
P0102 Mass or Volume Airflow Circuit Low Input
P0103 Mass or Volume Airflow Circuit High Input
P0105 Manifold Absolute Pressure or Barometric Pressure Circuit Problem
P0106 Manifold Absolute Pressure or Barometric Pressure Circuit Range or Performance Problem
P0107 Manifold Absolute Pressure or Barometric Pressure Circuit Low Input
P0108 Manifold Absolute Pressure or Barometric Pressure Circuit High Input
P0110 Intake Air Temperature Circuit Problem
P0111 Intake Air Temperature Circuit Range or Performance Problem
P0112 Intake Air Temperature Circuit Low Input
P0113 Intake Air Temperature Circuit High Input
P0115 Engine Coolant Temperature Circuit Problem
P0116 Engine Coolant Temperature Circuit Range or Performance Problem
P0117 Engine Coolant Temperature Circuit Low Input
P0118 Engine Coolant Temperature Circuit High Input
P0120 Throttle Position Circuit Problem
P0121 Throttle Position Circuit Range or Performance Problem
P0122 Throttle Position Circuit Low Input
P0123 Throttle Position Circuit High Input
P0125 Excessive Time to Enter Closed-Loop Fuel Control
P0128 Coolant Temperature Below Thermostat Regulating Temperature
P0130 O2 Sensor Circuit Problem (Bank 1* Sensor 1)
P0131 O2 Sensor Circuit Low Voltage (Bank 1* Sensor 1)
P0132 O2 Sensor Circuit High Voltage (Bank 1* Sensor 1)
P0133 O2 Sensor Circuit Slow Response (Bank 1* Sensor 1)
P0134 O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 1)
P0135 O2 Sensor Heater Circuit Problem (Bank 1* Sensor 1)
P0136 O2 Sensor Circuit Problem (Bank 1* Sensor 2)
P0137 O2 Sensor Circuit Low Voltage (Bank 1* Sensor 2)
P0138 O2 Sensor Circuit High Voltage (Bank 1* Sensor 2)
P0139 O2 Sensor Circuit Slow Response (Bank 1* Sensor 2)
P0140 O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 2)
P0141 O2 Sensor Heater Circuit Problem (Bank 1* Sensor 2)
P0142 O2 Sensor Circuit Problem (Bank 1* Sensor 3)
P0143 O2 Sensor Circuit Low Voltage (Bank 1* Sensor 3)
P0144 O2 Sensor Circuit High Voltage (Bank 1* Sensor 3)
P0145 O2 Sensor Circuit Slow Response (Bank 1* Sensor 3)
P0146 O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 3)
P0147 O2 Sensor Heater Circuit Problem (Bank 1* Sensor 3)
P0150 O2 Sensor Circuit Problem (Bank 2 Sensor 1)
P0151 O2 Sensor Circuit Low Voltage (Bank 2 Sensor 1)
P0152 O2 Sensor Circuit High Voltage (Bank 2 Sensor 1)
P0153 O2 Sensor Circuit Slow Response (Bank 2 Sensor 1)
P0154 O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 1)
P0155 O2 Sensor Heater Circuit Problem (Bank 2 Sensor 1)
P0156 O2 Sensor Circuit Problem (Bank 2 Sensor 2)
P0157 O2 Sensor Circuit Low Voltage (Bank 2 Sensor 2)
P0158 O2 Sensor Circuit High Voltage (Bank 2 Sensor 2)
P0159 O2 Sensor Circuit Slow Response (Bank 2 Sensor 2)
P0160 O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 2)
P0161 O2 Sensor Heater Circuit Problem (Bank 2 Sensor 2)
P0162 O2 Sensor Circuit Problem (Bank 2 Sensor 3)
P0163 O2 Sensor Circuit Low Voltage (Bank 2 Sensor 3)
P0164 O2 Sensor Circuit High Voltage (Bank 2 Sensor 3)
P0165 O2 Sensor Circuit Slow Response (Bank 2 Sensor 3)
P0166 O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 3)
P0167 O2 Sensor Heater Circuit Problem (Bank 2 Sensor 3)
P0170 Fuel Trim Problem (Bank 1*)
P0171 System Too Lean (Bank 1*)
P0172 System Too Rich (Bank 1*)
P0173 Fuel Trim Problem (Bank 2)
P0174 System Too Lean (Bank 2)
P0175 System Too Rich (Bank 2)
P0176 Fuel Composition Sensor Circuit Problem
P0177 Fuel Composition Sensor Circuit Range or Performance
P0178 Fuel Composition Sensor Circuit Low Input
P0179 Fuel Composition Sensor Circuit High Input
P0180 Fuel Temperature Sensor Problem
P0181 Fuel Temperature Sensor Circuit Range or Performance
P0182 Fuel Temperature Sensor Circuit Low Input
P0183 Fuel Temperature Sensor Circuit High Input

Fuel and Air Metering (Injector Circuit)

P0201 Injector Circuit Problem—Cylinder 1
P0202 Injector Circuit Problem—Cylinder 2
P0203 Injector Circuit Problem—Cylinder 3
P0204 Injector Circuit Problem—Cylinder 4
P0205 Injector Circuit Problem—Cylinder 5
P0206 Injector Circuit Problem—Cylinder 6
P0207 Injector Circuit Problem—Cylinder 7
P0208 Injector Circuit Problem—Cylinder 8
P0209 Injector Circuit Problem—Cylinder 9
P0210 Injector Circuit Problem—Cylinder 10
P0211 Injector Circuit Problem—Cylinder 11
P0212 Injector Circuit Problem—Cylinder 12
P0213 Cold Start Injector 1 Problem
P0214 Cold Start Injector 2 Problem

Ignition System or Misfire

P0300 Random Misfire Detected
P0301 Cylinder 1 Misfire Detected
P0302 Cylinder 2 Misfire Detected
P0303 Cylinder 3 Misfire Detected
P0304 Cylinder 4 Misfire Detected
P0305 Cylinder 5 Misfire Detected
P0306 Cylinder 6 Misfire Detected

P0307 Cylinder 7 Misfire Detected
P0308 Cylinder 8 Misfire Detected
P0309 Cylinder 9 Misfire Detected
P0310 Cylinder 10 Misfire Detected
P0311 Cylinder 11 Misfire Detected
P0312 Cylinder 12 Misfire Detected
P0320 Ignition or Distributor Engine Speed Input Circuit Problem
P0321 Ignition or Distributor Engine Speed Input Circuit Range or Performance
P0322 Ignition or Distributor Engine Speed Input Circuit No Signal
P0325 Knock Sensor 1 Circuit Problem
P0326 Knock Sensor 1 Circuit Range or Performance
P0327 Knock Sensor 1 Circuit Low Input
P0328 Knock Sensor 1 Circuit High Input
P0330 Knock Sensor 2 Circuit Problem
P0331 Knock Sensor 2 Circuit Range or Performance
P0332 Knock Sensor 2 Circuit Low Input
P0333 Knock Sensor 2 Circuit High Input
P0335 Crankshaft Position Sensor Circuit Problem
P0336 Crankshaft Position Sensor Circuit Range or Performance
P0337 Crankshaft Position Sensor Circuit Low Input
P0338 Crankshaft Position Sensor Circuit High Input

Auxiliary Emission Controls

P0400 Exhaust Gas Recirculation Flow Problem
P0401 Exhaust Gas Recirculation Flow Insufficient Detected
P0402 Exhaust Gas Recirculation Flow Excessive Detected
P0405 Air Conditioner Refrigerant Charge Loss
P0410 Secondary Air Injection System Problem
P0411 Secondary Air Injection System Insufficient Flow Detected
P0412 Secondary Air Injection System Switching Valve or Circuit Problem
P0413 Secondary Air Injection System Switching Valve or Circuit Open
P0414 Secondary Air Injection System Switching Valve or Circuit Shorted
P0420 Catalyst System Efficiency below Threshold (Bank 1*)
P0421 Warm Up Catalyst Efficiency below Threshold (Bank 1*)
P0422 Main Catalyst Efficiency below Threshold (Bank 1*)
P0423 Heated Catalyst Efficiency below Threshold (Bank 1*)
P0424 Heated Catalyst Temperature below Threshold (Bank 1*)
P0430 Catalyst System Efficiency below Threshold (Bank 2)
P0431 Warm Up Catalyst Efficiency below Threshold (Bank 2)
P0432 Main Catalyst Efficiency below Threshold (Bank 2)
P0433 Heated Catalyst Efficiency below Threshold (Bank 2)
P0434 Heated Catalyst Temperature below Threshold (Bank 2)
P0440 Evaporative Emission Control System Problem
P0441 Evaporative Emission Control System Insufficient Purge Flow
P0442 Evaporative Emission Control System Leak Detected
P0443 Evaporative Emission Control System Purge Control Valve Circuit Problem
P0444 Evaporative Emission Control System Purge Control Valve Circuit Open
P0445 Evaporative Emission Control System Purge Control Valve Circuit Shorted
P0446 Evaporative Emission Control System Vent Control Problem
P0447 Evaporative Emission Control System Vent Control Open
P0448 Evaporative Emission Control System Vent Control Shorted
P0450 Evaporative Emission Control System Pressure Sensor Problem
P0451 Evaporative Emission Control System Pressure Sensor Range or Performance
P0452 Evaporative Emission Control System Pressure Sensor Low Input
P0453 Evaporative Emission Control System Pressure Sensor High Input

Vehicle Speed Control and Idle Control

P0500 Vehicle Speed Sensor Problem
P0501 Vehicle Speed Sensor Range or Performance
P0502 Vehicle Speed Sensor Low Input
P0505 Idle Control System Problem
P0506 Idle Control System RPM Lower Than Expected
P0507 Idle Control System RPM Higher Than Expected
P0510 Closed Throttle Position Switch Problem

Computer Output Circuit

P0600 Serial Communication Link Problem
P0605 Internal Control Module (Module Identification Defined by J1979)

Transmission

P0703 Brake Switch Input Problem
P0705 Transmission Range Sensor Circuit Problem (PRNDL Input)
P0706 Transmission Range Sensor Circuit Range or Performance
P0707 Transmission Range Sensor Circuit Low Input
P0708 Transmission Range Sensor Circuit High Input
P0710 Transmission Fluid Temperature Sensor Problem
P0711 Transmission Fluid Temperature Sensor Range or Performance
P0712 Transmission Fluid Temperature Sensor Low Input
P0713 Transmission Fluid Temperature Sensor High Input
P0715 Input or Turbine Speed Sensor Circuit Problem
P0716 Input or Turbine Speed Sensor Circuit Range or Performance
P0717 Input or Turbine Speed Sensor Circuit No Signal
P0720 Output Speed Sensor Circuit Problem
P0721 Output Speed Sensor Circuit Range or Performance
P0722 Output Speed Sensor Circuit No Signal
P0725 Engine Speed Input Circuit Problem
P0726 Engine Speed Input Circuit Range or Performance

(*continued*)

P0727	Engine Speed Input Circuit No Signal
P0730	Incorrect Gear Ratio
P0731	Gear 1 Incorrect Ratio
P0732	Gear 2 Incorrect Ratio
P0733	Gear 3 Incorrect Ratio
P0734	Gear 4 Incorrect Ratio
P0735	Gear 5 Incorrect Ratio
P0736	Reverse Incorrect Ratio
P0740	Torque Converter Clutch System Problem
P0741	Torque Converter Clutch System Performance or Stuck Off
P0742	Torque Converter Clutch System Stuck On
P0743	Torque Converter Clutch System Electrical
P0745	Pressure Control Solenoid Problem
P0746	Pressure Control Solenoid Performance or Stuck Off
P0747	Pressure Control Solenoid Stuck On
P0748	Pressure Control Solenoid Electrical
P0750	Shift Solenoid A Problem
P0751	Shift Solenoid A Performance or Stuck Off
P0752	Shift Solenoid A Stuck On
P0753	Shift Solenoid A Electrical
P0755	Shift Solenoid B Problem
P0756	Shift Solenoid B Performance or Stuck Off
P0757	Shift Solenoid B Stuck On
P0758	Shift Solenoid B Electrical
P0760	Shift Solenoid C Problem
P0761	Shift Solenoid C Performance or Stuck Off
P0762	Shift Solenoid C Stuck On
P0763	Shift Solenoid C Electrical
P0765	Shift Solenoid D Problem
P0766	Shift Solenoid D Performance or Stuck Off
P0767	Shift Solenoid D Stuck On
P0768	Shift Solenoid D Electrical
P0770	Shift Solenoid E Problem
P0771	Shift Solenoid E Performance or Stuck Off
P0772	Shift Solenoid E Stuck On
P0773	Shift Solenoid E Electrical

* The side of the engine where number one cylinder is located.

OBD-II ACTIVE TESTS

The vehicle computer must run tests on the various emission-related components and turn on the malfunction indicator lamp (MIL) if faults are detected. OBD II is an *active* computer analysis system because it actually tests the operation of the oxygen sensors, exhaust gas recirculation system, and so forth whenever conditions permit. It is the purpose and function of the Powertrain Control Module (PCM) to monitor these components and perform these active tests.

For example, the PCM may open the EGR valve momentarily to check its operation while the vehicle is decelerating. A change in the manifold absolute pressure (MAP) sensor signal will indicate to the computer that the exhaust gas is, in fact, being introduced into the engine. Because these tests are active and certain conditions must be present before these tests can be run, the computer uses its internal diagnostic program to keep track of all the various conditions and to schedule active tests so that they will not interfere with each other.

OBD-II DRIVE CYCLE The vehicle must be driven under a variety of operating conditions for all active tests to be performed. A **trip** is defined as an engine-operating drive cycle that contains the necessary conditions for a particular test to be performed. For example, for the EGR test to be performed, the engine has to be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

TYPES OF OBD-II CODES Not all OBD-II diagnostic trouble codes are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer will only turn on the MIL for emissions-related DTCs.

TYPE A CODES. A type A diagnostic trouble code is emission related and will cause the MIL to be turned on at the *first trip* if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, would cause a type A diagnostic trouble code. These codes alert the driver to an emissions problem that may cause damage to the catalytic converter.

TYPE B CODES. A type B code will be stored as a pending code in the PCM and the MIL will be turned on only after the second consecutive trip, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and Type B codes are emission related and will cause the lighting of the malfunction indicator lamp, usually labeled "check engine" or "service engine soon."

TYPE C AND D CODES. Type C and type D codes are for use with non-emission-related diagnostic tests. They will cause the lighting of a "service" lamp (if the vehicle is so equipped).

OBD-II FREEZE-FRAME To assist the service technician, OBD II requires the computer to take a "snapshot" or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data. CARB and EPA regulations require that the controller store specific freeze-frame (engine-related) data when the first emission related fault is detected. The data stored in freeze-frame can only be replaced by data from a trouble code with a higher priority such as a trouble related to a fuel system or misfire monitor fault.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving enhanced data usually requires the use of an enhanced or factory level scan tool.

The freeze-frame has to contain data values that occurred at the time the code was set (these values are provided in standard units of measurement). Freeze-frame data is recorded during the first trip on a two-trip fault. As a result, OBD-II systems record the data present at the time an emission-related code is recorded and the MIL activated. This data can be accessed and displayed on a scan tool. Freeze-frame data is one frame or one instant in time. Freeze-frame data is not updated (refreshed) if the same monitor test fails a second time.

REQUIRED FREEZE-FRAME DATA ITEMS.

- Code that triggered the freeze-frame
- A/F ratio, airflow rate, and calculated engine load
- Base fuel injector pulse width
- ECT, IAT, MAF, MAP, TP, and VS sensor data
- Engine speed and amount of ignition spark advance
- Open- or closed-loop status
- Short-term and long-term fuel trim values
- For misfire codes—identify the cylinder that misfired

NOTE: All freeze-frame data will be lost if the battery is disconnected, power to the PCM is removed, or the scan tool is used to erase or clear trouble codes.

DIAGNOSING INTERMITTENT MALFUNCTIONS Of all the different types of conditions that you will see, the hardest to accurately diagnose and repair are intermittent malfunctions. These conditions may be temperature related (only occur when the vehicle is hot or cold), or humidity related (only occur when it is raining). Regardless of the conditions that will cause the malfunction to occur, you must diagnose and correct the condition.

When dealing with an intermittent concern, you should determine the conditions when the malfunction occurs, and then try to duplicate those conditions. If a cause is not readily apparent to you, ask the customer when the symptom occurs. Ask if there are any conditions that seem to be related to, or cause the concern.

Another consideration when working on an OBD-II-equipped vehicle is whether a concern is intermittent, or if it only occurs when a specific diagnostic test is performed by the PCM. Since OBD-II systems conduct diagnostic tests only under very precise conditions, some tests may only be run once during an ignition cycle. Additionally, if the requirements needed to perform the test are not met, the test will not run during an ignition cycle. This type of onboard diagnostics could be mistaken as "intermittent" when, in fact, the tests are only infrequent (depending on how the vehicle is driven). Examples of this type of diagnostic test are HO_2S heaters, evaporative canister purge, catalyst efficiency, and EGR flow. When diagnosing intermittent concerns on an OBD-II-equipped vehicle, a logical diagnostic strategy is essential. The use of stored freeze-frame information can also be very useful when diagnosing an intermittent malfunction if a code has been stored.

SERVICE/FLASH PROGRAMMING

Designing a program that allows an engine to meet strict air quality and fuel economy standards while providing excellent performance is no small feat. However, this is only part of the challenge facing engineers assigned with the task of developing OBD-II software. The reason for this is the countless variables involved with running the diagnostic monitors. Although programmers do their best to factor in any and all operating conditions when writing this complex code, periodic revisions are often required.

Reprogramming consists of downloading new calibration files from a scan tool, personal computer, or modem into the PCM's electronically erasable programmable read-only memory (EEPROM). This can be done on or off the vehicle using the appropriate equipment. Since reprogramming is not an OBD-II requirement however, many vehicles will need a new PCM in the event software changes become necessary. Physically removing and replacing the PROM chip is no longer possible.

The following are three industry-standard methods used to reprogram the EEPROM:

- Remote programming
- Direct programming
- Off-board programming

REMOTE PROGRAMMING. Remote programming uses the scan tool to transfer data from the manufacturer's shop PC to the vehicle's PCM. This is accomplished by performing the following steps:

- Connect the scan tool to the vehicle's DLC. ● **SEE FIGURE 40–17.**
- Enter the vehicle information into the scan tool through the programming application software incorporated in the scan tool. ● **SEE FIGURE 40–18.**
- Download VIN and current EEPROM calibration using a scan tool.
- Disconnect the scan tool from the DLC and connect the tool to the shop PC.
- Download the new calibration from the PC to the scan tool. ● **SEE FIGURE 40–19.**
- Reconnect the scan tool to the vehicle's DLC and download the new calibration into the PCM.

CAUTION: Before programming, the vehicle's battery must be between 11 and 14 volts. Do not attempt to program while charging the battery unless using a special battery charger which does not produce excessive ripple voltage such as the Midtronics PSC-300 (30 amp) or PSC-550 (55 amp) or similar as specified by the vehicle manufacturer.

FIGURE 40–17 The first step in the reprogramming procedure is to determine the current software installed using a scan tool. Not all scan tools can be used. In most cases using the factory scan tool is needed for reprogramming unless the scan tool is equipped to handle reprogramming.

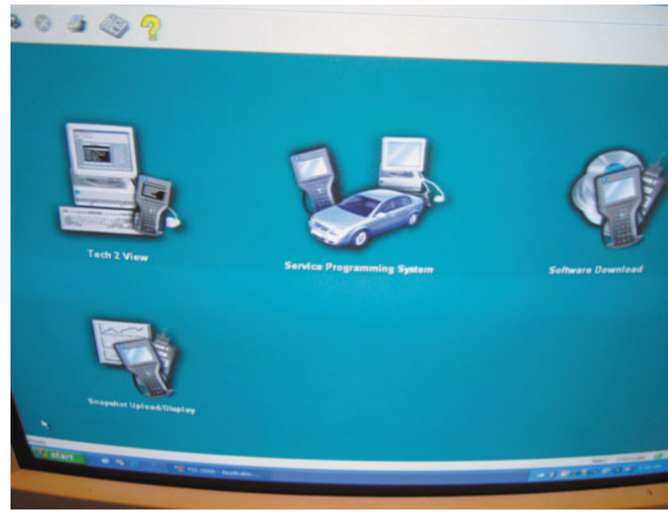


FIGURE 40–19 An Internet connection is usually needed to perform updates although some vehicle manufacturers use CDs which are updated regularly at a cost to the shop.

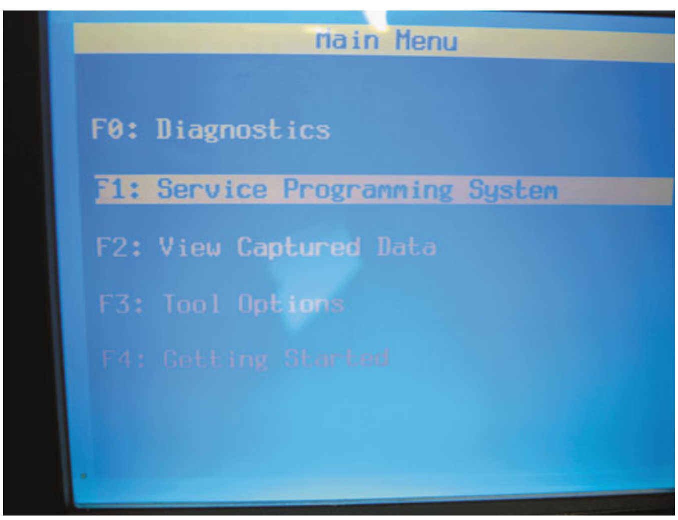


FIGURE 40–18 Follow the on-screen instructions.

FIGURE 40–20 Connecting cables and a computer to perform off-board programming.

DIRECT PROGRAMMING. Direct programming does utilize a connection between the shop PC and the vehicle DLC.

OFF-BOARD PROGRAMMING. Off-board programming is used if the PCM must be programmed away from the vehicle. This is preformed using the off-board programming adapter. ● **SEE FIGURE 40–20.**

J2534 REPROGRAMMING

Legislation has mandated that vehicle manufacturers meet the SAE J2534 standards for all emissions-related systems on all new vehicles starting with model year 2004. This standard enables independent service repair operators to program or reprogram emissions-related ECMs from a wide variety of vehicle manufacturers with a single tool. ● **SEE FIGURE 40–21.** A J2534 compliant pass-through system is a standardized programming and diagnostic system. It uses a personal computer (PC) plus a standard interface to a software device driver, and a hardware vehicle communication interface. The interface connects to a PC, and to a programmable ECM on a vehicle through the J1962 data link connector (DLC). This system allows programming of all vehicle manufacturer ECMs using a single set of programming hardware. Programming software made available by the vehicle manufacturer must be functional with a J2534 compliant pass-through system.

The software for a typical pass-through application consists of two major components including:

- The part delivered by the company that furnishes the hardware for J2534 enables the pass-through vehicle communication interface to communicate with the PC and provides

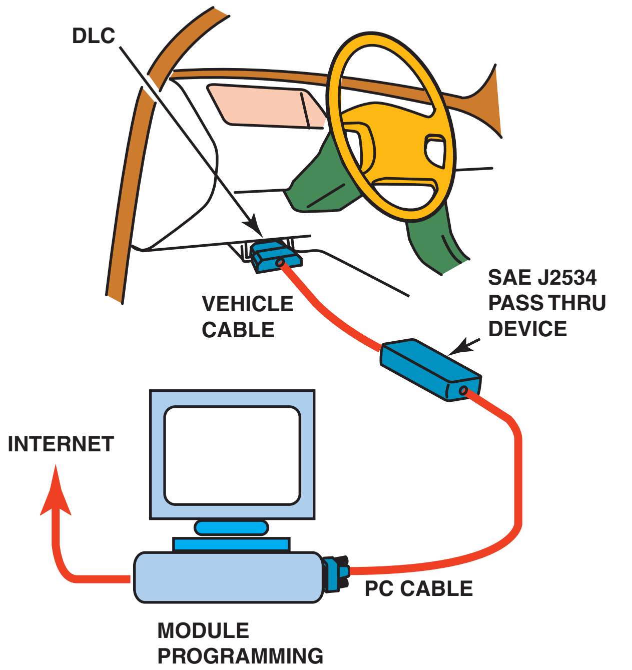


FIGURE 40–21 The J2534 pass-through reprogramming system does not need a scan tool to reflash the PCM on most 2004 and newer vehicles.

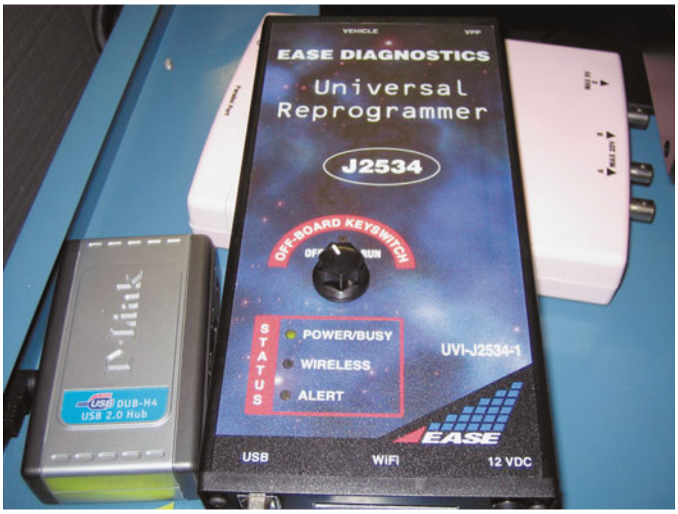


FIGURE 40–22 A typical J2534 universal reprogrammer that uses the J2534 standards.

for all Vehicle Communication Protocols as required by SAE J2534. It also provides for the software interface to work with the software applications as provided for by the vehicle manufacturers. ● **SEE FIGURE 40–22.**

- The second part of the pass-through enabling software is provided for by the vehicle manufacturers. This is normally a subset of the software used with their original equipment manufacturer (OEM) tools and their website will indicate how to obtain this software and under what conditions it can be used. Refer to the National Automotive Service Task Force (NASTF) website for the addresses for all vehicle manufacturers' service information and cost, *www.NASTF.org.*

Since the majority of vehicle manufacturers make this software available in downloadable form, having an Internet browser (Explorer/Netscape) and connection is a must.

MANUFACTURER'S DIAGNOSTIC ROUTINES

Each vehicle manufacturer has established their own diagnostic routines and they should be followed. Most include the following steps:

STEP 1 Retrieve diagnostic trouble codes.

STEP 2 Check for all technical service bulletins that could be related to the stored DTC.

STEP 3 If there are multiple DTCs, the diagnostic routine may include checking different components or systems instead of when only one DTC was stored.

STEP 4 Perform system checks.

STEP 5 Perform the necessary service or repair

STEP 6 Perform a road test matching the parameters recorded in the freeze-frame to check that the repair has corrected the malfunction.

STEP 7 Repeat the road test to cause the MIL to be extinguished.

NOTE: Do not clear codes (DTCs) unless instructed by the service information.

Following the vehicle manufacturer's specific diagnostic routines will ensure that the root cause is found and the repair verified. This is important for customer satisfaction.

COMPLETING SYSTEM REPAIRS

After the repair has been successfully completed, the vehicle should be driven under similar conditions that caused the original concern. Verify that the problem has been corrected. To perform this test drive, it is helpful to have a copy of the freeze-frame parameters that were present when the DTC was set. By driving under similar conditions, the PCM may perform a test of the system and automatically extinguish the MIL. This is the method preferred by most vehicle manufacturers. The DTC can be cleared using a scan tool, but then that means that monitors will have to be run and the vehicle may fail an emission inspection if driven directly to the testing station.

TECH TIP

The Brake Pedal Trick

If the vehicle manufacturer recommends that battery power be disconnected, first disconnect the negative battery cable and then depress the brake pedal. Because the brake lights are connected to battery power, depressing the brake pedal causes all of the capacitors in the electrical system and computer(s) to discharge through the brake lights.

TECH TIP

Drive the Light Out

If working on a vehicle that is subject to state emission testing, it is best to not clear codes. When diagnostic trouble codes are cleared, all of the monitors have to be rerun and this can be a time consuming job. Instead of clearing the code, simply drive the vehicle until the PCM clears the code. This will likely take less time compared to trying to drive the vehicle under varying conditions to run all of the monitors.

PROCEDURES FOR RESETTING THE PCM

The PCM can be reset or cleared of previously set DTCs and freeze-frame data in the following ways:

1. **Driving the Vehicle.** Drive the vehicle under similar conditions that were present when the fault occurred. If the conditions are similar and the PCM performed the noncontinuous monitor test and it passed three times, then the PCM will extinguish the MIL. This is the method preferred by most vehicle manufacturers, however, this method could be time consuming. If three passes cannot be achieved, the owner of the vehicle will have to be told that even though the check engine light (MIL) is on, the problem has been corrected and the MIL should go out in a few days of normal driving.
2. **Clear DTCs Using a Scan Tool.** A scan tool can be used to clear the diagnostic trouble code (DTC), which will also delete all of the freeze-frame data. The advantage of using a scan tool is that the check engine (MIL) will be out and the customer will be happy that the problem (MIL on) has been corrected. Do not use a scan tool to clear a DTC if the vehicle is going to be checked soon at a test station for state-mandated emission tests.
3. **Battery Disconnect.** Disconnecting the negative battery cable will clear the DTCs and freeze-frame on many vehicles but not all. Besides clearing the DTCs, disconnecting the battery for about 20 minutes will also erase radio station presets and other memory items in many cases. Most vehicle manufacturers do not recommend that the battery be disconnected to clear DTCs and it may not work on some vehicles.

ROAD TEST (DRIVE CYCLE)

Use the freeze-frame data and test-drive the vehicle so that the vehicle is driven to match the conditions displayed on the freeze-frame. If the battery has been disconnected, then the vehicle may have to be driven under conditions that allow the PCM to conduct monitor tests. This drive pattern is called a **drive cycle.** The drive cycle is different for each vehicle manufacturer but a universal drive cycle may work in many cases. In many cases performing a universal drive cycle will reset most monitors in most vehicles.

UNIVERSAL DRIVE CYCLE

PRECONDITIONING: Phase 1.

MIL must be off.

No DTCs present.

Fuel fill between 15% and 85%.

Cold start—Preferred = 8-hour soak at 68°F to 86°F.

Alternative = ECT below 86°F.

1. With the ignition off, connect scan tool.
2. Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
3. Stop and idle for 40 seconds, gradually accelerate to 55 mph.
4. Maintain 55 mph for 4 minutes using a steady throttle input.
5. Stop and idle for 30 seconds, then accelerate to 30 mph.
6. Maintain 30 mph for 12 minutes.
7. Repeat steps 4 and 5 four times.

Using scan tool, check readiness. If insufficient readiness set, continue to universal drive trace phase II.

Important: (Do not shut off engine between phases).

Phase II:

1. Vehicle at a stop and idle for 45 seconds, then accelerate to 30 mph.
2. Maintain 30 mph for 22 minutes.
3. Repeat steps 1 and 2 three times.
4. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 35 mph.
5. Maintain speed between 30 and 35 mph for 4 minutes.
6. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 30 mph.
7. Maintain 30 mph for 22 minutes.
8. Repeat steps 6 and 7 five times.
9. Using scan tool, check readiness.

SUMMARY

1. Funnel diagnostics—Visual approach to a diagnostic procedure:
   Step 1 Verify the problem (concern)
   Step 2 Perform a thorough visual inspection and basic tests
   Step 3 Retrieve the diagnostic trouble codes (DTCs)
   Step 4 Check for technical service bulletins (TSBs)
   Step 5 Look carefully at scan tool data
   Step 6 Narrow the problem to a system or cylinder
   Step 7 Repair the problem and determine the root cause
   Step 8 Verify the repair and check for any stored DTCs
2. A thorough visual inspection is important during the diagnosis and troubleshooting of any engine performance problem or electrical malfunction.
3. If the MIL is on, retrieve the DTC and follow the manufacturer's recommended procedure to find the root cause of the problem.
4. OBD-II vehicles use a 16-pin DLC and common DTCs.

REVIEW QUESTIONS

1. Explain the procedure to follow when diagnosing a vehicle with stored DTCs using a scan tool.
2. Discuss what the PCM does during a drive cycle to test emission-related components.
3. Explain the difference between a type A and type B OBD-II diagnostic trouble code.
4. List three things that should be checked as part of a thorough visual inspection.
5. List the eight-step funnel diagnostic procedure.
6. Explain why a bulletin search should be performed after stored DTCs are retrieved.
7. List the three methods that can be used to reprogram a PCM.

CHAPTER QUIZ

1. Technician A says that the first step in the diagnostic process is to verify the problem (concern). Technician B says the second step is to perform a thorough visual inspection. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Which item is *not* important to know before starting the diagnosis of an engine performance problem?
   a. List of previous repairs
   b. The brand of engine oil used
   c. The type of gasoline used
   d. The temperature of the engine when the problem occurs
3. A paper test can be used to check for a possible problem with ______________.
   a. The ignition system (bad spark plug wire)
   b. A faulty injector on a multiport engine
   c. A burned valve
   d. All of the above
4. Which step should be performed *last* when diagnosing an engine performance problem?
   a. Checking for any stored diagnostic trouble codes
   b. Checking for any technical service bulletins (TSBs)
   c. Performing a thorough visual inspection
   d. Verify the repair
5. Technician A says that if the opposite DTC can be set, the problem is the component itself. Technician B says if the opposite DTC cannot be set, the problem is with the wiring or grounds. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. The preferred method to clear diagnostic trouble codes (DTCs) is to ______________.
   a. Disconnect the negative battery cable for 10 seconds
   b. Use a scan tool
   c. Remove the computer (PCM) power feed fuse
   d. Cycle the ignition key on and off 40 times
7. Which is the factory scan tool for Chrysler brand vehicles equipped with CAN?
   a. Star Scan
   b. Tech 2
   c. NGS
   d. Master Tech
8. Technician A says that reprogramming a PCM using the J2534 system requires a factory scan tool. Technician B says that reprogramming a PCM using the J2534 system requires Internet access. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Technician A says that knowing if there are any stored diagnostic trouble codes (DTCs) may be helpful when checking for related technical service bulletins (TSBs). Technician B says that only a factory scan tool should be used to retrieve DTCs. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Which method can be used to reprogram a PCM?
   a. Remote
   b. Direct
   c. Off-board
   d. All of the above

chapter 41

HYBRID SAFETY AND SERVICE PROCEDURES

OBJECTIVES: After studying Chapter 41, the reader will be able to: • Safely de-power a hybrid electric vehicle. • Safely perform high-voltage disconnects. • Understand the unique service issues related to HEV high-voltage systems. • Correctly use appropriate personal protective equipment (PPE). • Perform routine vehicle service procedure on a hybrid electric vehicle. • Explain hazards while driving, moving, and hoisting a hybrid electric vehicle.

KEY TERMS: ANSI 602 • ASTM 602 • CAT III 603 • DMM 603 • Floating ground 605 • HV 602 • HV cables 602 • IEC 603 • Lineman's gloves 602 • NiMH 608 • OSHA 602 • Service plug 606

HIGH-VOLTAGE SAFETY

NEED FOR CAUTION There have been electrical systems on vehicles for over 100 years. Technicians have been repairing vehicle electrical systems without fear of serious injury or electrocution. However, when working with hybrid electric vehicles, this is no longer true. It is now possible to be seriously injured or electrocuted (killed) if proper safety procedures are not followed.

Hybrid electric vehicles and all electric vehicles use **high-voltage (HV)** circuits that if touched with an unprotected hand could cause serious burns or even death.

IDENTIFYING HIGH-VOLTAGE CIRCUITS **High-voltage cables** are identified by color of the plastic conduit and include:

- **Blue or yellow.** 42 volts (not a shock hazard but an arc will be maintained if a circuit is opened)
- **Orange.** 144 to 600 volts or higher

WARNING

Touching circuits or wires containing high voltage can cause severe burns or death.

HIGH-VOLTAGE SAFETY EQUIPMENT

RUBBER GLOVES Before working on the high-voltage system of a hybrid electric vehicle, be sure that high-voltage **lineman's gloves** are available. Be sure that the gloves are rated at least 1,000 volts and class "0" by ANSI/ASTM. The **American National Standards Institute (ANSI)** is a private, nonprofit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system. ASTM International, originally known as the **American Society for Testing and Materials (ASTM)**, was formed over a century ago, to address the need for component testing in industry. The **Occupational Safety and Health Administration (OSHA)** requirements specify that the HV gloves get inspected every six months by a qualified glove inspection laboratory. Use an outer leather glove to protect the HV rubber gloves. Inspect the gloves carefully before each use. High voltage and current (amperes) in combination is fatal. ● **SEE FIGURES 41–1 AND 41–2**.

NOTE: The high-voltage insulated safety gloves must be recertified every six months to remain within Occupational Safety and Health Administration (OSHA) guidelines.

Before using the rubber gloves, they should be tested for leaks using the following procedure:

1. Roll the glove up from the open end until the lower portion of the glove begins to balloon from the resulting air pressure. Be sure to "lean" into the sealed glove to raise the

FIGURE 41–1 Rubber lineman's gloves protect the wearer from a shock hazard.

FIGURE 41–2 Wearing leather gloves over the lineman's gloves helps protect the rubber gloves from damage.

> **WARNING**
>
> Cables and wiring are orange in color. High-voltage insulated safety gloves and a face shield must be worn when carrying out any diagnostics involving the high-voltage systems or components.

internal air pressure. If the glove leaks any air, discard the gloves. ● **SEE FIGURE 41–3**.

2. The gloves should not be used if they show any signs of wear and tear.

CAT III-RATED DIGITAL MULTIMETER Hybrid electric vehicles are equipped with electrical systems whose voltages can exceed 600 volts DC. A CAT III-certified **digital multimeter (DMM)** is required for making measurements on these high-voltage systems.

The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meter and meter leads. These categories are ratings for over-voltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category (CAT) rating, the greater the protection to the technician when measuring high-energy voltage. Under each category there are various voltage ratings.

FIGURE 41–3 Checking rubber lineman's gloves for pinhole leaks.

CAT I Typically a CAT I meter is used for low-voltage measurements, such as voltage measurements at wall outlets in the home. Meters with a CAT I rating are usually rated at 300 to 800 volts. CAT I is for relatively low-energy levels, and while the voltage level to be high enough for use when working on a hybrid electric vehicle, the protective energy level is lower than what is needed.

CAT II A higher-rated meter that would be typically used for checking voltages at the circuit-breaker panel in the home. Meters with a CAT II rating are usually rated at 300 to 600 volts. CAT II rated meters have similar voltage ratings as the other CAT ratings, but the energy level of protection is higher with a CAT II compared to a CAT I.

CAT III **CAT III** is the minimum-rated meter that should be used for hybrid vehicles. Meters with a CAT III rating are usually rated at 600 to 1,000 volts and the highest energy level which is needed to protect the service technician.

CAT IV CAT IV meters are for clamp-on meters only. A clamp-on meter is used to measure current (amperes) in a circuit by placing the clamp around the wire carrying the current. If a clamp-on meter also has meter leads for voltage measurements, that part of the meter will be rated as CAT III.

INSULATION TESTER An electrical insulation tester, such as the Fluke 1587, is used to test for electrical continuity between the high-voltage wires or components and the body of the vehicle. If a hybrid electric vehicle has been involved in any type of collision or any other incident where damage could occur to the insulation, the high-voltage system should be checked. An insulation tester is more expensive than a digital meter. This means that an individual service technician often

FIGURE 41–4 Be sure to only use a meter that is CAT III-rated when taking electrical voltage measurements on a hybrid electric or electric vehicle.

? FREQUENTLY ASKED QUESTION

Is It the Voltage Rating that Determines the CAT Rating?

Yes and no. The voltages stated for the various CAT ratings are important but the potential harm to a technician due to the energy level is what is most important. For example some CAT II rated meters may have a stated voltage higher than a meter that has a CAT III rating. Always use a meter that has a CAT III rating when working on a hybrid electric vehicle. ● **SEE FIGURES 41–4 AND 41–5**.

does not purchase one, but any technician or service shop that works on hybrid electric vehicles should have one available.

EYE PROTECTION Eye protection should be worn when testing for high voltage, which is considered by many experts to be over 60 volts. Eye protection should include the following features:

1. Plastic frames (avoid metal frames as these are conductive and could cause a shock hazard)
2. Side shields
3. Meet the standard ANSI Z87.1

Most hybrid electric systems use voltages higher than this threshold. If the system has not been powered down or has not had the high-voltage system disabled, a shock hazard is always possible. Even when the high-voltage system has been disconnected, there is still high voltage in the HV battery box.

NOTE: Some vehicle manufactures specify that full face shields be worn instead of safety glasses when working with high voltage circuits or components.

FIGURE 41–5 The meter leads should also be CAT III-rated when checking voltages on a hybrid electric vehicle.

SAFETY CONES Ford requires that cones be placed at the four corners of any hybrid electric vehicle when service work on the high voltage system is being performed. They are used to establish a safety zone around the vehicles so that other technicians will know that a possible shock hazard may be present.

FIBERGLASS POLE Ford requires that a ten foot insulated fiberglass pool be available outside the safety zone to be used to pull a technician away from the vehicle in the unlikely event of an accident where the technician is shocked or electrocuted.

ELECTRIC SHOCK POTENTIAL

LOCATIONS WHERE SHOCKS CAN OCCUR Accidental and unprotected contact with any electrically charged ("hot" or "live") high-voltage component can cause serious injury or death. However, receiving an electric shock from a hybrid vehicle is highly unlikely because of the following:

1. Contact with the battery module or other components inside the battery box can occur only if the box is damaged and the contents are exposed, or the box is opened without following proper precautions.
2. Contact with the electric motor can occur only after one or more components are removed.
3. The high-voltage cables can be easily identified by their distinctive orange color, and contact with them can be avoided.
4. The system main relays (SMRs) disconnect power from the cables the moment the ignition is turned off.

LOCATIONS OF AUXILIARY BATTERIES ● **SEE CHART 41–1** for a summary of the locations of auxiliary batteries.

As a rule of thumb, the auxiliary battery is usually a flood-type if it is located under the hood and an AGM-type if it is in the trunk area.

HYBRID VEHICLE AUXILIARY BATTERY CHART		
VEHICLE	AUXILIARY BATTERY TYPE	AUXILIARY BATTERY LOCATION
Honda Insight Hybrid	Flooded lead acid	Underhood; center near bulkhead
Honda Civic Hybrid	Flooded lead acid	Underhood; driver's side
Honda Accord Hybrid	Flooded lead acid	Underhood; driver's side
Ford Escape Hybrid	Flooded lead acid	Underhood; driver's side
Toyota Prius Hybrid (2001–2003)	Absorbed glass mat (AGM)	Trunk; driver's side
Toyota Prius Hybrid (2004–2007)	Absorbed glass mat (AGM)	Trunk; passenger side
Toyota Highlander Hybrid	Flooded lead acid	Underhood; passenger side
Toyota Camry Hybrid	Absorbed glass mat (AGM)	Trunk; passenger side
Lexus RX 400h Hybrid	Flooded lead acid	Underhood; passenger side
Lexus GS 450h Hybrid	Absorbed glass mat (AGM)	Trunk; driver's side
Chevrolet/GMC Hybrid Pickup Truck	Flooded lead acid	Underhood; driver's side

CHART 41–1

As a rule of thumb, the auxiliary battery is usually a flood-type if it is located under the hood and an AGM-type if it is in the trunk area.

TECH TIP

Silence Is NOT Golden

Never assume the vehicle is shut off just because the engine is off. When working with a Toyota or Lexus hybrid electric vehicle, always look for the **READY** indicator status on the dash display. The vehicle is shut off when the **READY** indicator is off.

The vehicle may be powered by:

1. The electric motor only.
2. The gasoline engine only.
3. A combination of both the electric motor and the gasoline engine.

The vehicle computer determines the mode in which the vehicle operates to improve fuel economy and reduce emissions. The driver cannot manually select the mode. ● **SEE FIGURE 41–6**.

FIGURE 41–6 The Ford Escape Hybrid instrument panel showing the vehicle in park and the tachometer on "EV" instead of 0 RPM. This means that the gasoline engine could start at any time depending on the state-of-charge of the high-voltage batteries and other factors.

WARNING

Power remains in the high-voltage electrical system for up to 10 minutes after the HV battery pack is shut off. Never touch, cut, or open any orange high-voltage power cable or high-voltage component without confirming that the high-voltage has been completely discharged.

TECH TIP

High Voltage Is Insulated from the Vehicle Body

Both positive and negative high-voltage power cables are isolated from the metal chassis, so there is no possibility of shock by touching the metal chassis. This design is called a **floating ground**.

A ground fault monitor continuously monitors for high-voltage leakage to the metal chassis while the vehicle is running. If a malfunction is detected, the vehicle computer will illuminate the master warning light in the instrument cluster and the hybrid warning light in the LCD display. The HV battery pack relays will automatically open to stop electricity flow in a collision sufficient to activate the SRS airbags.

DE-POWERING THE HIGH-VOLTAGE SYSTEM

THE NEED TO DE-POWER THE HV SYSTEM During routine vehicle service work there is no need to go through any procedures needed to de-power or to shut off the high-voltage circuits. However, if work is going to be performed on any of the following components then service information procedures must be followed to prevent possible electrical shock and personal injury.

- The high-voltage (HV) battery pack
- Any of the electronic controllers that use orange cables such as the inverter and converters
- The air-conditioning compressor if electrically driven and has orange cables attached

To safely de-power the vehicle always follow the instructions found in service information for the exact vehicle being serviced. The steps usually include:

STEP 1 Turn the ignition off and remove the key (if equipped) from the ignition.

CAUTION: If a push-button start is used, remove the key fob at least 15 feet (5 meters) from the vehicle to prevent the vehicle from being powered up.

STEP 2 Remove the 12-volt power source to the HV controller. This step could involve:

- Removing a fuse or a relay
- Disconnecting the negative battery cable from the auxiliary 12-volt battery

STEP 3 Remove the high-voltage (HV) fuse or **service plug** or switch.

WARNING

Even if all of the above steps are followed, there is still a risk for electrical shock at the high-voltage batteries. Always follow the vehicle manufacturer's instructions exactly and wear high-voltage gloves and other specified personal protective equipment (PPE).

COLLISION AND REPAIR INDUSTRY ISSUES

JUMP STARTING The 12-volt auxiliary battery may be jump started if the vehicle does not start. The 12-volt auxiliary battery is located under the hood or in the cargo (trunk) area of

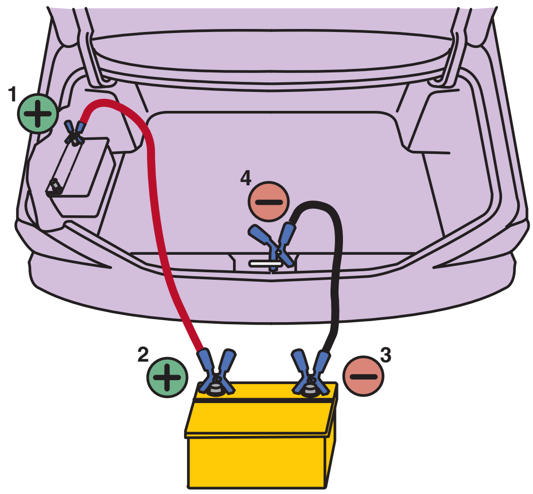


FIGURE 41–7 Jump starting a 2001–2003 Toyota Prius using a 12-volt supply to boost the 12-volt auxiliary battery in the trunk.

FIGURE 41–8 The underhood 12-volt jump-start terminal on this 2004+ Toyota Prius has a red plastic cover with a "+" sign. The positive booster cable clamp will attach directly to the vertical metal bracket.

some HEVs. Using a jump box or jumper cable from another vehicle, make the connections to the positive and negative battery terminals. ● **SEE FIGURE 41–7**.

On the 2004+ Toyota Prius vehicles, there is a stud located under the hood that can be used to jump start the auxiliary battery, which is located in the truck. ● **SEE FIGURE 41–8**.

NOTE: The high-voltage HV battery pack cannot be jump started on most HEVs. One exception is the Ford Escape/Mercury Mariner hybrids that use a special "jump-start" button located behind the left kick panel. When this button is pushed, the auxiliary battery is used to boost the HV battery through a DC-DC converter.

FIGURE 41–9 Using a warning cover over the steering wheel helps others realize that work is being performed on the high-voltage system and that no one is to attempt to start or move the vehicle.

FREQUENTLY ASKED QUESTION

When Do I Need to De-Power the High-Voltage System?

During routine service work, there is no need for a technician to de-power the high-voltage system. The only time when this process is needed is if service repairs or testing is being performed on any circuit that has an orange cable attached. These include:

- AC compressor if electrically powered
- High-voltage battery pack or electronic controllers

The electric power steering system usually operates on 12 volts or 42 volts and neither is a shock hazard. However, an arc will be maintained if a 42-volt circuit is opened. Always refer to service information if servicing the electric power steering system or any other system that may contain high voltage.

MOVING AND TOWING A HYBRID

TOWING If a disabled vehicle needs to be moved a short distance (to the side of the road, for example) and the vehicle can still roll on the ground, the easiest way is to shift the transmission into neutral and manually push the vehicle. To transport a vehicle away from an emergency location, a flatbed truck should be used if the vehicle might be repaired. If a flatbed is not available, the vehicle should be towed by wheel-lift equipment with the front wheels off the ground (FWD hybrid electric

FIGURE 41–10 A lock box is a safe location to keep the ignition keys of a hybrid electric vehicle while it is being serviced.

vehicles only). Do not use sling-type towing equipment. In the case of 4WD HEVs such as the Toyota Highlander, only a flatbed vehicle should be used.

MOVING THE HYBRID VEHICLE IN THE SHOP After an HEV has been serviced, it may be necessary to push the vehicle to another part of the shop or outside as parts are ordered. Make sure to tape any orange cable ends that were disconnected during the repair procedure. Permanent magnets are used in all the drive motors and generators and it is possible that a high-voltage arc could occur as the wheels turn and produce voltage. Another way to prevent this is to use wheel dollies. A sign that says "HIGH VOLTAGE—DO NOT TOUCH" could also be added to the roof of the vehicle. Remove the keys from the vehicle and keep in a safe location. ● **SEE FIGURES 41–9 AND 41–10**.

REMOVING THE HIGH-VOLTAGE BATTERIES

PRECAUTIONS The HV battery box should always be removed as an assembly, placed on a rubber-covered work bench, and handled carefully. Every other part, especially the capacitors, should be checked for voltage reading while wearing HV rubber gloves. Always check for voltage as the components become accessible before proceeding. When removing high-voltage components, it is wise to use insulated tools. ● **SEE FIGURE 41–11**.

STORING THE HIGH-VOLTAGE BATTERIES If a hybrid is to be stored for any length of time, the state of charge of the HV batteries must be maintained. If possible, start the vehicle every month and run it for at least 30 minutes to help recharge the HV batteries. This is necessary because NiMH batteries suffer from self-discharge over time. High-voltage battery chargers

FIGURE 41–11 Insulated tools, such as this socket set, would provide an additional margin of safety to the service technician when working around high-voltage components and systems.

FREQUENTLY ASKED QUESTION

Will the Heat from Paint Ovens Hurt the High-Voltage Batteries?

Nickel-metal hydride (NiMH) batteries may be damaged if exposed to high temperatures, such as in a paint oven. The warning labels on hybrid vehicles specify that the battery temperature not exceed 146°F (63°C). Therefore be sure to check the temperature of any paint oven before allowing a hybrid electric vehicle into one that may be hotter than specified. Check service information for details on the vehicle being repaired.

are expensive and may be hard to find. If the HV battery SOC was over 60% when it was put into storage, the batteries may be stored for about a month without a problem. If, however, the SOC is less than 60%, a problem with a discharged HV battery may result.

HOISTING A HYBRID VEHICLE When hoisting or using a floor jack, pay attention to the lift points. Orange cables run under the vehicle just inside the fame rails on most hybrids. ● **SEE FIGURE 41–12**.

Some Honda hybrid vehicles use an aluminum pipe painted orange that includes three HV cables for the starter/generator and also three more cables for the HV air-conditioning compressor. If any damage occurs to any high-voltage cables, the MIL will light up and a no-start will result if the PCM senses a fault. The cables are not repairable and are expensive. The cables can be identified by an orange outer casing, but in some cases, the orange casing is not exposed until a black plastic underbelly shield is removed first.

FIGURE 41–12 The high-voltage wiring on this Honda hybrid is colored orange for easy identification.

TECH TIP

High-Voltage Battery SOC Considerations

NiMH batteries do not store well for long lengths of time. After a repair job, or when the HV system has been powered down by a technician and powered up again, do not be surprised if a warning lamp lights, diagnostic trouble codes are set, and the MIL are illuminated. If everything was done correctly, a couple road tests may be all that is required to reset the MIL. The HV battery indicator on the dash may also read zero charge level. After a road test, the HV battery level indicator will most likely display the proper voltage level.

HV BATTERY DISPOSAL The hybrid electric vehicle manufacturers are set up to ship NiMH battery packs to a recycling center. There is an 800 number located under the hood or on the HV battery pack that can be used to gain information on how to recycle these batteries.

Always follow the proper safety procedures, and then minor service to hybrid vehicles can be done with a reasonable level of safety.

ROUTINE SERVICE PROCEDURES

DIAGNOSIS PROCEDURES Hybrid electric vehicles should be diagnosed the same as any other type of vehicle. This means following a diagnostic routine, which usually includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Check for diagnostic trouble codes (DTCs). An enhanced or factory level scan tool may be needed to get access to codes and sub-codes.

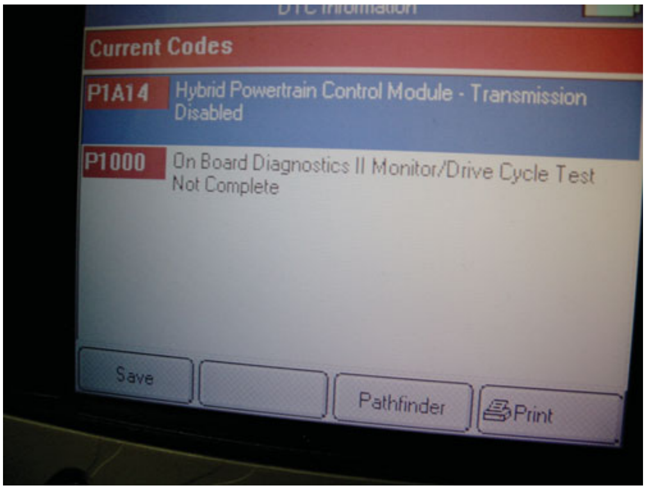


FIGURE 41–13 A scan tool display showing two hybrid-related faults in this Ford Escape hybrid.

STEP 3 Perform a thorough visual inspection. If a DTC is stored, carefully inspect those areas that might be the cause of the trouble code.

STEP 4 Check for technical service bulletins (TSBs) that may relate to the customer concern.

STEP 5 Follow service information specified steps and procedures. This could include checking scan tool data for sensors or values that are not within normal range.

STEP 6 Determine and repair the root cause of the problem.

STEP 7 Verify the repair and clear any stored diagnostic trouble codes unless in an emission testing area. If in an emission test area, drive the vehicle until the Powertrain Control Module (PCM) passes the fault and turns off the malfunction indicator lamp (MIL) thereby allowing the vehicle to pass the inspection.

STEP 8 Complete the work order and record the "three Cs" (complaint, cause, and correction).

● **SEE FIGURE 41–13**.

OIL CHANGE Performing an oil change is similar to changing oil in any vehicle equipped with an internal combustion engine. However, there are several items to know when changing oil in a hybrid electric vehicle including:

- **Use vehicle manufacturer's recommended hoisting locations.** Use caution when hoisting a hybrid electric vehicle and avoid placing the pads on or close to the orange high-voltage cables that are usually located under the vehicle.
- **Always use the specified oil viscosity.** Most hybrid electric vehicles require either:

  SAE 0W-20

  SAE 5W-20

  Using the specified oil viscosity is important because the engine stops and starts many times and using the incorrect viscosity not only can cause a decrease in fuel economy but also could cause engine damage. ● **SEE FIGURE 41–14**.

FIGURE 41–14 Always use the specified viscosity of oil in a hybrid electric vehicle not only for best fuel economy but also because of the need for fast lubrication because of the engine (idle) stop feature.

REAL WORLD FIX

A Bad Day Changing Oil

A shop owner was asked by a regular customer who had just bought a Prius if the oil could be changed there. The owner opened the hood, made sure the filter was in stock (it is a standard Toyota filter used on other models), and said yes. A technician with no prior knowledge of hybrids drove the warmed-up vehicle into the service bay. The internal combustion engine never started, as it was in electric (stealth) mode at the time. Not hearing the engine running, the technician hoisted the vehicle into the air, removed the drain bolt, and drained the oil into the oil drain unit. When the filter was removed, oil started to fly around the shop. The engine was in "standby" mode during the first part of the oil change. When the voltage level dropped, the onboard computer started the engine so that the HV battery could recharge. The technician should have removed the key to keep this from happening. Be sure that the "ready" light is off before changing the oil or doing any other service work that may cause personal harm or harm to the vehicle if the engine starts.

- **Always follow the specified procedures.** Be sure that the internal combustion engine (ICE) is off and that the "READY" lamp is off. If there is a smart key or the vehicle has a push-button start, be sure that the key fob is at least 15 feet (5 meters) away from the vehicle to help prevent the engine from starting accidentally.

COOLING SYSTEM SERVICE Performing cooling system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the cooling system on a hybrid electric vehicle including:

- **Always check service information for the exact procedure to follow.** The procedure will include the following:
  1. **The specified coolant.** Most vehicle manufacturers will recommend using premixed coolant because using water (half of the coolant) that has minerals could cause corrosion issues.
  2. **The specified coolant replacement interval.** While this may be similar to the coolant replacement interval for a conventional vehicle, always check to be sure that this service is being performed at the specified time or mileage interval.
  3. **The specified precautions.** Some Toyota Prius HEVs use a coolant storage bottle that keeps the coolant hot for up to three days. Opening a coolant hose could cause the release of this hot coolant and can cause serious burns to the technician.
  4. Always read, understand, and follow all of the service information instructions when servicing the cooling system on a hybrid electric vehicle.

AIR FILTER SERVICE Performing air filter service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the air filter on a hybrid electric vehicle including:

1. Always follow the service information recommended air filter replacement interval.
2. For best results use the factory type and quality air filter.
3. Double-check that all of the air ducts are securely fastened after checking or replacing the air filter.

NOTE: Check the air filter to be sure that it is a high quality filter and fits the housing properly.

AIR-CONDITIONING SERVICE Performing air-conditioning system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the air-conditioning system on a hybrid electric vehicle including:

1. Many hybrid electric vehicles use an air-conditioning compressor that uses high voltage from the high-voltage (HV) battery pack to operate the compressor either all of the time, such as many Toyota/Lexus models, or during idle stop periods, such as on Honda hybrids.
2. If the system is electrically driven, then special refrigerant oil is used that is nonconductive. This means that a separate recovery machine should be used to avoid the possibility of mixing regular refrigerant oils in with the oil used in hybrids.
3. Always read, understand, and follow all of the service information instructions when servicing the air-conditioning system on a hybrid electric vehicle.

STEERING SYSTEM SERVICE Performing steering system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the steering system on a hybrid electric vehicle including:

1. Check service information for any precautions that are specified to be followed when servicing the steering system on a hybrid electric vehicle.
2. Most hybrid electric vehicles use an electric power steering system. These can be powered by one of two voltages:
   - **12 volts**—These systems can be identified by the red or black wiring conduit and often use an inverter that increases the voltage to operate the actuator motor (usually to 42 volts). While this higher voltage is contained in the controller and should not create a shock hazard, always follow the specified safety precautions and wear protective high-voltage gloves as needed.
   - **42 volts**—These systems use a yellow or blue plastic conduit over the wires to help identify the possible hazards from this voltage level. This voltage level is not a shock hazard but can maintain an arc if a circuit carrying 42 volts is opened.

BRAKING SYSTEM SERVICE Performing braking system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the braking system on a hybrid electric vehicle including:

1. Check service information for any precautions that are specified to be followed when servicing the braking system on a hybrid electric vehicle.
2. All hybrid electric vehicles use a regenerative braking system, which captures the kinetic energy of the moving vehicle and converts it to electrical energy and is sent to the high-voltage battery pack. The amount of current produced during hard braking can exceed 100 amperes. This current is stored in the high-voltage battery pack and is then used as needed to help power the vehicle.
3. The base brakes used on hybrid electric vehicles are the same as any other conventional vehicle except for the master cylinder and related control systems. There is no high-voltage circuits associated with the braking system as the regeneration occurs inside the electric drive (traction) motors and is controlled by the motor controller.
4. The base brakes on many hybrid vehicles are often found to be stuck or not functioning correctly because the brakes are not doing much work and can rust.

NOTE: Always check the base brakes whenever there is a poor fuel economy complaint heard from an owner of a hybrid vehicle. Often when a disc brake caliper sticks, the brakes drag but the driver is not aware of any performance problems but the fuel economy drops.

TIRES Performing tire-related service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing tires on a hybrid electric vehicle including:

1. Tire pressure is very important to not only the fuel economy but also on the life of the tire. Lower inflation pressure increases rolling resistance and reduces load carrying capacity and tire life. Always inflate the tires to the pressure indicated on the door jamb sticker or found in service information or the owner's manual.
2. All tires create less rolling resistance as they wear. This means that even if the same identical tire is used as a replacement, the owner may experience a drop in fuel economy.
3. Tires can have a big effect on fuel economy. It is best to warn the owner that replacement of the tires can and often will cause a drop in fuel economy, even if low rolling resistance tires are selected.
4. Try to avoid using tires that are larger than used from the factory. The larger the tire, the heavier it is and it takes more energy to rotate, resulting in a decrease in fuel economy.
5. Follow normal tire inspections and tire rotation intervals as specified by the vehicle manufacturer.

AUXILIARY BATTERY TESTING AND SERVICE

Performing auxiliary battery service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the auxiliary battery on a hybrid electric vehicle including:

1. Auxiliary 12-volt batteries used in hybrid electric vehicles are located in one of two general locations.
   - **Under the hood**—If the 12-volt auxiliary battery is under the hood it is generally a flooded-type lead–acid battery and should be serviced the same as any conventional battery. ● **SEE FIGURE 41–15**.
   - **In the passenger or trunk area**—If the battery is located in the passenger or truck area of the vehicle, it is usually of the absorbed glass mat (AGM) design. This type of battery requires that a special battery charger that limits the charging voltage be used.
2. The auxiliary 12-volt battery is usually smaller than a battery used in a conventional vehicle because it is not used to actually start the engine unless under extreme conditions on Honda hybrids only.
3. The 12-volt auxiliary battery can be tested and serviced the same as any battery used in a conventional vehicle.
4. Always read, understand, and follow all of the service information instructions when servicing the auxiliary battery on a hybrid electric vehicle.

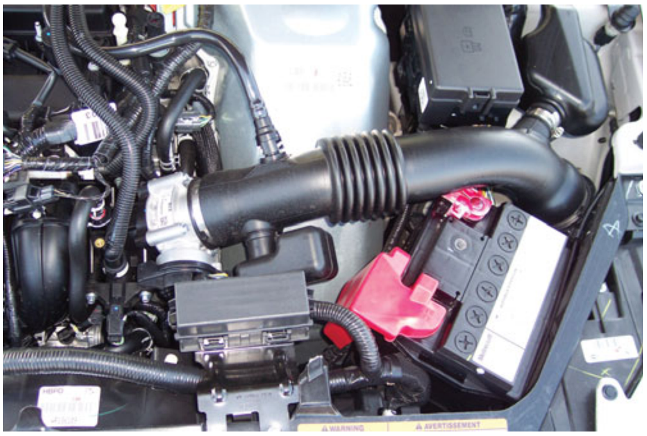
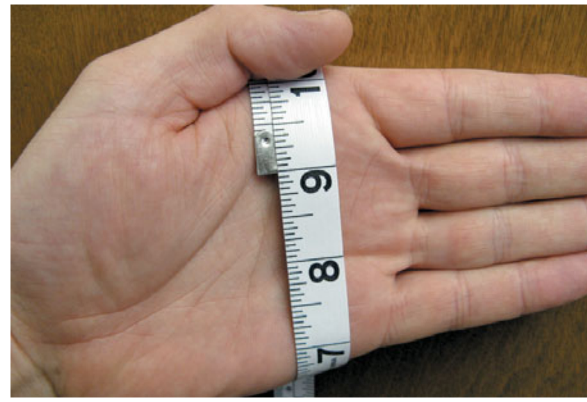


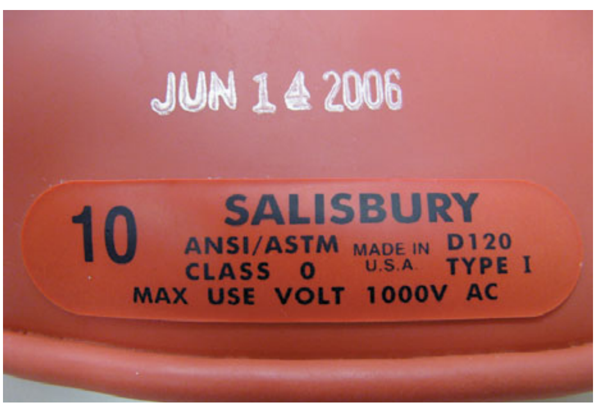
FIGURE 41–15 This 12 volt battery under the hood on a Ford Fusion hybrid is a flooded cell type auxiliary battery.

HV GLOVE USE

1 The cuff of the rubber glove should extend at least 1/2 inch beyond the cuff of the leather protector.



2 To determine correct glove size, use a soft tape to measure around the palm of the hand. A measurement of 9 inches would correspond with a glove size of 9.



3 The glove rating and the date of the last test should be stamped on the glove cuff.

4 Start with a visual inspection of the glove fingertips, making sure that no cuts or other damage is present.

5 The damage on this glove was easily detected with a simple visual inspection. Note that the rubber glove material can be damaged by petroleum products, detergents, certain hand soaps, and talcum powder.

6 Manually inflate the glove to inspect for pinhole leaks. Starting at the cuff, roll up the glove and trap air at the finger end. Listen and watch carefully for deflation of the glove. If a leak is detected, the glove must be discarded.

7 Petroleum on the leather protector's surfaces will damage the rubber glove underneath.

8 Glove powder (glove dust) should be used to absorb moisture and reduce friction.

9 Put on the gloves and tighten the straps on the back of the leather protectors.

10 Technicians MUST wear HV gloves and leather protectors whenever working around the high-voltage areas of a hybrid electric vehicle.

11 HV gloves and leather protectors should be placed in a canvas storage bag when not in use. Note the ventilation hole at the bottom of this bag.

12 Make sure that the rubber gloves are not folded when placed in the canvas bag. Folding increases mechanical stress on the rubber and can lead to premature failure of the glove material.

SUMMARY

1. Personal protective equipment (PPE) for work on hybrid electric vehicles includes the wearing of high-voltage rubber gloves rated at 1,000 volts or more worn with outer leather gloves to help protect the rubber gloves.
2. A digital meter that meets CAT III standards should be used when working around the high-voltage section of a hybrid electric vehicle.
3. Safety glasses and a face shield should be worn whenever working around the high-voltage circuits of a hybrid electric vehicle.
4. The high-voltage system can be shut off at the battery pack by simply being certain that the ignition is off. Disconnecting the 12-volt battery is additional security that the high-voltage circuits are de-powered.
5. When servicing a hybrid electric vehicle, always observe safety procedures.

REVIEW QUESTIONS

1. What are the recommended items that should be used when working with the high-voltage circuits of a hybrid electric vehicle?
2. What actions are needed to disable the high-voltage (HV) circuit?
3. What are the precautions that service technicians should adhere to when servicing hybrid electric vehicles?

CHAPTER QUIZ

1. Rubber gloves should be worn whenever working on or near the high-voltage circuits or components of a hybrid electric vehicle. Technician A says that the rubber gloves should be rated at 1,000 volts or higher. Technician B says that leather gloves should be worn over the high-voltage rubber gloves. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A CAT-III certified DMM should be used whenever measuring high-voltage circuits or components. The CAT III rating relates to _____________.
   a. High voltage
   b. High energy
   c. High electrical resistance
   d. Both a and b
3. All of the following will shut off the high voltage to components and circuits, except _____________.
   a. Opening the driver's door
   b. Turning the ignition off
   c. Disconnecting the 12-volt auxiliary battery
   d. Removing the main fuse, relay, or HV plug
4. If the engine is not running, Technician A says that the high-voltage circuits are de-powered. Technician B says that all high-voltage wiring is orange-colored. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which statement is false about high-voltage wiring?
   a. Connects the battery pack to the electric controller
   b. Connects the controller to the motor/generator
   c. Is electrically grounded to the frame (body) of the vehicle
   d. Is controlled by a relay that opens if the ignition is off
6. What routine service procedure could result in lower fuel economy, which the owner may discover?
   a. Using the wrong viscosity engine oil
   b. Replacing tires
   c. Replacing the air filter
   d. Either a or b

7. Two technicians are discussing jump starting a hybrid electric vehicle. Technician A says that the high-voltage (HV) batteries can be jumped on some HEV models. Technician B says that the 12-volt auxiliary battery can be jumped using a conventional jump box or jumper Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. What can occur if a hybrid electric vehicle is pushed in the shop?
   a. The HV battery pack can be damaged
   b. The tires will be locked unless the ignition is on
   c. Damage to the electronic controller can occur
   d. High voltage will be generated by the motor/generator
9. Nickel-metal hydride (NiMH) batteries can be damaged if exposed to temperatures higher than about ___________.
   a. 150°F (66°C)
   b. 175°F (79°C)
   c. 200°F (93°C)
   d. 225°F (107°C)
10. How should nickel-metal hydride (NiMH) batteries be disposed?
   a. In regular trash
   b. Call an 800 number shown under the hood of the vehicle for information
   c. Submerged in water and then disposed of in regular trash
   d. Burned at an EPA-certified plant

chapter 42

FUEL CELLS AND ADVANCED TECHNOLOGIES

OBJECTIVES: **After studying Chapter 42, the reader will be able to:** • Explain how a fuel cell generates electricity. • Discuss the advantages and disadvantages of fuel cells. • List the types of fuel cells. • Explain how ultracapacitors work. • Describe the advantages and disadvantages of electric vehicles. • Discuss alternative energy sources.

KEY TERMS: Double-layer technology 621 • Electrolysis 616 • Electrolyte 618 • Energy carrier 616 • Energy density 619 • Farads 621 • Fuel cell 616 • Fuel cell hybrid vehicle (FCHV) 617 • Fuel-cell stack 618 • Fuel cell vehicle (FCV) 617 • Homogeneous Charge Compression Ignition (HCCI) 625 • Hydraulic Power Assist (HPA) 625 • Inverter 622 • Low-grade heat 620 • Membrane Electrode Assembly (MEA) 618 • NEDRA 628 • Plug-in hybrid electric vehicle (PHEV) 626 • Polymer Electrolyte Fuel Cell (PEFC) 618 • Proton Exchange Membrane (PEM) 618 • Range 627 • Specific energy 616 • Ultracapacitor 620 • Wheel motors 622 • Wind farms 628

FUEL-CELL TECHNOLOGY

WHAT IS A FUEL CELL? A **fuel cell** is an electrochemical device in which the chemical energy of hydrogen and oxygen is converted into electrical energy. The principle of the fuel cell was first discovered in 1839 by Sir William Grove, a Welsh physician. In the 1950s, NASA put this principle to work in building devices for powering space exploration vehicles. In the present day, fuel cells are being developed to power homes and vehicles while producing low or zero emissions. ● **SEE FIGURE 42–1.**

The chemical reaction in a fuel cell is the opposite of **electrolysis.** Electrolysis is the process in which electrical current is passed through water in order to break it into its components, hydrogen and oxygen. While energy is required to bring about electrolysis, this same energy can be retrieved by allowing hydrogen and oxygen to reunite in a fuel cell. It is important to note that while hydrogen can be used as a fuel, it is **not** an energy source. Instead, hydrogen is only an **energy carrier,** as energy must be expended to generate the hydrogen and store it so it can be used as a fuel.

In simple terms, a fuel cell is a hydrogen-powered battery. Hydrogen is an excellent fuel because it has a very high **specific energy** when compared to an equivalent amount of fossil fuel. One kilogram (kg) of hydrogen has three times the energy content as one kilogram of gasoline. Hydrogen is the most abundant element on earth, but it does not exist by itself in nature. This is because its natural tendency is to react with oxygen in the atmosphere to form water (H_2O). Hydrogen is also found in many other compounds, most notably hydrocarbons,

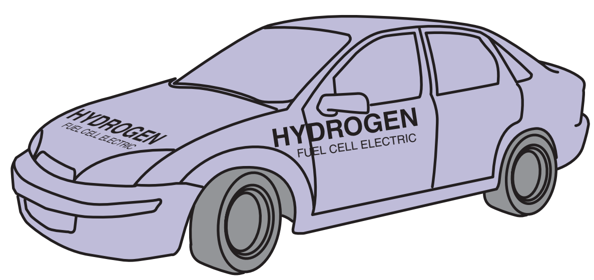


FIGURE 42–1 Ford Motor Company has produced a number of demonstration fuel-cell vehicles based on the Ford Focus.

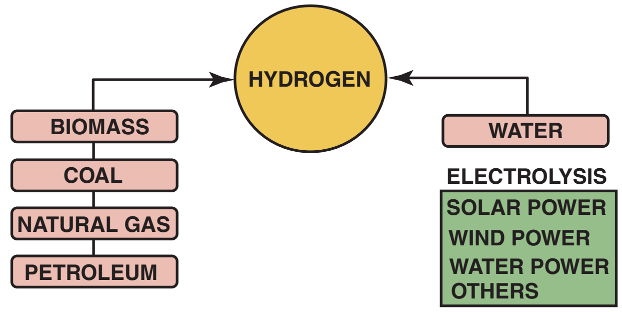


FIGURE 42–2 Hydrogen does not exist by itself in nature. Energy must be expended to separate it from other, more complex materials.

such as natural gas or crude oil. In order to store hydrogen for use as a fuel, processes must be undertaken to separate it from these materials. ● **SEE FIGURE 42–2.**

BENEFITS OF A FUEL CELL A fuel cell can be used to move a vehicle by generating electricity to power electric drive motors, as well as powering the remainder of the vehicle's

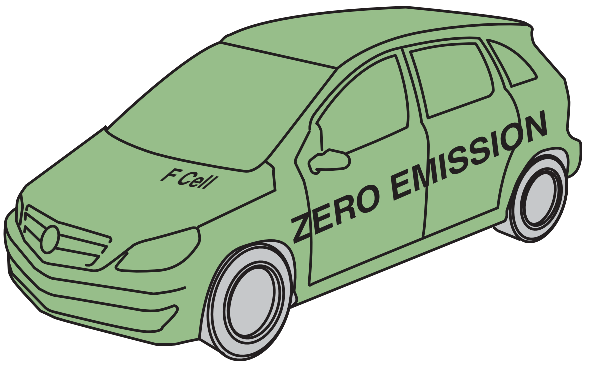


FIGURE 42–3 The Mercedes-Benz B-Class fuel-cell car was introduced in 2005.

electrical system. Since they are powered by hydrogen and oxygen, fuel cells by themselves do not generate carbon emissions such as CO_2. Instead, their only emissions are water vapor and heat, and this makes the fuel cell an ideal candidate for a ZEV (zero-emission vehicle).

A fuel cell is also much more energy-efficient than a typical internal combustion engine. While a vehicle powered by an internal combustion engine (ICE) is anywhere from 15% to 20% efficient, a fuel-cell vehicle can achieve efficiencies upwards of 40%. Another major benefit of fuel cells is that they have very few moving parts and have the potential to be very reliable. A number of OEMs have spent many years and millions of dollars in order to develop a low-cost, durable, and compact fuel cell that will operate satisfactorily under all driving conditions. ● **SEE FIGURE 42–3.**

A **fuel-cell vehicle (FCV)** uses the fuel cell as its only source of power, whereas a **fuel-cell hybrid vehicle (FCHV)** would also have an electrical storage device that can be used to power the vehicle. Most new designs of fuel-cell vehicles are now based on a hybrid configuration due to the significant increase in efficiency and driveability that can be achieved with this approach. ● **SEE FIGURE 42–4.**

FUEL-CELL CHALLENGES While major automobile manufacturers continue to build demonstration vehicles and work on improving fuel-cell system design, no vehicle powered by a fuel cell has been placed into mass production. There are a number of reasons for this, including:

- High cost
- Lack of refueling infrastructure
- Safety perception
- Insufficient vehicle range
- Lack of durability
- Freeze starting problems
- Insufficient power density

All of these problems are being actively addressed by researchers, and significant improvements are being made. Once cost and performance levels meet that of current vehicles, fuel cells will be adopted as a mainstream technology. ● **SEE CHART 42-1.**

FIGURE 42–4 The Toyota FCHV is based on the Highlander platform and uses much of Toyota's Hybrid Synergy Drive (HSD) technology in its design.

TYPES OF FUEL CELLS There are a number of different types of fuel cells, and these are differentiated by the type of **electrolyte** that is used in their design. Some electrolytes operate best at room temperature, whereas others are made to operate at up to 1800°F. See the accompanying chart showing the various fuel-cell types and applications.

The fuel-cell design that is best suited for automotive applications is the **Proton Exchange Membrane (PEM).** A PEM fuel cell must have hydrogen for it to operate, and this may be stored on the vehicle or generated as needed from another type of fuel.

PEM FUEL CELLS

DESCRIPTION AND OPERATION The Proton Exchange Membrane fuel cell is also known as a **Polymer Electrolyte Fuel Cell (PEFC).** The PEM fuel cell is known for its lightweight and compact design, as well as its ability to operate at ambient temperatures. This means that a PEM fuel cell can start quickly and produce full power without an extensive warmup period. The PEM is a simple design based on a membrane that is coated on both sides with a catalyst such as platinum or palladium. There are two electrodes, one located on each side of the membrane. These are responsible for distributing hydrogen and oxygen over the membrane surface, removing waste heat, and providing a path for electrical current flow. The part of the PEM fuel cell that contains the membrane, catalyst coatings, and electrodes is known as the **Membrane Electrode Assembly (MEA).**

The negative electrode (anode) has hydrogen gas directed to it, while oxygen is sent to the positive electrode (cathode). Hydrogen is sent to the negative electrode as H2 molecules, which break apart into H^+ ions (protons) in the presence of the catalyst. The electrons (e^-) from the hydrogen atoms are sent through the external circuit, generating electricity that can be utilized to perform

	PAFC (PHOSPHORIC ACID FUEL CELL)	PEM (POLYMER ELECTROLYTE MEMBRANE)	MCFC (MOLTEN CARBONATE FUEL CELL)	SOFC (SOLID OXIDE FUEL CELL)
Electrolyte	Orthophosphoric acid	Sulfonic acid in polymer	Li and K carbonates	Yttrium-stabilized zirconia
Fuel	Natural gas, hydrogen	Natural gas, hydrogen, methanol	Natural gas, synthetic gas	Natural gas, synthetic gas
Operating Temp (F) (C)	360–410°F	176–212°F	1100–1300°F	1200–3300°F
	180–210°C	80–100°C	600–700°C	650–1800°C
Electric Efficiency	40%	30–40%	43–44%	50–60%
Manufacturers	ONSI Corp.	Avista, Ballard, Energy Partners, H-Power, International, Plug Power	Fuel Cell Energy, IHI, Hitachi, Siemens	Honeywell, Siemens-Westinghouse, Ceramic
Applications	Stationary power	Vehicles, portable power, small stationary power	Industrial and institutional power	Stationary power, military vehicles

CHART 42-1

Fuel cell types and their temperature operating range.

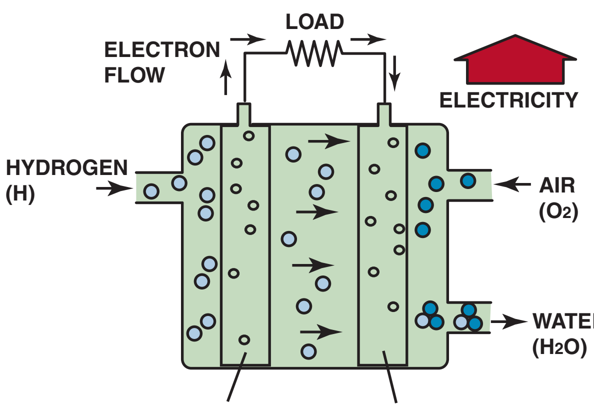


FIGURE 42–5 The polymer electrolyte membrane only allows H^+ ions (protons) to pass through it. This means that electrons must follow the external circuit and pass through the load to perform work.

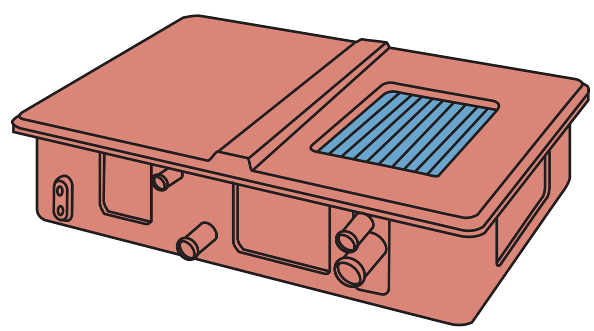


FIGURE 42–6 A fuel-cell stack is made up of hundreds of individual cells connected in series.

work. These same electrons are then sent to the positive electrode where they rejoin the H^+ ions that have passed through the membrane and have reacted with oxygen in the presence of the catalyst. This creates H_2O and waste heat, which are the only emissions from a PEM fuel cell. ● **SEE FIGURE 42–5.**

NOTE: It is important to remember that a fuel cell generates direct current (DC) electricity as electrons only flow in one direction (from the anode to the cathode).

FUEL-CELL STACKS A single fuel cell by itself is not particularly useful, as it will generate less than 1 volt of electrical potential. It is more common for hundreds of fuel cells to be built together in a **fuel-cell stack.** In this arrangement, the fuel cells are connected in series so that total voltage of the stack is the sum of the individual cell voltages. The fuel cells are placed end-to-end in the stack, much like slices in a loaf of bread.

TECH TIP

CO Poisons the PEM Fuel-Cell Catalyst

Purity of the fuel gas is critical with PEM fuel cells. If more than 10 parts per million (ppm) of carbon monoxide is present in the hydrogen stream being fed to the PEM anode, the catalyst will be gradually poisoned and the fuel cell will eventually be disabled. This means that the purity must be "five nines" (99.999% pure). This is a major concern in vehicles where hydrogen is generated by reforming hydrocarbons such as gasoline, because it is difficult to remove all CO from the hydrogen during the reforming process. In these applications, some means of hydrogen purification must be used to prevent CO poisoning of the catalyst.

Automotive fuel-cell stacks contain upwards of 400 cells in their construction. ● **SEE FIGURE 42–6.**

The total voltage of the fuel-cell stack is determined by the number of individual cells incorporated into the assembly. The

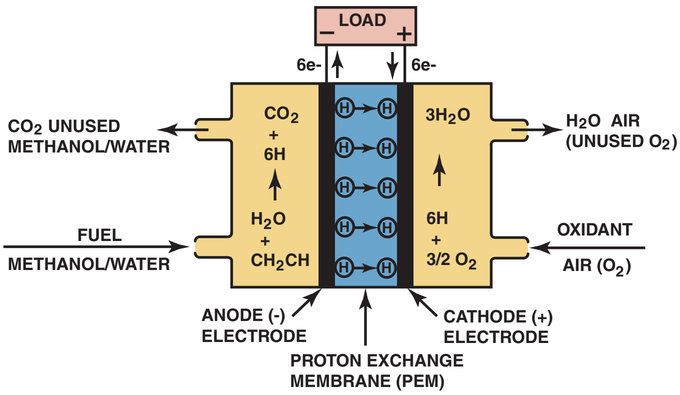


FIGURE 42–7 A direct methanol fuel cell uses a methanol/water solution for fuel instead of hydrogen gas.

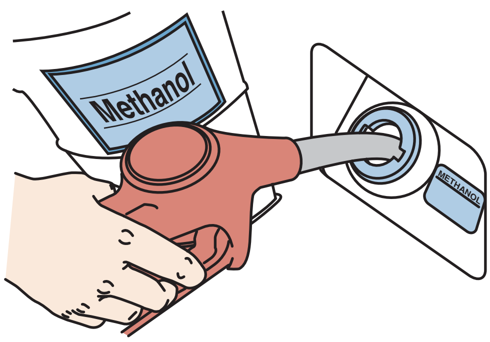


FIGURE 42–8 A direct methanol fuel cell can be refueled similar to a gasoline-powered vehicle.

current-producing ability of the stack, however, is dependent on the surface area of the electrodes. Since output of the fuel-cell stack is related to both voltage and current (voltage × current = power), increasing the number of cells or increasing the surface area of the cells will increase power output. Some fuel-cell vehicles will use more than one stack, depending on power output requirements and space limitations.

DIRECT METHANOL FUEL CELLS High-pressure cylinders are one method of storing hydrogen onboard a vehicle for use in a fuel cell. This is a simple and lightweight storage method, but often does not provide sufficient vehicle driving range. Another approach has been to fuel a modified PEM fuel cell with liquid methanol instead of hydrogen gas. ● **SEE FIGURE 42–7.**

Methanol is most often produced from natural gas and has a chemical symbol of CH_3OH. It has a higher **energy density** than gaseous hydrogen because it exists in a liquid state at normal temperatures, and is easier to handle since no compressors or other high-pressure equipment is needed. This means that a fuel-cell vehicle can be refueled with a liquid instead of high-pressure gas, which makes the refueling process simpler and produces a greater vehicle driving range. ● **SEE FIGURE 42–8.**

Unfortunately, direct methanol fuel cells suffer from a number of problems, not the least of which is the corrosive nature of methanol itself. This means that methanol cannot be stored in existing tanks and thus requires a separate infrastructure for handling and storage. Another problem is "fuel crossover," in which methanol makes its way across the membrane assembly and diminishes performance of the cell. Direct methanol fuel cells also require much greater amounts of catalyst in their construction, which leads to higher costs. These challenges are leading researchers to look for alternative electrolyte materials and catalysts to lower cost and improve cell performance.

NOTE: Direct methanol fuel cells are not likely to see service in automotive applications. However, they are well suited for low-power applications, such as cell phones or laptop computers.

? FREQUENTLY ASKED QUESTION

What Is the Role of the Humidifier in a PEM Fuel Cell?

The polymer electrolyte membrane assembly in a PEM fuel cell acts as conductor of positive ions and as a gas separator. However, it can only perform these functions effectively if it is kept moist. A fuel-cell vehicle uses an air compressor to supply air to the positive electrodes of each cell, and this air is sometimes sent through a humidifier first to increase its moisture content. The humid air then comes in contact with the membrane assembly and keeps the electrolyte damp and functioning correctly.

FUEL-CELL VEHICLE SYSTEMS

HUMIDIFIERS Water management inside a PEM fuel cell is critical. Too much water can prevent oxygen from making contact with the positive electrode; too little water can allow the electrolyte to dry out and lower its conductivity. The amount of water and where it resides in the fuel cell is also critical in determining at how low a temperature the fuel cell will start, because water freezing in the fuel cell can prevent it from starting. The role of the humidifier is to achieve a balance where it is providing sufficient moisture to the fuel cell by recycling water that is evaporating at the cathode. The humidifier is located in the air line leading to the cathode of the fuel-cell stack. ● **SEE FIGURE 42–9.**

Some newer PEM designs manage the water in the cells in such a way that there is no need to pre-humidify the incoming reactant gases. This eliminates the need for the humidifier assembly and makes the system simpler overall.

FUEL-CELL COOLING SYSTEMS Heat is generated by the fuel cell during normal operation. Excess heat can lead to a breakdown of the polymer electrolyte membrane, so a liquid cooling system must be utilized to remove waste heat from the

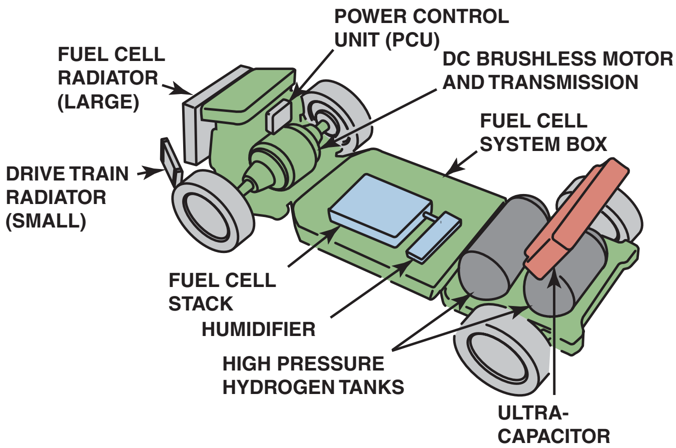


FIGURE 42–9 Powertrain layout in a Honda FCX fuel-cell vehicle. Note the use of a humidifier behind the fuel-cell stack to maintain moisture levels in the membrane electrode assemblies.

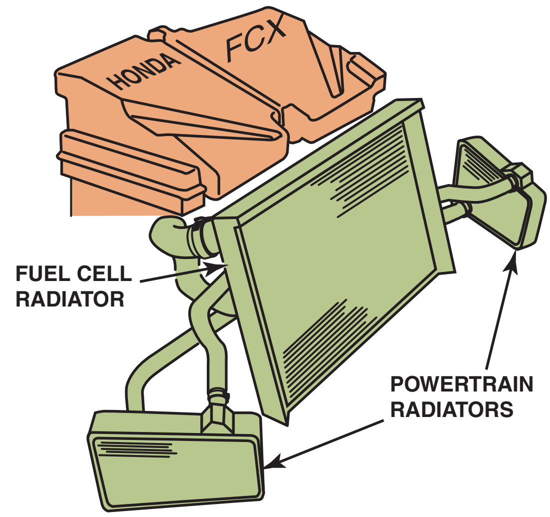


FIGURE 42–10 The Honda FCX uses one large radiator for cooling the fuel cell, and two smaller ones on either side for cooling drive train components.

? FREQUENTLY ASKED QUESTION

When Is Methanol Considered to Be a "Carbon-Neutral" Fuel?

Most of the methanol in the world is produced by reforming natural gas. Natural gas is a hydrocarbon, but does not increase the carbon content of our atmosphere as long as it remains in reservoirs below the earth's surface. However, natural gas that is used as a fuel causes extra carbon to be released into the atmosphere, which is said to contribute to global warming. Natural gas is not a carbon-neutral fuel, and neither is methanol that is made from natural gas.

Fortunately, it is possible to generate methanol from biomass and wood waste. Methanol made from renewable resources is carbon neutral, because no extra carbon is being released into the earth's atmosphere than what was originally absorbed by the plants used to make the methanol.

FIGURE 42–11 Space is limited at the front of the Toyota FCHV engine compartment, so an auxiliary heat exchanger is located under the vehicle to help cool the fuel-cell stack.

fuel-cell stack. One of the major challenges for engineers in this regard is the fact that the heat generated by the fuel cell is classified as **low-grade heat.** This means that there is only a small difference between the temperature of the coolant and that of the ambient air. Heat transfers very slowly under these conditions, so heat exchangers with a much larger surface area must be utilized. ● **SEE FIGURE 42–10.**

In some cases, heat exchangers may be placed in other areas of the vehicle when available space at the front of the engine compartment is insufficient. In the case of the Toyota FCHV, an auxiliary heat exchanger is located underneath the vehicle to increase the cooling system heat-rejection capacity. ● **SEE FIGURE 42–11.**

An electric water pump and a fan drive motor are used to enable operation of the fuel cell's cooling system. These and other support devices use electrical power that is generated by the fuel cell, and therefore tend to decrease the overall efficiency of the vehicle.

AIR SUPPLY PUMPS Air must be supplied to the fuel-cell stack at the proper pressure and flow rate to enable proper performance under all driving conditions. This function is performed by an onboard air supply pump that compresses atmospheric air and supplies it to the fuel cell's positive electrode (cathode). This pump is often driven by a high-voltage electric drive motor.

FUEL-CELL HYBRID VEHICLES Hybridization tends to increase efficiency in vehicles with conventional drive trains, as energy that was once lost during braking and otherwise normal operation is instead stored for later use in a high-voltage battery or **ultracapacitor.** This same advantage can be gained

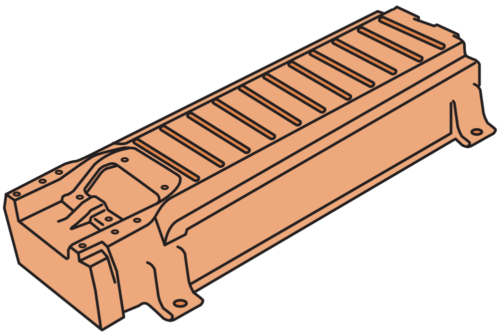


FIGURE 42–12 The secondary battery in a fuel-cell hybrid vehicle is made up of many individual cells connected in series, much like a fuel-cell stack.

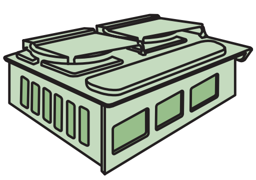


FIGURE 42–13 The Honda ultracapacitor module and construction of the individual cells.

by applying the hybrid design concept to fuel-cell vehicles. Whereas the fuel cell is the only power source in a fuel-cell vehicle, the fuel-cell hybrid vehicle (FCHV) relies on both the fuel cell and an electrical storage device for motive power. Driveability is also enhanced with this design, as the electrical storage device is able to supply energy immediately to the drive motors and overcome any "throttle lag" on the part of the fuel cell.

SECONDARY BATTERIES All hybrid vehicle designs require a means of storing electrical energy that is generated during regenerative braking and other applications. In most FCHV designs, a high-voltage nickel-metal hydride (NiMH) battery pack is used as a secondary battery. This is most often located near the back of the vehicle, either under or behind the rear passenger seat. ● **SEE FIGURE 42–12.** The secondary battery is built similar to a fuel-cell stack, because it is made up of many low-voltage cells connected in series to build a high-voltage battery.

ULTRACAPACITORS An alternative to storing electrical energy in batteries is to use ultracapacitors. A capacitor is best known as an electrical device that will block DC current, but allow AC to pass. However, a capacitor can also be used to store electrical energy, and it is able to do this without a chemical reaction. Instead, a capacitor stores electrical energy using the principle of electrostatic attraction between positive and negative charges.

Ultracapacitors are built very different from conventional capacitors. Ultracapacitor cells are based on **double-layer technology,** in which two activated-carbon electrodes are immersed in an organic electrolyte. The electrodes have a very large surface area and are separated by a membrane that allows ions to migrate but prevents the electrodes from touching. ● **SEE FIGURE 42–13**. Charging and discharging occurs as

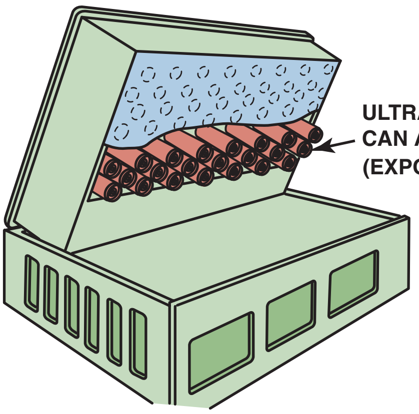


FIGURE 42–14 An ultracapacitor can be used in place of a high-voltage battery in a hybrid electric vehicle. This example is from the Honda FCX fuel-cell hybrid vehicle.

ions move within the electrolyte but no chemical reaction takes place. Ultracapacitors can charge and discharge quickly and efficiently, making them especially suited for electric assist applications in fuel-cell hybrid vehicles.

Ultracapacitors that are used in fuel-cell hybrid vehicles are made up of multiple cylindrical cells connected in parallel. ● **SEE FIGURE 42–14.** This results in the total capacitance being the sum of the values of each individual cell. For example, ten 1.0-**farad** capacitors connected in parallel will have a total capacitance of 10.0 farads. Greater capacitance means greater electrical storage ability, and this contributes to greater assist for the electric motors in a fuel-cell hybrid vehicle.

Ultracapacitors have excellent cycle life, meaning that they can be fully charged and discharged many times without degrading their performance. They are also able to operate over a wide temperature range and are not affected by low temperatures to the same degree as many battery technologies. The one major downside of ultracapacitors is a lack of specific energy, which means that they are best suited for sudden bursts of energy as opposed to prolonged discharge cycles. Research is being conducted to improve this and other aspects of ultracapacitor performance.

FUEL-CELL TRACTION MOTORS Much of the technology behind the electric drive motors being used in fuel-cell vehicles was developed during the early days of the California ZEV mandate. This was a period when battery-powered electric vehicles were being built by the major vehicle manufacturers in an effort to meet a legislated quota in the state of California. The ZEV mandate rules were eventually relaxed to allow other types of vehicles to be substituted for credit, but the technology that had been developed for pure electric vehicles was now put to work in these other vehicle designs.

The electric traction motors used in fuel-cell hybrid vehicles are very similar to those being used in current hybrid electric vehicles. The typical drive motor is based on an AC synchronous design, which is sometimes referred to as a DC brushless motor. This design is very reliable as it does not use a commutator or brushes, but instead has a three-phase stator

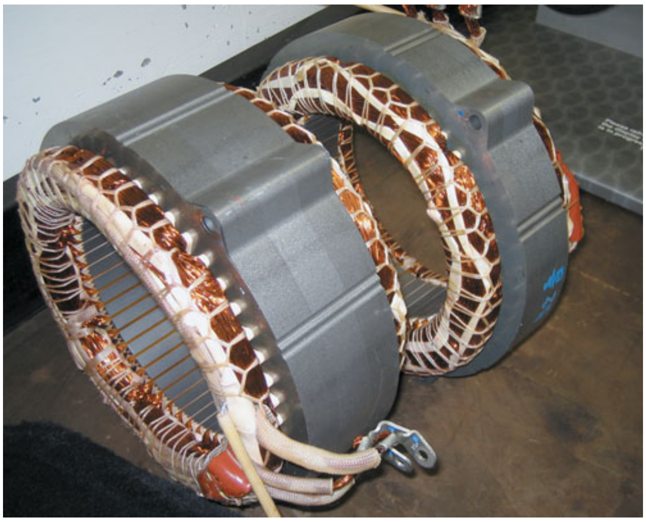


FIGURE 42–15 Drive motors in fuel-cell hybrid vehicles often use stator assemblies similar to ones found in Toyota hybrid electric vehicles. The rotor turns inside the stator and has permanent magnets on its outer circumference.

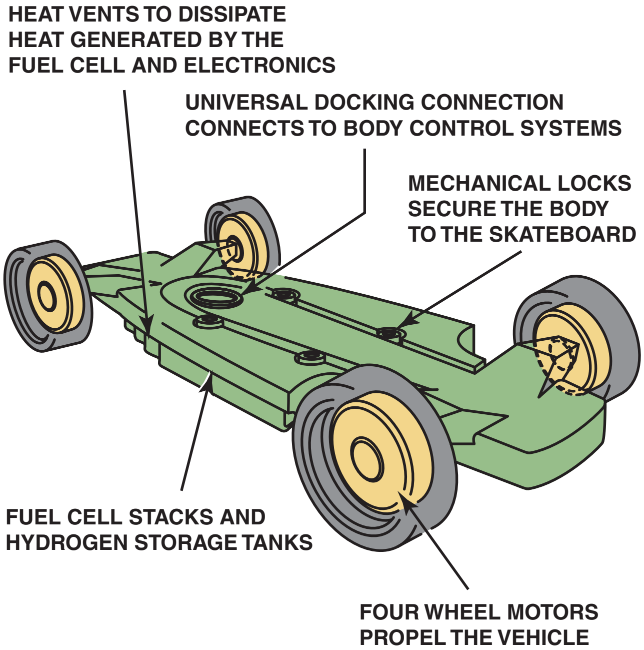


FIGURE 42–16 The General Motors "Skateboard" concept uses a fuel-cell propulsion system with wheel motors at all four corners.

and a permanent magnet rotor. ● **SEE FIGURE 42–15.** An electronic controller (inverter) is used to generate the three-phase high-voltage AC current required by the motor. While the motor itself is very simple, the electronics required to power and control it are complex.

Some fuel-cell hybrid vehicles use a single electric drive motor and a transaxle to direct power to the vehicle's wheels. It is also possible to use **wheel motors** to drive individual wheels. While this approach adds a significant amount of unsprung weight to the chassis, it allows for greater control of the torque being applied to each individual wheel. ● **SEE FIGURE 42–16.**

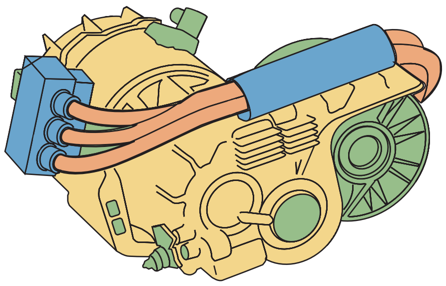


FIGURE 42–17 The electric drive motor and transaxle assembly from a Toyota FCHV. Note the three orange cables, indicating that this motor is powered by high-voltage three-phase alternating current.

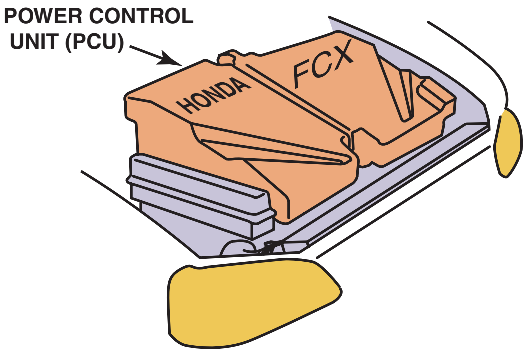


FIGURE 42–18 The power control unit (PCU) on a Honda FCX fuel-cell hybrid vehicle is located under the hood.

TRANSAXLES Aside from the hydrogen fueling system, fuel-cell hybrid vehicles are effectively pure electric vehicles in that their drive train is electrically driven. Electric motors work very well for automotive applications because they produce high torque at low RPMs and are able to maintain a consistent power output throughout their entire RPM range. This is in contrast to vehicles powered by internal combustion engines, which produce very little torque at low RPMs and have a narrow range where significant horsepower is produced.

ICE-powered vehicles require complex transmissions with multiple speed ranges in order to accelerate the vehicle quickly and maximize the efficiency of the ICE. Fuel-cell hybrid vehicles use electric drive motors that require only a simple reduction in their final drive and a differential to send power to the drive wheels. No gear shifting is required and mechanisms such as torque converters and clutches are done away with completely. A reverse gear is not required either, as the electric drive motor is simply powered in the opposite direction. The transaxles used in fuel-cell hybrid vehicles are extremely simple with few moving parts, making them extremely durable, quiet, and reliable. ● **SEE FIGURE 42–17.**

POWER CONTROL UNITS The drive train of a fuel-cell hybrid vehicle is controlled by a power control unit (PCU), which controls fuel-cell output and directs the flow of electricity between the various components. One of the functions of the PCU is to act as an **inverter,** which changes direct current from the fuel-cell stack into three-phase alternating current for use in the vehicle drive motor(s). ● **SEE FIGURE 42–18.**

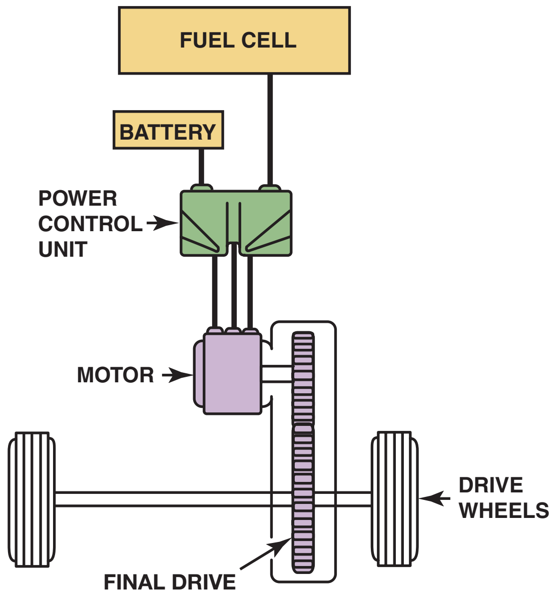


FIGURE 42–19 Toyota's FCHV uses a power control unit that directs electrical energy flow between the fuel cell, battery, and drive motor.

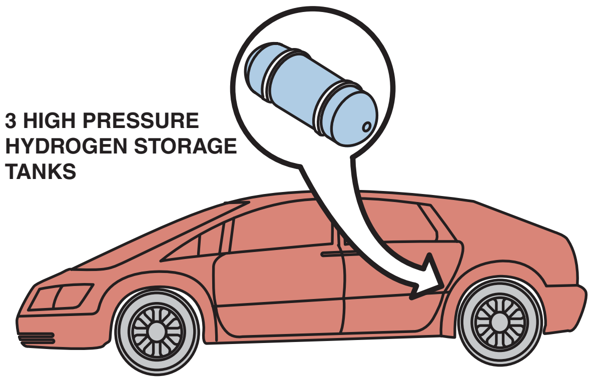


FIGURE 42–20 This GM fuel-cell vehicle uses compressed hydrogen in three high-pressure storage tanks.

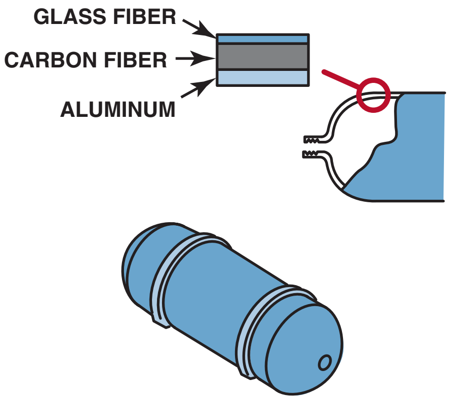


FIGURE 42–21 The Toyota FCHV uses high-pressure storage tanks that are rated at 350 bar. This is the equivalent of 5,000 pounds per square inch.

Power to and from the secondary battery is directed through the power control unit, which is also responsible for maintaining the battery pack's state of charge and for controlling and directing the output of the fuel-cell stack. ● **SEE FIGURE 42–19.**

During regenerative braking, the electric drive motor acts as a generator and converts kinetic (moving) energy of the vehicle into electricity for recharging the high-voltage battery pack. The PCU must take the three-phase power from the motor (generator) and convert (or *rectify*) this into DC voltage to be sent to the battery. DC power from the fuel cell will also be processed through the PCU for recharging the battery pack.

A DC-to-DC converter is used in hybrid-electric vehicles for converting the high voltage from the secondary battery pack into the 12 volts required for the remainder of the vehicle's electrical system. Depending on the vehicle, there may also be 42 volts required to operate accessories such as the electric-assist power steering. In fuel-cell hybrid vehicles, the DC-to-DC converter function may be built into the power control unit, giving it full responsibility for the vehicle's power distribution.

HYDROGEN STORAGE

One of the pivotal design issues with fuel-cell hybrid vehicles is how to store sufficient hydrogen onboard to allow for reasonable vehicle range. Modern drivers have grown accustomed to having a minimum of 300 miles between refueling stops, a goal that is extremely difficult to achieve when fueling the vehicle with hydrogen. Hydrogen has a very high energy content on a pound-for-pound basis, but its energy density is less than that of conventional liquid fuels. This is because gaseous hydrogen, even at high pressure, has a very low physical density (mass per unit volume). ● **SEE FIGURE 42–20.**

A number of methods of hydrogen storage are being considered for use in fuel-cell hybrid vehicles. These include high-pressure compressed gas, liquefied hydrogen, and solid storage in metal hydrides. Efficient hydrogen storage is one of the technical issues that must be solved in order for fuel cells to be adopted for vehicle applications. Much research is being conducted to solve the issue of onboard hydrogen storage.

HIGH-PRESSURE COMPRESSED GAS Most current fuel-cell hybrid vehicles use compressed hydrogen that is stored in tanks as a high-pressure gas. This approach is the least complex of all the storage possibilities, but also has the least energy density. Multiple small storage tanks are often used rather than one large one in order to fit them into unused areas of the vehicle. One drawback with this approach is that only cylinders can be used to store gases at the required pressures. This creates a good deal of unused space around the outside of the cylinders and leads to further reductions in hydrogen storage capacity. It is common for a pressure of 5000 PSI (350 bar) to be used, but technology is available to store hydrogen at up to 10000 PSI (700 bar). ● **SEE FIGURE 42–21.**

FIGURE 42–22 The high-pressure fitting used to refuel a fuel-cell hybrid vehicle.

FIGURE 42–23 Note that high-pressure hydrogen storage tanks must be replaced in 2020.

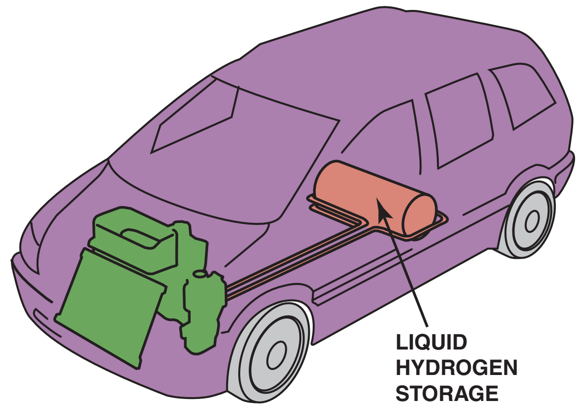


FIGURE 42–24 GM's Hydrogen3 has a range of 249 miles when using liquid hydrogen.

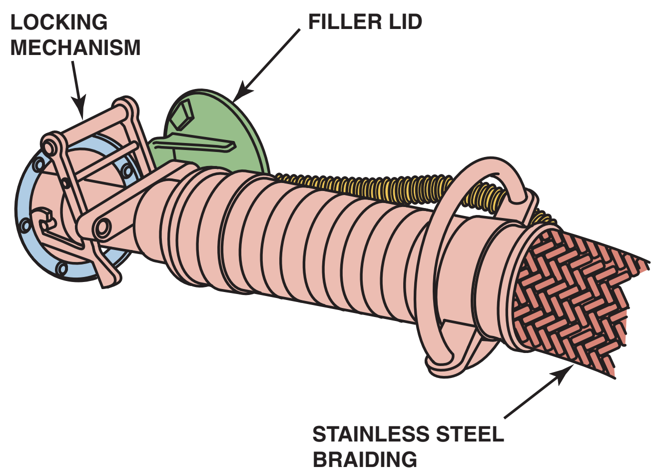


FIGURE 42–25 Refueling a vehicle with liquid hydrogen.

The tanks used for compressed hydrogen storage are typically made with an aluminum liner wrapped in several layers of carbon fiber and an external coating of fiberglass. In order to refuel the compressed hydrogen storage tanks, a special high-pressure fitting is installed in place of the filler neck used for conventional vehicles. ● **SEE FIGURE 42–22.** There is also a special electrical connector that is used to enable communication between the vehicle and the filling station during the refueling process. ● **SEE FIGURE 42–23.**

The filling station utilizes a special coupler to connect to the vehicle's high-pressure refueling fitting. The coupler is placed on the vehicle fitting, and a lever on the coupler is rotated to seal and lock it into place.

LIQUID HYDROGEN Hydrogen can be liquefied in an effort to increase its energy density, but this requires that it be stored in cryogenic tanks at −423°F (−253°C). This increases vehicle range, but impacts overall efficiency, as a great deal of energy is required to liquefy the hydrogen and a certain amount of the liquid hydrogen will "boil off" while in storage.

One liter of liquid hydrogen only has one-fourth the energy content of 1 liter of gasoline. ● **SEE FIGURES 42–24 AND 42–25.**

SOLID STORAGE OF HYDROGEN One method discovered to store hydrogen in solid form is as a metal hydride, similar to how a nickel-metal hydride (NiMH) battery works.

A demonstration vehicle features a lightweight fiber-wrapped storage tank under the body that stores 3 kg (about 6.6 pounds) of hydrogen as a metal hydride at low pressure. The vehicle can travel almost 200 miles with this amount of fuel. One kilogram of hydrogen is equal to 1 gallon of gasoline. Three gallons of water will generate 1 kilogram of hydrogen.

A metal hydride is formed when gaseous hydrogen molecules disassociate into individual hydrogen atoms and bond with the metal atoms in the storage tank. This process uses powdered metallic alloys capable of rapidly absorbing hydrogen to make this occur.

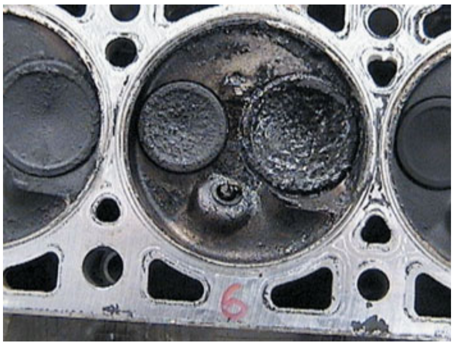


FIGURE 42–26 Carbon deposits, such as these, are created by incomplete combustion of a hydrocarbon fuel.

TECH TIP

Hydrogen Fuel = No Carbon

Most fuels contain hydrocarbons or molecules that contain both hydrogen and carbon. During combustion, the first element that is burned is the hydrogen. If combustion is complete, then all of the carbon is converted to carbon dioxide gas and exits the engine in the exhaust. However, if combustion is not complete, carbon monoxide is formed, plus leaving some unburned carbon to accumulate in the combustion chamber. ● **SEE FIGURE 42–26**.

HYDRAULIC HYBRID STORAGE SYSTEM

Ford Motor Co. is experimenting with a system it calls **Hydraulic Power Assist (HPA).** This system converts kinetic energy to hydraulic pressure, and then uses that pressure to help accelerate the vehicle. It is currently being tested on a four-wheel-drive (4WD) Lincoln Navigator with a 4.0-L V-8 engine in place of the standard 5.4-L engine.

A variable-displacement hydraulic pump/motor is mounted on the transfer case and connected to the output shaft that powers the front drive shaft. The HPA system works with or without 4WD engaged. A valve block mounted on the pump contains solenoid valves to control the flow of hydraulic fluid. A 14-gallon, high-pressure accumulator is mounted behind the rear axle, with a low-pressure accumulator right behind it to store hydraulic fluid. The master cylinder has a “deadband,” meaning the first few fractions of an inch of travel do not pressurize the brake system. When the driver depresses the brake pedal, a pedal movement sensor signals the control unit, which then operates solenoid valves to send hydraulic fluid from the low-pressure reservoir to the pump. The pumping action slows the vehicle, similar to engine compression braking, and the fluid is pumped into the high-pressure reservoir. Releasing the brake and pressing on the accelerator signals the control unit to send that high-pressure fluid back to the pump, which then acts as a hydraulic motor and adds torque to the drive line. The system can be used to launch the vehicle from a stop and/or add torque for accelerating from any speed.

While the concept is simple, the system itself is very complicated. Additional components include:

- Pulse suppressors
- Filters
- An electric circulator pump for cooling the main pump/motor

Potential problems with this system include leakage problems with seals and valves, getting air out of the hydraulic fluid system, and noise. In prototype stages the system demands different driving techniques. Still, this system was built to prove the concept, and the engineers believe that these problems can be solved and that a control system can be developed that will make HPA transparent to the driver. A 23% improvement in fuel economy and improvements in emissions reduction were achieved using a dynamometer set for a 7,000-pound vehicle. While the HPA system could be developed for any type of vehicle with any type of drive train, it does add weight and complexity, which would add to the cost.

HCCI

Homogeneous Charge Compression Ignition (HCCI) is a combustion process. HCCI is the combustion of a very lean gasoline air–fuel mixture without the use of a spark ignition. It is a low-temperature, chemically controlled (flameless) combustion process. ● **SEE FIGURE 42–27.**

HCCI combustion is difficult to control and extremely sensitive to changes in temperature, pressure, and fuel type. While the challenges of HCCI are difficult, the advantages include having a gasoline engine being able to deliver 80% of diesel efficiency (a 20% increase in fuel economy) for 50% of the cost. A diesel engine using HCCI can deliver gasoline-like emissions. Spark and injection timing are no longer a factor as they are in a conventional port-fuel injection system.

While much research and development needs to be performed using this combustion process, it has been shown to give excellent performance from idle to mid-load, and from ambient to warm operating temperatures as well as cold-start and run capability. Because an engine only operates in HCCI mode at light throttle settings, such as during cruise conditions at highway speeds, engineers need to improve the transition in and out of the HCCI mode. Work is also being done on piston and combustion chamber shape to reduce combustion noise and vibration that is created during operation in the HCCI operating mode.

Ongoing research is focusing on improving fuel economy under real-world operating conditions as well as controlling costs.

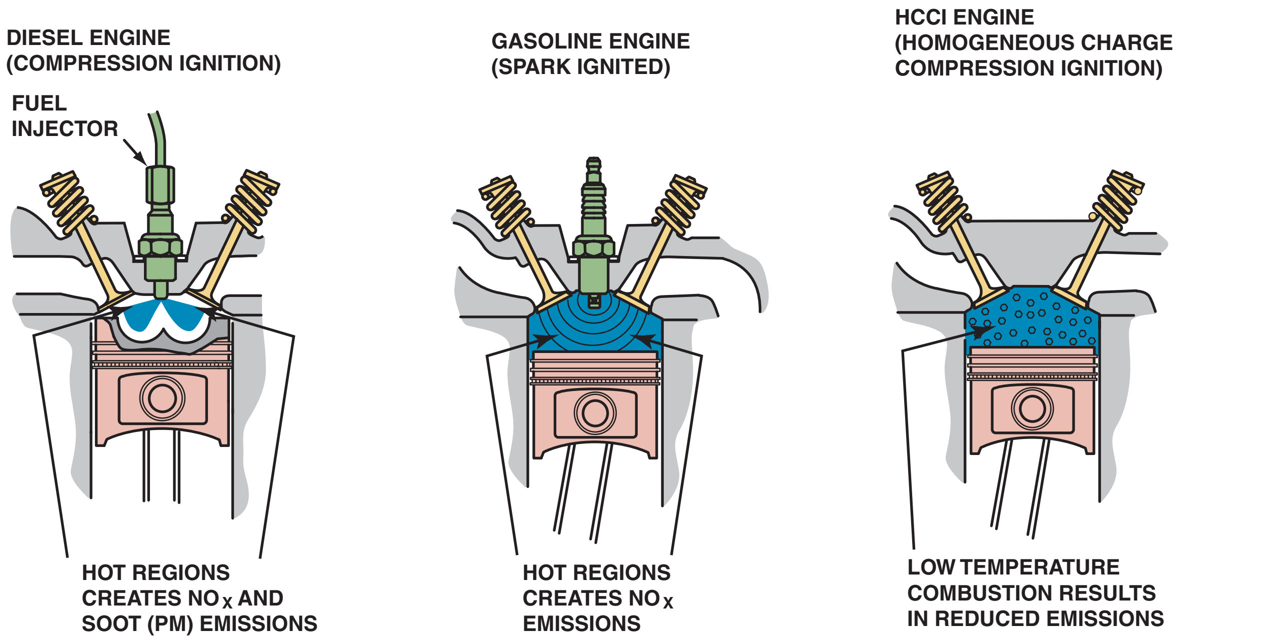


FIGURE 42–27 Both diesel and conventional gasoline engines create exhaust emissions due to high peak temperatures created in the combustion chamber. The lower combustion temperatures during HCCI operation result in high efficiency with reduced emissions.

PLUG-IN HYBRID ELECTRIC VEHICLES

A **plug-in hybrid electric vehicle (PHEV)** is a hybrid electric vehicle that is designed to be plugged into an electrical outlet at night to charge the batteries. By charging the batteries in the vehicle, it can operate using electric power alone (stealth mode) for a longer time, thereby reducing the use of the internal combustion engine (ICE). The less the ICE is operating, the less fuel is consumed and the lower the emissions. At the present time, plug-in hybrids are not offered by any major manufacturer but many conventional HEVs are being converted to plug-in hybrids by adding additional batteries.

If a production plug-in hybrid is built, it should be able to get about twice the fuel economy of a conventional hybrid. The extra weight of the batteries will be offset, somewhat, by the reduced weight of a smaller ICE. At highway speeds, fuel efficiency is affected primarily by aerodynamics, and therefore the added weight of the extra batteries is equal to one or two additional passengers and thus would only slightly reduce fuel economy. Recharging will normally take place at night during cheaper off-peak hours. Counting fuel and service, the total lifetime cost of ownership will be lower than a conventional gasoline-powered vehicle.

There are emissions related to the production of the electricity, which are called *well-to-wheel emissions*. These emissions, including greenhouse gases, are far lower than those of gasoline, even for the national power grid, which is 50% coal. Vehicles charging off-peak will use power from plants that cannot be turned off at night and often use cleaner sources such as natural gas and hydroelectric power. Plug-in hybrids could be recharged using rooftop photovoltaic systems, which would create zero emissions.

THE FUTURE FOR ELECTRIC VEHICLES

The future of electric vehicles depends on many factors, including:

1. The legislative and environmental incentives to overcome the cost and research efforts to bring a usable electric vehicle to the market.
2. The cost of alternative energy. If the cost of fossil fuels increases to the point that the average consumer cannot afford to drive a conventional vehicle, then electric vehicles (EVs) may be a saleable alternative.
3. Advancement in battery technology that would allow the use of lighter-weight and higher-energy batteries.

COLD-WEATHER CONCERNS Past models of electric vehicles such as the General Motors electric vehicle (EV1) were restricted to locations such as Arizona and southern California that had a warm climate, because cold weather is a major disadvantage to the use of electric vehicles for the following reasons:

- Cold temperatures reduce battery efficiency.
- Additional electrical power from the batteries is needed to heat the batteries themselves to be able to achieve reasonable performance.

FIGURE 42–28 A typical electric vehicle charging station on the campus of a college in southern California.

- Passenger compartment heating is a concern for an electric vehicle because it would require the use of resistance units or other technology that would reduce the range of the vehicle.

HOT-WEATHER CONCERNS Batteries do not function well at high temperatures, and therefore some type of battery cooling must be added to the vehicle to allow for maximum battery performance. This would then result in a reduction of vehicle range due to the use of battery power needed just to keep the batteries working properly. Besides battery concerns, the batteries would also have to supply the power needed to keep the interior cool as well as all of the other accessories. These combined electrical loads represent a huge battery drain and reduce the range of the vehicle.

RECHARGING METHODS AND CONCERNS How far an electric vehicle can travel on a full battery charge is called its **range.** The range of an electric vehicle depends on many factors, including:

- Battery energy storage capacity
- Vehicle weight
- Outside temperature
- Terrain (driving in hilly or mountainous areas requires more energy from the battery)
- Use of air conditioning and other electrical devices

Because electric vehicles have a relatively short range, charging stations must be made available in areas where these vehicles are driven. For example, when the state of California mandated the sale of zero-emission vehicles (ZEV), charging stations were set up in many areas, usually in parking lots of businesses and schools. ● **SEE FIGURE 42–28.** The parking spaces near the charging stations were designated for electric vehicles only and could be used for free to recharge electric vehicles. If electric vehicles are going to become widely used, charging stations will have to be established to allow the necessary recharging for trips to work and back home.

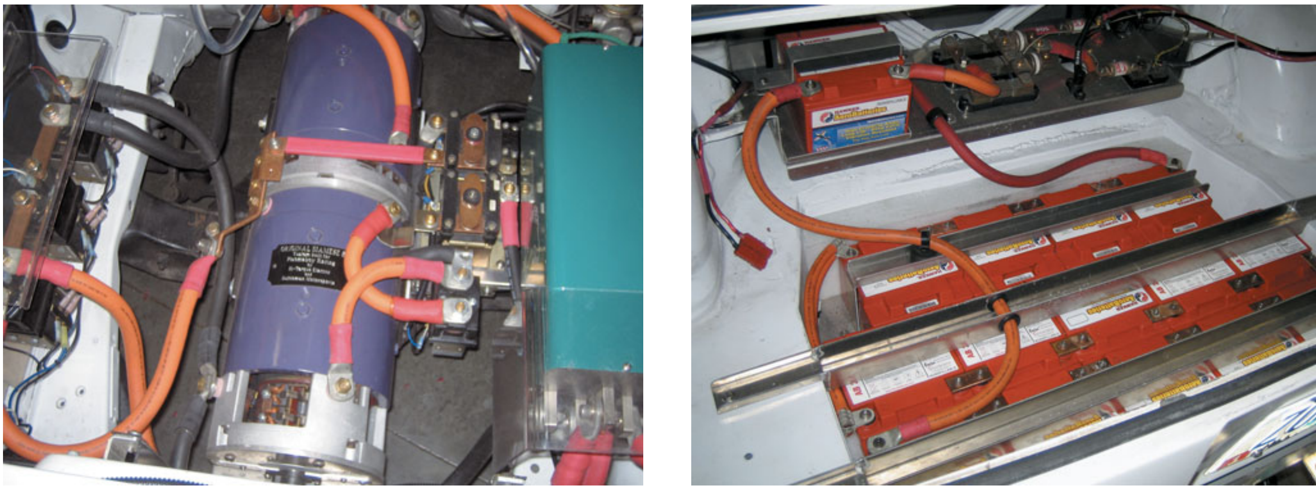
FIGURE 42–29 A conductive-type charging connector. This type of battery charging connector is sometimes called an AVCON connector, named for the manufacturer.

FIGURE 42–30 An inductive-type electric vehicle battery charger connector. This type of connector fits into a charging slot in the vehicle, but does not make electrical contact.

CHARGING METHODS When the state of California set up electric vehicle charging stations, both a conductive- and inductive-type charger was made available at each station.

CONDUCTIVE CHARGING Conductive charging uses an electrical plug that makes physical contact with terminals in the vehicle. The charger can be powered by 110-V AC, or most commonly 220-V AC. ● **SEE FIGURE 42–29.** This type of charger connection is used on some Ford and Honda electric vehicles.

INDUCTIVE CHARGING Inductive charging is achieved by inserting a paddlelike probe into a charging receptacle (opening) in the vehicle. The charger is powered by 220-volt AC and does not make physical contact with the vehicle. ● **SEE FIGURE 42–30.**



(a) (b)

FIGURE 42–31 (a) The motor in a compact electric drag car. This 8-inch-diameter motor is controlled by an electronic controller that limits the voltage to 170 volts to prevent commutator flash-over yet provides up to 2,000 amperes. This results in an amazing 340,000 watts or 455 Hp. (b) The batteries used for the compact drag car include twenty 12-volt absorbed glass mat (AGM) batteries connected in series to provide 240 volts.

? FREQUENTLY ASKED QUESTION

What Is NEDRA?

NEDRA is the **National Electric Drag Racing Association** that holds drag races for electric-powered vehicles throughout the United States. The association does the following:

1. Coordinates a standard rule set for electric vehicle drag racing, to balance the needs and interests of all those involved in the sport.
2. Sanctions electric vehicle drag racing events, to:
   - Make the events as safe as possible.
   - Record and maintain official records.
   - Maintain consistency on a national scale.
   - Coordinate and schedule electric vehicle drag racing events.
3. Promotes electric vehicle drag racing to:
   - Educate the public and increase people's awareness of electric vehicles while eliminating any misconceptions.
   - Have fun in a safe and silent drag racing environment.

● **SEE FIGURE 42–31.**

An inductive charger paddle contains a coil of wire and the AC current from the charger flows through the winding, which creates a moving magnetic field around the paddle. Inside the charging receptacle of the vehicle is another coil of wire. The alternating magnetic field induces an AC voltage in the coil winding.

The electronics in the vehicle then changes the induced AC current into DC current to charge the batteries. Inductive-type chargers are used with the General Motors EV-1, as well as Nissan and Toyota electric vehicles.

WIND POWER

Wind power is used to help supplement electric power generation in many parts of the country. Because AC electricity cannot be stored, this energy source is best used to reduce the use of natural gas and coal to help reduce CO_2 emissions. Wind power is most economical if the windmills are located where the wind blows consistently above 8 miles per hour (13 km/h). Locations include the eastern slope of mountain ranges, such as the Rocky Mountains, or on high ground in many states. Often, wind power is used as supplemental power in the evenings when it is most needed, and is allowed to stop rotating in daylight hours when the power is not needed. Windmills are usually grouped together to form **wind farms,** where the product is electrical energy. Energy from wind farms can be used to charge plug-in hybrid vehicles, as well as for domestic lighting and power needs. ● **SEE FIGURES 42–32 AND 42–33.**

HYDROELECTRIC POWER

Hydroelectric power is limited to locations where there are dammed rivers and hydroelectric plants. However, electricity can and is transmitted long distances—so that electricity

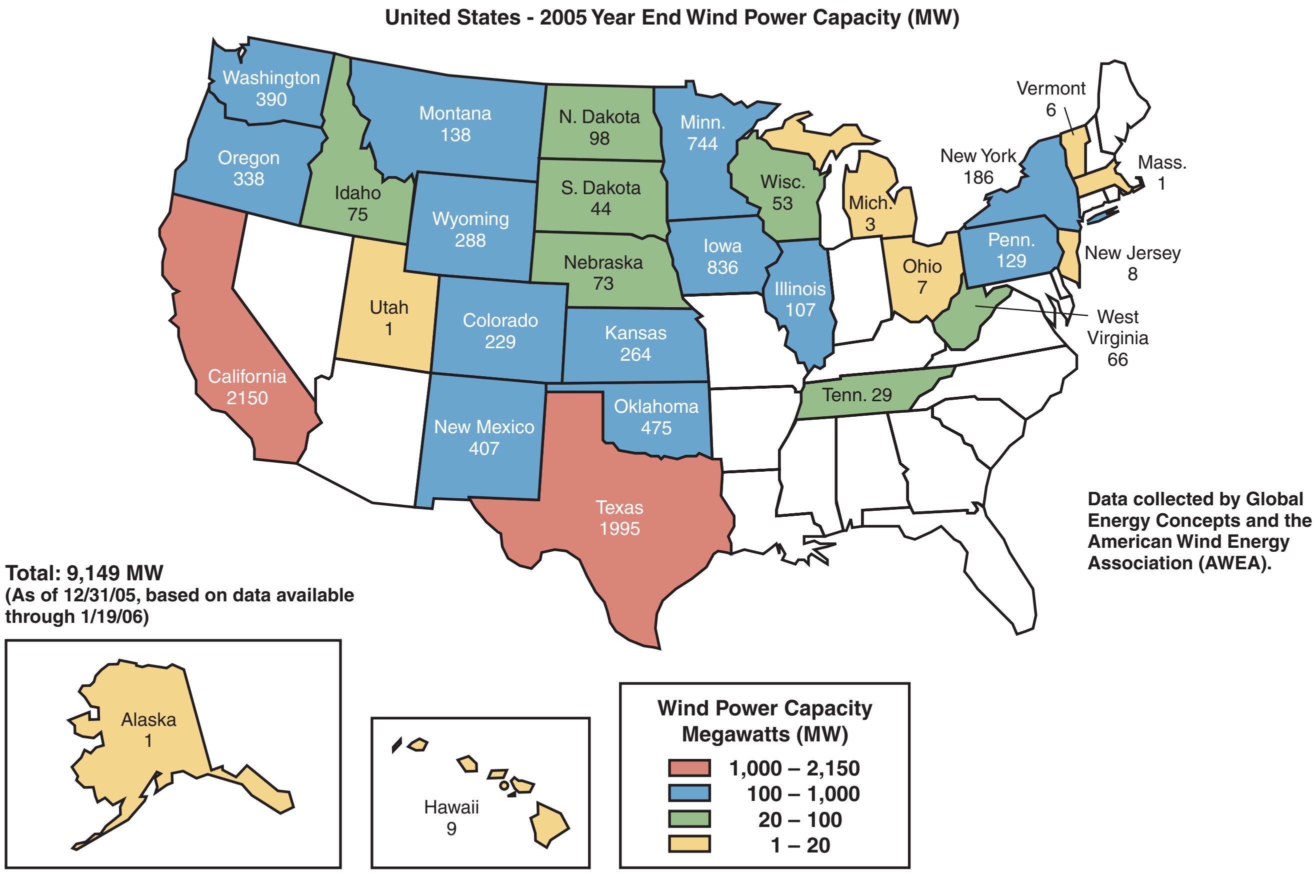


FIGURE 42–32 Wind power capacity by area. *(Courtesy of U.S. Department of Energy)*

FIGURE 42–33 A typical wind generator that is used to generate electricity.

FIGURE 42–34 The Hoover Dam in Nevada/Arizona is used to create electricity for use in the southwest United States.

generated at the Hoover Dam can be used in California and other remote locations. Electrical power from hydroelectric sources can be used to charge plug-in hybrid electric vehicles, thereby reducing emissions that would normally be created by burning coal or natural gas to create electricity. However, hydroelectric plants are limited as to the amount of power they can produce, and constructing new plants is extremely expensive. ● **SEE FIGURE 42–34.**

SUMMARY

1. The chemical reaction inside a fuel cell is the opposite of electrolysis in that electricity is created when hydrogen and oxygen are allowed to combine in the fuel cell.
2. A fuel cell produces electricity and releases heat and water as the only by-products.
3. The major disadvantages of fuel cells include:
   - High cost
   - Lack of hydrogen refueling stations
   - Short range
   - Freezing-temperature starting problems
4. Types of fuel cells include PEM (the most commonly used), PAFC, MCFC, and SOFC.
5. Ultracapacitors are an alternative to batteries for the storage of electrical energy.
6. A gasoline-powered engine can be more efficient if it uses a homogeneous charge compression ignition (HCCI) combustion process.
7. Plug-in hybrid electric vehicles could expand the range of hybrid vehicles by operating on battery power alone.
8. Wind power and hydroelectric power are being used to recharge plug-in hybrids and provide electrical power for all uses, without harmful emissions.

REVIEW QUESTIONS

1. How does a fuel cell work?
2. What are the advantages and disadvantages of fuel cells?
3. What are the uses of the various types of fuel cells?
4. How does an ultracapacitor work?
5. What are the advantages and disadvantages of using hydrogen?
6. What alternative power sources could be used for vehicles?

CHAPTER QUIZ

1. A fuel cell produces electricity from ____________ and ____________.
   a. Gasoline/oxygen
   b. Nitrogen/hydrogen
   c. Hydrogen/oxygen
   d. Water/oxygen
2. What are the by-products (emissions) from a fuel cell?
   a. Water
   b. CO_2
   c. CO
   d. Nonmethane hydrocarbon
3. Which type of fuel cell is the most likely to be used to power vehicles?
   a. PAFC
   b. PEM
   c. MCFC
   d. SOFC
4. Which liquid fuel could be used to directly power a fuel cell?
   a. Methanol
   b. Ethanol
   c. Biodiesel
   d. Unleaded gasoline
5. Which is *not* a function of an ultracapacitor?
   a. Can pass AC current
   b. Can be charged with DC current
   c. Discharges DC current
   d. Can pass DC current
6. Hydrogen is commonly stored at what pressure?
   a. 100,000 PSI
   b. 50,000 PSI
   c. 5,000 PSI
   d. 1,000 PSI
7. Hydrogen storage tanks are usually constructed from ____________.
   a. Steel
   b. Aluminum
   c. Carbon fiber
   d. Both b and c
8. HCCI is a process that eliminates what parts or components in a gasoline engine?
   a. Fuel tank
   b. Battery
   c. Fuel injectors
   d. Ignition system
9. A plug-in hybrid is different from a conventional hybrid electric vehicle because it has ____________.
   a. A built-in battery charger
   b. Li Ox batteries
   c. More batteries
   d. Bigger motor/generator
10. Which energy source(s) is (are) currently being used to help reduce the use of fossil fuels?
    a. Hydrogen
    b. Wind power
    c. Hydroelectric power
    d. Both b and c

appendix 1
NATEF TASK LIST CORRELATION CHART

ELECTRICAL/ELECTRONIC SYSTEMS (A6)

NATEF TASK LIST	TEXTBOOK PAGE NO.	WORKTEXT PAGE NO.
A. GENERAL ELECTRICAL SYSTEM DIAGNOSIS		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. P-1	4	4
2. Identify and interpret electrical/electronic system concern; determine necessary action. P-1	122–130	34
3. Research applicable vehicle and service information, such as electrical/electronic system operation, vehicle service history, service precautions, and technical service bulletins. P-1	1–3	5, 6, 7
4. Locate and interpret vehicle and major component identification numbers. P-1	1–3	8, 9
5. Diagnose electrical/electronic integrity of series, parallel, and series-parallel circuits using principles of electricity (Ohm's Law). P-1	63–73	16–24
6. Use wiring diagrams during diagnosis of electrical circuit problems. P-1	117–126	35
7. Demonstrate the proper use of a digital multimeter (DMM) during diagnosis of electrical circuit problems, including: source voltage, voltage drop, current flow, and resistance. P-1	78–92	25
8. Check electrical circuits with a test light; determine necessary action. P-2	77–78	26
9. Check electrical/electronic circuit waveforms; interpret readings and determine needed repairs.	94–99	28
10. Check electrical circuits using fused jumper wires; determine necessary action. P-2	76	27
11. Locate shorts, grounds, opens, and resistance problems in electrical/electronic circuits; determine necessary action. P-1	125–130	36
12. Measure and diagnose the cause(s) of excessive parasitic draw; determine necessary action. P-1	211–214	42
13. Inspect and test fusible links, circuit breakers, and fuses; determine necessary action. P-1	105–109	29
14. Inspect and test switches, connectors, relays, solenoid solid state devices, and wires of electrical/electronic circuits; perform necessary action. P-1	110–114	30, 38
15. Remove and replace terminal end from connector; replace connectors and terminal ends. P-1	110–111	31
16. Repair wiring harness (including CAN/BUS systems). P-1	110–114	32
17. Perform solder repair of electrical wiring. P-1	111–112	33
18. Identify location of hybrid vehicle high voltage circuit disconnect (service plug) location and safety procedures. P-2	30–31, 602–606	11, 122

NATEF TASK LIST	TEXTBOOK PAGE NO.	WORKTEXT PAGE NO.
B. BATTERY DIAGNOSIS AND SERVICE		
1. Perform battery state-of-charge test; determine necessary action. P-1	204–205	44
2. Perform battery capacity test; confirm proper battery capacity for vehicle application; determine necessary action. P-1	205–207	44
3. Maintain or restore electronic memory functions. P-1	212–213	45
4. Inspect, clean, fill, and/or replace battery, battery cables, connectors, clamps, and hold-downs. P-1	203	45
5. Perform battery charge. P-1	207–210	47
6. Start a vehicle using jumper cables or an auxiliary power supply. P-1	210	48
7. Identify high voltage circuits of electric or hybrid electric vehicle and related safety precautions. P-3	30–31, 209, 602–606	10, 123, 124
8. Identify electronic modules, security systems, radios, and other accessories that require reinitialization or code entry following battery disconnect. P-1	212	49
9. Identify hybrid vehicle auxiliary (12v) battery service, repair, and test procedures. P-3	208–209	50
C. STARTING SYSTEM DIAGNOSIS AND REPAIR		
1. Perform starter current draw tests; determine necessary action. P-1	231–232	54
2. Perform starter circuit voltage drop tests; determine necessary action. P-1	229–231	54
3. Inspect and test starter relays and solenoids; determine necessary action. P-2	232–233	55
4. Remove and install starter in a vehicle. P-1	232–234	56
5. Inspect and test switches, connectors, and wires of starter control circuits; perform necessary action. P-2	231	55
6. Differentiate between electrical and engine mechanical problems that cause a slow-crank or no-crank condition. P-2	231–232	54
D. CHARGING SYSTEM DIAGNOSIS AND REPAIR		
1. Perform charging system output test; determine necessary action. P-1	259–260	62
2. Diagnose charging system for the cause of undercharge, no-charge, and overcharge conditions. P-1	254–255	63
3. Inspect, adjust, or replace generator (alternator) drive belts, pulleys, and tensioners; check pulley and belt alignment. P-1	255–257	64
4. Remove, inspect, and install generator (alternator). P-1	261, 265	64
5. Perform charging circuit voltage drop tests; determine necessary action. P-1	258–259	65
E. LIGHTING SYSTEMS DIAGNOSIS AND REPAIR		
1. Diagnose the cause of brighter than normal, intermittent, dim, or no light operation; determine necessary action. P-1	274–279	66
2. Inspect, replace, and aim headlights and bulbs. P-2	282–284	66
3. Inspect and diagnose incorrect turn signal or hazard light operation; perform necessary action. P-2	280–282	66
4. Identify system voltage and safety precautions associated with high intensity discharge headlights. P-2	284–286	67

NATEF TASK LIST	TEXTBOOK PAGE NO.	WORKTEXT PAGE NO.
F. GAUGES, WARNING DEVICES, AND DRIVER INFORMATION SYSTEMS DIAGNOSIS AND REPAIR		
1. Inspect and test gauges and gauge sending units for cause of abnormal gauge readings; determine necessary action. P-1	300–303	68
2. Inspect and test connectors, wires, and printed circuit boards of gauge circuits; determine necessary action. P-3	307–308	69
3. Diagnose the cause of incorrect operation of warning devices and other driver information systems; determine necessary action. P-1	297–300	69
4. Inspect and test sensors, connectors, and wires of electronic (digital) instrument circuits; determine necessary action. P-3	307–308	69
G. HORN AND WIPER/WASHER DIAGNOSIS AND REPAIR		
1. Diagnose incorrect horn operation; perform necessary action. P-1	322–323	70
2. Diagnose incorrect wiper operation; diagnose wiper speed control and park problems; perform necessary action. P-1	324–329	71
3. Diagnose incorrect washer operation; perform necessary action. P-2	329–330	71
H. ACCESSORIES DIAGNOSIS AND REPAIR		
1. Diagnose incorrect operation of motor-driven accessory circuits; determine necessary action. P-1	343–348	72, 73
2. Diagnose incorrect heated glass, mirror, or seat operation; determine necessary action. P-3	341–342, 348–349	73
3. Diagnose incorrect electric lock operation (including remote keyless entry); determine necessary action. P-1	351–352	73
4. Diagnose incorrect operation of cruise control systems; determine necessary action. P-3	336–339	73
5. Diagnose supplemental restraint system (SRS) concerns; determine necessary action. P-1	375–377	77
6. Disarm and enable the airbag system for vehicle service. P-1	377	12, 78
7. Diagnose radio static and weak, intermittent, or no radio reception; determine necessary action. P-3	387, 395–398	37, 79
8. Remove and reinstall door panel. P-1	366–367	74
9. Diagnose body electronic system circuits using a scan tool; determine necessary action. P-2	188–191	75
10. Check for module communication (including CAN/BUS systems) errors using a scan tool. P-2	178–188	75
11. Diagnose the cause of false, intermittent, or no operation of anti-theft systems. P-3	359–364	76
12. Describe the operation of keyless entry/remote-start systems. P-3	352–359	76
13. Perform software transfers, software updates, or flash reprogramming on electronic modules. P-3	360–364	76

appendix 2

NATEF TASK LIST CORRELATION CHART

ENGINE PERFORMANCE (A8)

TASK	TEXTBOOK PAGE NO.	WORKTEXT PAGE NO.
A. GENERAL ENGINE DIAGNOSIS		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P-1)	4	4
2. Identify and interpret engine performance concern; determine necessary action. (P-1)	687	122
3. Research applicable vehicle and service information, such as engine management system operation, vehicle service history, service precautions, and technical service bulletins. (P-1)	3–4	89
4. Locate and interpret vehicle and major component identification numbers. (P-1)	1–3	80, 118
5. Prepare 4 or 5 gas analyzer; inspect and prepare vehicle for test, and obtain exhaust readings; interpret readings, and determine necessary action. (P-3)	549–551	107
B. COMPUTERIZED ENGINE CONTROLS DIAGNOSIS AND REPAIR		
1. Retrieve and record diagnostic trouble codes, OBD monitor status, and freeze frame data; clear codes when applicable. (P-1)	587–590	101
2. Diagnose the causes of emissions or driveability concerns with stored or active diagnostic trouble codes; obtain, graph, and interpret scan tool data. (P-1)	593–597	89, 119
3. Diagnose emissions or driveability concerns without stored diagnostic trouble codes; determine necessary action. (P-1)	589–590	102, 108
4. Check for module communication (including CAN/BUS systems) errors using a scan tool. (P-2)	188–191	119
5. Inspect and test computerized engine control system sensors, powertrain/engine control module (PCM/ECM), actuators, and circuits using a graphing multimeter (GMM)/digital storage oscilloscope (DSO); perform necessary action. (P-1)	410–414, 422–423, 432–433, 438–439, 447–451	40, 83–88
6. Perform active tests of actuators using a scan tool; determine necessary action. (P-1)	521, 533	82, 99
7. Describe the importance of running all OBDII monitors for repair verification. (P-1)	583–588	82
C. IGNITION SYSTEM DIAGNOSIS AND REPAIR		
1. Diagnose ignition system related problems such as no-starting, hard starting, engine misfire, poor driveability, spark knock, power loss, poor mileage, and emissions concerns; determine necessary action. (P-1)	472–476	90
2. Inspect and test ignition primary and secondary circuit wiring and solid state components; test ignition coil(s); perform necessary action. (P-1)	472–476	91, 94
3. Inspect and test crankshaft and camshaft position sensor(s); perform necessary action. (P-1)	463	95
4. Inspect, test, and/or replace ignition control module, powertrain/engine control module; re-program as necessary. (P-2)	463	95

TASK	TEXTBOOK PAGE NO.	WORKTEXT PAGE NO.
D. FUEL, AIR INDUCTION, AND EXHAUST SYSTEMS DIAGNOSIS AND REPAIR		
1. Diagnose hot or cold no-starting, hard starting, poor driveability, incorrect idle speed, poor idle, flooding, hesitation, surging, engine misfire, power loss, stalling, poor mileage, dieseling, and emissions problems; determine necessary action. (P-1)	524–537	103
2. Inspect and test fuel pumps and pump control systems for pressure, regulation, and volume; perform necessary action. (P-1)	493–499	96, 97
3. Replace fuel filters. (P-2)	493	98
4. Inspect throttle body, air induction system, intake manifold and gaskets for vacuum leaks and/or unmetered air. (P-2)	439	99
5. Inspect and test fuel injectors. (P-1)	527–533	104–106
6. Verify idle control operation. (P-1)	533–534	99
7. Perform exhaust system back-pressure test; determine necessary action. (P-1)	533–534	109
E. EMISSIONS CONTROL SYSTEMS DIAGNOSIS AND REPAIR		
1. Diagnose oil leaks, emissions, and driveability concerns caused by the positive crankcase ventilation (PCV) system; determine necessary action. (P-2)	563–565	110
2. Inspect, test, and service positive crankcase ventilation (PCV) filter/breather cap, valve, tubes, orifices, and hoses; perform necessary action. (P-2)	563–565	110
3. Diagnose emissions and driveability concerns caused by the exhaust gas recirculation (EGR) system; determine necessary action. (P-1)	559–561	111
4. Inspect, test, service, and replace components of the EGR system, including EGR tubing, exhaust passages, vacuum/pressure controls, filters, and hoses; perform necessary action. (P-1)	561	112
5. Inspect and test electrical/electronic sensors, controls, and wiring of exhaust gas recirculation (EGR) systems; perform necessary action. (P-2)	560–561	113
6. Diagnose emissions and driveability concerns caused by the secondary air injection and catalytic converter systems; determine necessary action. (P-2)	567–568	114
7. Inspect and test mechanical components of secondary air injection systems; perform necessary action. (P-3)	567	115
8. Inspect and test electrical/electronically-operated components and circuits of air injection systems; perform necessary action. (P-3)	567	115
9. Inspect and test catalytic converter efficiency. (P-1)	571–572	114
10. Diagnose emissions and driveability concerns caused by the evaporative emissions control system; determine necessary action. (P-1)	576–579	116
11. Inspect and test components and hoses of the evaporative emissions control system; perform necessary action. (P-1)	576–579	117
12. Interpret diagnostic trouble codes (DTCs) and scan tool data related to the emissions control systems; determine necessary action. (P-1)	561, 565, 568, 573	117

ENGLISH GLOSSARY

AC coupling A signal that passes the AC signal component to the meter, but blocks the DC component. Useful to observe an AC signal that is normally riding on a DC signal; for example, a charging ripple.

AC/DC clamp-on DMM A type of meter with a clamp placed around the wire to measure current.

Accumulator A temporary location for fluid under pressure.

Active crossover A type of crossover that uses electronic components to block certain frequencies.

Actuator An electromechanical device that performs mechanical movement as commanded by a controller.

Adhesive-lined heat shrink tubing A type of heat shrink tubing that shrinks to one-third of its original diameter and has glue inside.

Adjustable wrench A wrench with a movable jaw, allowing it to fit many sizes of fasteners.

AFS Active front headlight system. A name for the system that causes the headlights to turn when cornering.

AGM Absorbed glass mat. AGM batteries are lead-acid batteries, but use an absorbent material between the plates to hold the electrolyte. AGM batteries are classified as valve-regulated lead acid (VRLA) batteries.

AGST Aboveground storage tank, used to store used oil.

AIR Air injection reaction.

Airbag An inflatable fabric bag that deploys in the event of a collision severe enough to cause personal injury.

Alternator An electric generator that produces alternating current; also called an AC generator.

Alternator whine A noise made by an alternator with a defective diode(s).

AM Amplitude modulation.

American wire gauge A method used to measure wire diameter.

Ammeter An electrical test instrument used to measure amperes (unit of the amount of current flow).

Ampere The unit that measures the amount of current flow. Named for André Ampère (1775–1836).

Ampere-turns The unit of measurement for electrical magnetic field strength.

Analog-to-digital (AD) converter An electronic circuit that converts analog signals into digital signals that can then be used by a computer.

Anode The positive electrode; the electrode toward which electrons flow.

ANSI American National Standards Institute, an organization that publishes safety standards for safety glasses and other personal protective equipment.

Armature The rotating unit inside a DC generator or starter, consisting of a series of coils of insulating wire wound around a laminated iron core.

Arming sensor A sensor used in an airbag circuit that is most sensitive and completes the circuit; first of two sensors that are needed to deploy an airbag.

Asbestosis A health condition in which asbestos causes scar tissue to form in the lungs, causing shortness of breath.

ASD Automatic shutdown relay.

ASM Acceleration simulation mode.

ASTM American Society for Testing Materials.

Atom The smallest unit of matter that still retains its separate unique characteristic.

Auto link A type of automotive fuse.

Backlight Light that illuminates the test tool's display from the back of the LCD.

Baffle A plate or shield used to direct the flow of a liquid or gas.

BARO sensor Barometric pressure sensor.

BAS Belt alternator starter system. A hybrid electric vehicle system that uses a motor generator connected to the ICE through an accessory drive belt.

Base The name for the section of a transistor that controls the current flow through the transistor.

Battery cables Cables that attach to the positive and negative terminals of the battery.

Battery electrical drain test A test to determine if a component or circuit is draining the battery.

Baud rate The speed at which bits of computer information are transmitted on a serial data stream. Measured in bits per second (bps).

BCI Battery Council International.

Bench testing Testing a component such as a starter before installing it in the vehicle.

BEV Battery electric vehicle.

Bias voltage In electrical terms, bias is the voltage applied to a device or component to establish the reference point for operation.

Binary system A computer system that uses a series of zeros and ones to represent the information.

Bipolar transistor A type of transistor that has a base, emitter, and collector.

Bluetooth A short range wireless communication standard named after a Danish king that had a blue tooth.

BMAP Barometric manifold absolute pressure.

BNC connector Coaxial-type input connector. Named for its inventor, Neil Councilman.

BOB Break out box.

Bound electrons Electrons that are close to the nucleus of the atom.

Braided ground straps Ground wires that are not insulated and braided to help increase flexibility and reduce RFI.

Branches Electrical parts of a parallel circuit.

Breaker bar A handle used to rotate a socket; also called a flex handle.

Brush-end housing The end of a starter or generator (alternator) where the brushes are located.

Brushes A copper or carbon conductor used to transfer electrical current from, or to, a revolving electrical part such as that used in an electrical motor or generator.

Bump cap A hat that is hard and plastic to protect the head from bumps.

Burn-in A process of operating an electronic device for a period from several hours to several days.

BUS A term used to describe a communication network.

CAA Clean Air Act. Federal legislation passed in 1970 that established national air quality standards.

Calibration codes Codes used on many powertrain control modules.

California Air Resources Board A state of California agency which regulates the air quality standards for the state.

Campaign A recall where vehicle owners are contacted to return a vehicle to a dealer for corrective action.

CAN Controller area network. A type of serial data transmission.

Candlepower Measures the amount of light produced by a bulb.

CANP Canister purge.

Cap screw A bolt that is threaded into a casting.

Capacitance A term used to measure or describe how much charge can be stored in a capacitor (condenser) for a given voltage potential difference. Capacitance is measured in farads or smaller increments of farads such as microfarads.

Casting number An identification code cast into an engine block or other large cast part of a vehicle.

CAT III An electrical measurement equipment rating created by the International Electrotechnical Commission (IEC). CAT III indicates the lowest level of instrument protection that should be in place when performing electrical measurements on hybrid electric vehicles.

Catalytic converter An emission control device located in the exhaust system that changes HC and CO into harmless H_2O and CO_2. If a three-way catalyst, NO_x is also divided into harmless separate nitrogen (N_2) and Oxygen (O_2).

Cathode The negative electrode.

CCA Cold cranking amps. A rating of a battery tested at zero degrees F.

CCM Comprehensive component monitor.

Cells A group of negative and positive plates that form a cell capable of producing 2.1 V.

CEMF Counter electromotive force.

CFR Code of Federal Regulations.

Charging voltage test Using a voltmeter and an ammeter to test the condition of the charging circuit.

Cheater bar A pipe or other object used to lengthen the handle of a ratchet or breaker bar. Not recommended as the extra force can cause the socket or ratchet to break.

CHMSL Centrally high mounted stop light; the third brake light.

CHT Cylinder head temperature.

Circuit A circuit is the path that electrons travel from a power source, through a resistance, and back to the power source.

Circuit breaker A mechanical unit that opens an electrical circuit in the event of excessive flow.

Clamping diode A diode installed in a circuit with the cathode toward the positive. The diode becomes forward biased when the circuit is turned off, thereby reducing the high voltage surge created by the current flowing through a coil.

Class 2 A type of BUS communication used in General Motors vehicles.

Claw poles The magnetic points of a generator (alternator) rotor.

Clock generator A crystal that determines the speed of computer circuits.

Clockspring A flat ribbon of wire used under the steering wire to transfer airbag electrical signals. May also carry horn and steering wheel control circuits depending on the make and model of vehicle.

CMOS Complementary metal oxide semiconductor.

Coil-on-plug ignition system An ignition system without a distributor, where each spark plug is integrated with an ignition coil.

Cold solder joint A type of solder joint that was not heated to high enough temperature to create a good electrical connection. Often has a dull gray appearance rather than being shiny for a good solder connection.

Collector The name of one section of a transistor.

Color shift A term used to describe the change in the color of an HID arc tube assembly over time.

Combination circuit Another name for a series-parallel electrical circuit.

Commutator-end housing The end of a starter motor that contains the commutator and brushes. Also called the brush-end housing.

Complete circuit A type of electrical circuit that has continuity; current would flow if connected to power and ground.

Composite headlight A type of headlight that uses a separate, replaceable bulb.

Compound circuit Another name for a series-parallel electrical circuit.

Compression spring A spring that is part of a starter drive and acts on the starter pinion gear.

Condenser An A/C system component located in front of the radiator in most vehicles that removes heat from the refrigerant and causes it to change from a gas to a liquid.

Conductor A material that conducts electricity and heat. A metal that contains fewer than four electrons in its atom's outer shell.

Continuity Instrument setup to check wiring, circuits, connectors, or switches for breaks (open circuit) or short circuits (closed circuit).

Continuity light A test light that has a battery; it lights if there is continuity (electrical connection) between the two points that are connected to the tester.

Control wires The wires in a power window circuit used to control the operation of the windows.

Controller A term that usually refers to a computer or an electronic control unit (ECU).

Conventional theory The theory that electricity flows from positive (+) to negative (−).

Coulomb A measurement of electrons. A coulomb is 6.28 101 (6.28 billion) electrons.

Courtesy lights General term used to describe all interior lights.

CPA Connector position assurance. A clip used to help hold the two parts of an electrical connector together.

CPU Central processor unit.

Crest The outside diameter of a bolt measured across the threads.

Crimp-and-seal connectors A type of electrical connector that has glue inside which provides a weather-proof seal after it is heated.

Crossover An electronic circuit that separates frequencies in a sound (audio) system.

CRT Cathode ray tube.

Cruise control A system that maintains the desired vehicle speed. Also called speed control.

Darlington pair Two transistors electrically connected to form an amplifier. This permits a very small current flow to control a large current flow. Named for Sidney Darlington, a physicist at Bell Laboratories from 1929 to 1971.

dB Decibels.

DC coupling A signal transmission that passes both AC and DC signal components to the meter. See also AC coupling.

DDS Demand delivery system.

Deceleration sensor A sensor mounted to the body or frame of a vehicle that detects and measures the deceleration of the vehicle. Used to control the activation of the airbags and vehicle stability systems.

Deep cycling The full discharge, and then the full recharge, of a battery.

Despiking diode Another name for a clamping diode.

Detonation A violent explosion in the combustion chamber created by uncontrolled burning of the air–fuel mixture; often causes a loud, audible knock. Also known as spark knock or ping.

Dielectric Resistance to electrical penetration.

Digital A method of display that uses numbers instead of a needle or similar device.

Digital computer A computer that uses on and off signals only. Uses an A to D converter to change analog signals to digital before processing.

Diode An electrical device that allows current to flow in one direction only.

Direction wires The wires from the control switch to the lift motor on a power window circuit. The direction of current flow through these wires determines which direction the window moves.

DIS Distributorless ignition system.

Division A specific segment of a waveform, as defined by the grid on the display.

DLC Data link connector.

DMM Digital multimeter. A digital multimeter is capable of measuring electrical current, resistance, and voltage.

Doping The adding of impurities to pure silicon or germanium to form either P- or N-type material.

DOT Abbreviation for the Department of Transportation.

Double-layer technology Technology used to build ultracapacitors. Involves the use of two carbon electrodes separated by a membrane.

DPDT Double-pole, double-throw switch.

DPFE Delta pressure feedback EGR.

DPST Double-pole, single-throw switch.

Drive size The size in fractions of an inch of the square drive for sockets.

Drive-end (DE) housing The end of a starter motor that has the drive pinion gear.

DRL Daytime running lights. Lights that are located in the front of the vehicle and come on whenever the ignition is on. Some vehicles have to be moving before they come on. Used as a safety device on many vehicles and required in many countries such as Canada since 1990.

DSO Digital storage oscilloscope.

Dual inline pins A type of electronic chip that has two parallel lines of pins.

Dual-stage airbags Airbags that can deploy with minimum force, full force, or both together based on the information sent to the airbag controller regarding the forces involved in the collision.

Duty cycle Refers to the percentage of on-time of the signal during one complete cycle.

DVOM Digital volt-ohm-millimeter.

Dwell The amount of time, recorded on a dwell meter in degrees, that voltage passes through a closed switch.

Dynamic Voltage Voltage measured with the circuit energized and current flowing through the circuit.

E & C Entertainment and comfort.

EAC Electronic air control.

ECA Electronic control module. The name Ford used to describe the computer that controlled spark and fuel on older model vehicles.

ECM Electronic control module on a vehicle.

ECT Engine coolant temperature.

ECU Electronic control unit on a vehicle.

EDR Event data recorder. The hardware and software used to record vehicle information before, during, and after an airbag deployment.

EEPROM Electronically erasable programmable read-only memory.

EGR An emission control device used to reduce NO_x (oxides of nitrogen).

EI Electronic ignition.

EIS Electronic ignition system.

Electrical load Applying a load to a component such as a battery to measure its performance.

Electrical potential Another term to describe voltage.

Electricity The movement of free electrons from one atom to another.

Electrochemistry The chemical reaction that occurs inside a battery to produce electricity.

Electrolysis The process in which electric current is passed through water in order to break it into hydrogen and oxygen gas.

Electrolyte Any substance which, in solution, is separated into ions and is made capable of conducting an electric current. The acid solution of a lead-acid battery.

Electromagnet An electromagnet consists of a soft iron core surrounded by a coil of wire. Electrical current flowing through the coiled wire creates a magnetic field around the core.

Electromagnetic induction The generation of a current in a conductor that is moved through a magnetic field. Electromagnetic induction was discovered in 1831 by Michael Faraday.

Electromagnetism A magnetic field created by current flow through a conductor.

Electromotive force The force (pressure) that can move electrons through a conductor.

Electron theory The theory that electricity flows from negative (−) to positive (+).

Element Any substance that cannot be separated into different substances.

EMI Electromagnetic interference. An undesirable electronic signal. It is caused by a magnetic field building up and collapsing, creating unwanted electrical interference on a nearby circuit.

Emitter The name of one section of a transistor. The arrow used on a symbol for a transistor is on the emitter and the arrow points toward the negative section of the transistor.

Energy carrier Any medium that is utilized to store or transport energy. Hydrogen is an energy carrier because energy is used to generate hydrogen gas that is used as a fuel.

Energy density A measure of the amount of energy that can be stored in a battery relative to the volume of the battery container. Energy density is measured in terms of Watt-hours per liter (Wh/L).

Engine mapping A computer program that uses engine test data to determine the best fuel–air ratio and spark advance to use at each speed of the engine for best performance.

EPA Environmental Protection Agency.

EPM Electrical power management. A General Motors term used to describe a charging system control sensor and the control of the generator (alternator) output based on the needs of the vehicle.

ERFS Electronic returnless fuel system. A fuel delivery system that does not return fuel to the tank.

ESD Electrostatic discharge. Another term for ESD is static electricity.

EST Electronic spark timing.

ETC Electronic throttle control. The intake system throttle plate is controlled by a servo motor instead of a mechanical linkage. Also known as drive-by wire.

ETR Electronically tuned receiver.

EV Electric vehicle. A term used to describe battery-powered vehicles.

EVP EGR valve position.

EVRV Electronic vacuum regulator valve.

Extension A socket wrench tool used between a ratchet or breaker bar and a socket.

External trigger Using an oscilloscope to trigger or start another scope measuring a circuit.

Eye wash station A water fountain designed to rinse the eyes with a large volume of water.

Farad A unit of capacitance named for Michael Faraday (1791–1867), an English physicist. A farad is the capacity to store 1 coulomb of electrons at 1 volt of potential difference.

FCHV Fuel cell hybrid vehicle.

FCV Fuel cell vehicle.

Feedback The reverse flow of electrical current through a circuit or electrical unit that should not normally be operating. This feedback current (reverse-bias current flow) is most often caused by a poor ground connection for the same normally operating circuit.

FET Field effect transistor.

Fiber optics The transmission of light through special plastic that keeps the light rays parallel even if the plastic is tied in a knot.

Field coils Coils of wire wound around metal pole shoes to form the electromagnetic field inside an electric motor.

Field housing The part of a starter that supports the field coils.

Field poles The magnets used as field coils in a starter motor.

Fire blanket A fire-proof wool blanket used to cover a person who is on fire and smother the fire.

Fire extinguisher classes The types of fire extinguishers designed for specific types of fires.

Flare-nut wrench A type of wrench used to remove fuel, brake, or air-conditioning lines.

Floating ground An electrical system where neither the power nor ground circuits are connected to a chassis or body ground.

Flux density The density of the magnetic lines of force around a magnet or other object.

FM Frequency modulation.

Forward bias Current flow in normal direction.

Free electrons The outer electrons in an atom that has fewer than four electrons in its outer orbit.

Frequency The number of times a waveform repeats in one second, measured in Hertz (Hz), frequency band.

FTP Federal test procedure.

Fuel cell An electrochemical device that converts the energy stored in hydrogen gas into electricity, water, and heat.

Fuel trim A computer function that adjusts fuel delivery during closed-loop operation to bring the air–fuel mixture to as close to 14.7:1 as possible.

Fuel-cell stack A collection of individual fuel cells, which are stacked end-to-end into one compact package.

Full hybrid A hybrid electric vehicle that utilizes high voltages (200 volts and above) and is capable of propelling the vehicle using "all-electric" mode at low speeds. Also known as a "strong" hybrid.

Fuse An electrical safety unit constructed of a fine tin conductor that will melt and open the electrical circuit if excessive current flows through the fuse.

Fuse link A safety device used on a solvent washer which melts and causes the lid to close in the event of a fire. A type of fuse used to control the maximum current in a circuit.

Fusible link A type of fuse that will melt and open the protected circuit in the event of a short circuit, which could cause excessive current flow through the fusible link. Most fusible links are actually wires that are four gauge sizes smaller than the wire of the circuits being protected.

Gassing The release of hydrogen and oxygen gas from the plates of a battery during charging or discharging.

GAWR Gross axle weight rating. A rating of the load capacity of a vehicle; included on placards on the vehicle and in the owner's manual.

GDI A fuel injection system design in which gasoline is injected directly into the combustion chamber.

Gel Battery A lead-acid battery with silica added to the electrolyte to make it leak proof and spill proof.

Generator A device that converts mechanical energy into electrical energy.

Germanium A semiconductor material.

GMLAN GM local area network. A type of serial data transmission by General Motors.

GMM Graphing multimeter.

Grade The strength rating of a bolt.

Graticule The series of squares on the face of a scope. Usually 8 by 10 on a screen.

Grid The lead-alloy framework (support) for the active materials of an automotive battery.

Ground brushes The brushes in a starter motor that carry current to the housing of the starter or ground.

Ground plane A part of an antenna that is metal and usually the body of the vehicle.

Ground (return) path The electrical return path that the current flows through in a complete circuit.

Growler Electrical tester designed to test the starter and DC generator armatures.

GVWR Gross vehicle weight rating. The total weight of the vehicle including the maximum cargo.

Hall-effect switch A semiconductor moving relative to a magnetic field, creating a variable voltage output. Used to determine position. A type of electromagnetic sensor used in electronic ignition and other systems. Named for Edwin H. Hall, who discovered the Hall effect in 1879.

Hazard warning A sticker or decal warning that a hazard is close.

Heat-shrink tubing A type of rubber tubing that shrinks to about half of its original diameter when heated. Used over a splice during a wire repair.

Heat sink Usually, a metallic-finned unit used to keep electronic components cool.

HEI High energy ignition.

HEPA vacuum High efficiency particulate air filter vacuum used to clean brake dust.

Hertz A unit of measurement of frequency. One Hertz is one cycle per second, abbreviated Hz. Named for Heinrich R. Hertz, a 19th-century German physicist.

HEV Hybrid electric vehicle. Describes any vehicle that uses more than one source of propulsion, such as an internal combustion engine (ICE) and electric motor(s).

HID High intensity discharge. A type of headlight that uses high voltage to create an arc inside the arc tube assembly, which then produces a blue-white light.

High energy ignition The brand name for the electronic ignition used in General Motors vehicles.

High impedance meter A digital meter that has at least 10 million ohms of internal resistance as measured between the test leads, with the meter set to read volts.

High-pass filter A filter in an audio system that blocks low frequencies and only allows high frequencies to pass through to the speakers.

HO2S1 Heated oxygen sensor.

Hold-in winding One of two electromagnetic windings inside a solenoid; used to hold the movable core into the solenoid.

Hole theory A theory which states that as an electron flows from negative (−) to positive (+), it leaves behind a hole. According to the hole theory, the hole would move from positive (+) to negative (−).

HomeLink A brand name of a system used and included in many new vehicles to operate the automatic garage door opener.

Homogeneous-charge compression ignition A low-temperature combustion process that involves air–fuel mixtures being burned without the use of spark ignition.

Horn An electromechanical device that creates a loud sound when activated.

HOV lane High-occupancy vehicle lane. Sometimes known as the carpool or diamond lane.

HSD High-side drivers.

HV High voltage. Applies to any voltage above 50 volts.

HV cables Vehicle cables that carry high voltage.

Hybrid Abbreviated version of hybrid electric vehicle (HEV); a type of vehicle that uses two types of propulsion.

Hybrid flasher A type of flasher unit that can operate two or more bulbs at a constant rate.

Hydraulic power assist A hybrid vehicle configuration that utilizes hydraulic pumps and accumulators for energy regeneration.

Hydrometer An instrument used to measure the specific gravity of a liquid. A battery hydrometer is calibrated to read the expected specific gravity of battery electrolyte.

IAC Idle air control.

IAT Intake air temperature.

IC Ignition control.

ICE Internal combustion engine.

ICM Ignition control module.

Idle stop mode A phase in hybrid electric vehicle operation in which the internal combustion engine shuts off during idle operation.

IEC International Electrotechnical Commission.

Ignition coil An electrical device consisting of two separate coils of wire: a primary and a secondary winding. The purpose of an ignition is to produce a high-voltage (20,000 to 40,000 V), low amperage (about 80 mA) current necessary for spark ignition.

Ignition timing The exact point of ignition in relation to piston position.

Impedance The resistance of a coil of wire, measured in ohms.

Impurities Doping elements.

Independent switches Switch located at each door and used to raise or lower the power window for that door only.

Inductive ammeter A type of ammeter used as a Hall-effect sensor in a clamp that is used around a conductor carrying a current.

Inductive reactance An opposing current created in a conductor whenever there is a charging current flow in a conductor.

Input Information on data from sensors to an electronic controller is called input. Sensors and switches provide the input signals.

Input conditioning What the computer does to the input signals to make them useful; usually includes an analog-to-digital converter and other electronic circuits that eliminate electrical noise.

Insulated brushes Brushes used in a starter motor that connect to battery power through the solenoid.

Insulated path The power side of an electrical circuit.

Insulators Thin strips of plastic or hard rubber used to separate the leaves of a leaf spring.

Integral sensor A term used to describe a crash sensor that is built into the airbag control module.

Integrated circuit An electronic circuit that contains many circuits all in one chip.

Inverter An electronic device used to convert DC (direct current) into AC (alternating current).

IOD Ignition off draw. A Chrysler term used to describe battery electrical drain or parasitic draw.

Ion An atom with an excess or deficiency of electrons forming either a negative or a positive charged particle.

Ion-sensing ignition An electronic ignition system that uses the spark plug as a sensor to determine camshaft position, misfire, and knock.

ISC Idle speed control.

ISO International Standards Organization.

Jumper cables Heavy-gauge (4 to 00) electrical cables with large clamps, used to connect a vehicle that has a discharged battery to a vehicle that has a good battery.

Junction The point where two types of materials join.

KAM Keep-alive memory.

Kelvin A temperature scale where absolute zero is zero degrees. Nothing is colder than absolute zero.

Key Fob A decorative unit attached to keys. Often includes a remote control to unlock/lock vehicles.

Keyword A type of network communication used in many General Motors vehicles.

Kilo Means 1,000; abbreviated k or K.

Kirchhoff's current law A law that states: "The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction."

Kirchhoff's voltage law A law about electrical circuits that states: "The voltage around any closed circuit is equal to the sum (total) of the resistances."

Knock sensor A sensor that can detect engine spark knock.

KOEO Key-on–engine off test.

KOER Key-on–engine running test.

LAF Lean Air–Fuel Ratio Sensor.

LDP Leak detection pump.

LED Light-emitting diode. A high-efficiency light source that uses very little electricity and produces very little heat.

Left-hand rule A method of determining the direction of magnetic lines of force around a conductor. The left-hand rule is used with the electron flow theory (+ flowing to +).

Legs Another name for the branches of a parallel circuit.

Lenz's law The relative motion between a conductor and a magnetic field is opposed by the magnetic field of the current it has induced.

Leyden jar A device first used to store an electrical charge. The first type of capacitor.

Lineman's gloves Type of gloves worn by technicians when working around high-voltage circuits. Usually includes a rubber inner glove rated at 1,000 volts and a protective leather outer glove used for hybrid electric vehicle service.

Load A term used to describe a device an electrical current is flowing through.

Load test A type of battery test where an electrical load is applied to the battery and the voltage is monitored to determine the condition of a battery.

LOC Light-off converter.

Lock tang A mechanical tab that is used to secure a terminal into a connector. This lock tang must be depressed to be able to remove the terminal from the connector.

Lockout switch A lock placed on the circuit breaker box to ensure that no one turns on the electrical circuit while repairs are being made.

Logic probe A type of tester that can detect either power or ground. Most testers can detect voltage but most of the others cannot detect if a ground is present without further testing.

Low-grade heat Cooling system temperatures that are very close to the temperature of the ambient air, resulting in lowered heat transfer efficiency.

Low-pass filter A device in an audio system that blocks high frequencies and only allows low frequencies to pass to the speakers.

Low-water loss battery A type of battery that uses little water in normal service. Most batteries used in cars and light trucks use this type of battery.

LSD Low-side drivers.

Lumbar The lower section of the back.

MAF Mass airflow sensor.

Magnetic flux The lines of force produced in a magnetic field.

Magnetic induction The transfer of the magnetic lines of force to another nearby metal object or coil of wire.

Magnetism A form of energy that is recognized by the attraction it exerts on other materials.

Maintenance-free battery A type of battery that does not require routine adding of water to the cells. Most batteries used in cars and light trucks are maintenance-free design.

Malfunction indicator lamp This amber dashboard warning light may be labeled check engine or service engine soon.

MAP Manifold absolute pressure.

Master control switch The control switch for the power windows located near the driver who can operate all of the windows.

MCA Marine cranking amps. A battery specification.

Medium hybrid A hybrid electric vehicle design that utilizes "medium" voltage levels (between 50 and 200 volts). Medium hybrids use regenerative braking and idle stop but are not capable of starting the vehicle from a stop using electric mode.

Mega Million. Used when writing larger numbers or measuring large amounts of resistance.

Membrane electrode assembly The part of the PEM fuel cell that contains the membrane, catalyst coatings, and electrodes.

Meniscus The puckering or curvature of a liquid in a tube. A battery is properly filled with water when the electrolyte first becomes puckered.

Mercury A heavy metal.

Mesh spring A spring used behind the starter pinion on a starter drive to force the drive pinion into mesh with the ring gear on the engine.

Meter accuracy The accuracy of a meter measured in percent.

Meter resolution The specification of meter that indicates how small or fine a measurement the meter can detect and display.

Metric bolts Bolts manufactured and sized in the metric system of measurement.

Metric wire gauge The metric method for measuring wire size in square millimeters. This is the measure of the core of the wire and does not include the insulation.

Micro One-millionth of a volt or ampere.

Micro-hybrid drive A term used to describe belt alternator starter (BAS) and other mild hybrid systems.

Mild hybrid A hybrid electric vehicle design that utilizes regenerative braking and idle stop but cannot propel the vehicle in electric-only mode. Also called an assist hybrid; typically operates below 50 volts.

Milli One-thousandth of a volt or ampere.

MNHC Non-methane hydrocarbon.

Modulation The combination of these two frequencies is referred to as modulation.

Momentary switch A type of switch that toggles between on and off.

MOSFET Metal oxide semiconductor field-effect transistor. A type of transistor.

Motoring mode A phase of BAS hybrid vehicle operation where the motor-generator cranks the ICE to start it.

MOV Metal oxide varistor. An electronic device that operates like two back-to-back zener diodes.

MRFS A returnless fuel delivery system design that uses a mechanical pressure regulator located in the fuel tank.

MSDS Material safety data sheets.

Multiplexing A process of sending multiple signals of information at the same time over a signal wire.

Mutual induction The generation of an electric current due to a changing magnetic field of an adjacent coil.

N.C. Normally closed.

N.O. Normally open.

NEDRA National Electric Drag Racing Association.

Network A communications system used to link multiple computers or modules.

Neutral charge An atom that has the same number of electrons as protons.

Neutral safety switch A switch connected in series in the starter control circuit that allows operation of the starter motor to occur only when the gear selector is in neutral (N) or park (P).

NiMH Nickel-metal hydride. A battery design used for the high voltage batteries in most hybrid electric vehicles.

Node A module and computer that is part of a communications network.

NPN transistor A type of transistor that uses the P-type material in the base and the N-type material for the emitter and collector.

NTC Negative temperature coefficient. Usually used in reference to a temperature sensor (coolant or air temperature). As the temperature increases, the resistance of the sensor decreases.

N-type material Silicon or germanium doped with phosphorus, arsenic, or antimony.

O2 sensor Oxygen sensor.

OAD Override alternator dampener.

OAP Override alternator pulley.

OBD On-board diagnosis.

Occupant detection systems An airbag system with a sensor in the passenger seat to detect whether or not a passenger is seated in the passenger side and, if so, the weight range of that passenger.

Ohm The unit of electrical resistance. Named for Georg Simon Ohm (1787–1854).

Ohmmeter An electrical test instrument used to measure ohms (unit of electrical resistance).

Ohm's law An electrical law that requires 1 volt to push 1 ampere through 1 ohm of resistance.

OL Overload or over limit.

OP-amps Used in circuits to control and simplify digital signals.

Open circuit Any circuit that is not complete and in which no current flows.

Open circuit voltage Voltage measured without the circuit in operation.

Open-end wrench A type of wrench that allows access to the flats of a bolt or nut from the side.

Open-loop operation A phase of computer-controlled engine operation where the air–fuel mixture is calculated in the absence of oxygen sensor signals. During open loop, calculations are based primarily on throttle position, engine RPM, and engine coolant temperature.

ORVR Onboard refueling vapor recovery.

OSC Oxygen storage capacity.

Oscilloscope A visual display of electrical waves on a fluorescent screen or cathode ray tube.

OSHA Occupational Safety and Health Administration. OSHA is the main federal agency responsible for enforcement of workplace safety and health legislation.

Overrunning alternator dampener An alternator (generator) drive pulley that has a one-way clutch and a dampener spring used to smooth the operation of the alternator and reduce the stress on the drive belt.

Overrunning alternator pulley An alternator (generator) drive pulley that has a one-way clutch used to smooth the operation of the alternator and reduce the stress on the drive belt.

Overrunning clutch A mechanical coupling device that allows torque to be transmitted in one direction of rotation, but freewheels when turned in the opposite direction. Also known as a one-way clutch.

Ozone Oxygen rich (O_3) gas created by sunlight reaction with unburned hydrocarbons (HC) and oxides of nitrogen (NO_x); also called smog.

Pacific fuse element A type of automotive fuse.

Parallel circuit An electrical circuit with more than one path from the power side to the ground side. Has more than one branch or leg.

Parallel hybrid A hybrid vehicle design where the electric machine (or other source of energy) assists the ICE to propel the vehicle.

Parasitic load test An electrical test that measures how much current (amperes) is draining from the battery with the ignition off and all electrical loads off.

Partitions Separations between the cells of a battery. Partitions are made of the same material as that used on the outside case of the battery.

Passenger presence system An airbag system with a sensor in the passenger seat to detect whether or not a passenger is seated in the passenger side and, if so, the weight range of that passenger.

Passkey I and II A type of anti-theft system used in General Motors vehicles.

PATS Passive anti-theft system. A type of anti-theft system used in Ford, Lincoln, and Mercury vehicles.

PCM Powertrain control module.

PCV Pressure control valve.

PEFC Polymer electrolyte fuel cell.

Peltier effect A French scientist, Peltier found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the Peltier effect.

PEM Proton exchange membrane fuel cell. A low-temperature fuel cell known for fast starts and relatively simple construction.

Permanent magnet electric motors Electric motors that use permanent magnets for the field instead of electromagnets.

Permeability The measure of how well a material conducts magnetic lines of force.

PFE Pressure feedback EGR.

PHEV Plug-in hybrid electric vehicle.

Photodiodes A type of diode used as a sun-load sensor. Connected in reverse bias, the current flow is proportional to the sun load.

Photoelectricity When certain metals are exposed to light, some of the light energy is transferred to the free electrons of the metal. This excess energy breaks the electrons loose from the surface of the metal. They can then be collected and made to flow in a conductor, which is called photoelectricity.

Photons Light is emitted from an LED by the release of energy in the form of photons.

Photoresistor A semiconductor that changes in resistance with the presence or absence of light. Dark is high resistance and light is low resistance.

Phototransistor An electronic device that can detect light and turn on or off. Used in some suspension height sensors.

PID Parameter identification.

Pinch weld seam A strong section under a vehicle where two body panels are welded together.

Ping Secondary rapid burning of the last 3% to 5% of the air–fuel mixture in the combustion chamber. This causes a second flame front that collides with the first flame front, causing a knock noise. Also called detonation or spark knock.

Pitch The pitch of a threaded fastener refers to the number of threads per inch.

PIV Peak inverse voltage. A rating for a diode.

PNP transistor A type of transistor that used N-type material for the base and P-type material for the emitter and collector.

Polarity The condition of being positive or negative in relation to a magnetic pole.

Pole The point where magnetic lines of force enter or leave a magnet.

Pole shoes The metal part of the field coils in a starter motor.

Potentiometer A three-terminal variable resistor that varies the voltage drop in a circuit.

Porous lead Lead with many small holes to make a surface porous for use in battery negative plates; the chemical symbol for lead is Pb.

Power assist mode A phase of hybrid vehicle operation in which the ICE is assisted by the electric motor(s) to propel the vehicle.

Power source In electrical terms, the battery or generator (alternator).

Powertrain control module The on-board computer that controls both the engine management and transmission functions of the vehicle.

PPE Personal protective equipment, which can include gloves, safety glasses, and other items.

Pressure differential A difference in pressure from one brake circuit to another.

Pretensioners An explosive device used to remove the slack from a safety belt when an airbag is deployed.

Prevailing torque nut A special design of nut fastener that is deformed slightly or has other properties that permit the nut to remain attached to the fastener without loosening.

Primary wire Wire used for low voltage automotive circuits, typically 12 volts.

Programmable controller interface A type of network communications protocol used in Chrysler brand vehicles.

PROM Programmable read-only memory.

PRV See PIV.

P-type material Silicon or germanium doped with boron or indium.

Pull-in winding One of two electromagnetic windings inside a solenoid used to move a movable core.

Pulse train A DC voltage that turns on and off in a series of pulses.

Pulse width The amount of "on" time of an electronic fuel injector.

Pulse wipers Windshield wipers that operate intermittently. Also called delay wipers.

PVV A valve located in the fuel tank to prevent overpressure due to the thermal expansion of the fuel.

PWM Pulse-width modulation. The control of a device by varying the on-time of the current flowing through the device.

Radio choke A small coil of wire installed in the power lead, leading to a pulsing unit such as an IVR to prevent radio interference.

Radio frequency A high-frequency type of EMI that is in the radio frequency band.

RAM Random access memory.

Range The distance a vehicle can travel on a full charge or full-fuel tank without recharging or refueling. Range is measured in miles or kilometers.

RCRA Resource Conservation and Recovery Act.

Recall A notification to the owner of a vehicle that a safety issue needs to be corrected.

Recombinent battery A battery design that does not release gases during normal operation. AGM batteries are known as recombinant batteries.

Rectifier bridge A group of six diodes, three positive (+) and three negative (−), commonly used in alternators.

Relay An electromagnetic switch that uses a movable arm.

Reluctance The resistance to the movement of magnetic lines of force.

Reserve capacity The number of minutes a battery can produce 25 A and still maintain a battery voltage of 1.75 V per cell (10.5 V for a 12 V battery).

Residual magnetism Magnetism remaining after the magnetizing force is removed.

Resistance The opposition to current flow measured in ohms.

Reverse bias Current flow in the opposite direction from normal.

Rheostat A two-terminal variable resistor.

Right-hand rule A method of determining the direction of the magnetic lines of force in a current-carrying conductor. The right-hand rule is used with conventional current flow theory (+ flowing to −).

Right-to-know laws Laws that state that employees have a right to know when the materials they use at work are hazardous.

Ripple voltage Excessive AC voltage produced by a generator (alternator), usually caused by a defective diode.

RMS Root-mean-square.

ROM Read-only memory.

Rosin-core solder A type of solder for use in electrical repairs. Inside the center of the solder is a rosin that acts as a flux to clean and help the solder flow.

Rotor The rotating part of a generator where the magnetic field is created.

Rubber coupling A flexible connection between the power seat motor and the drive cable.

RVS Remote vehicle start. A General Motors term for the system that allows the driver to start the engine using a remote control.

SAE Society of Automotive Engineers.

SAI Secondary air injection.

SAR Supplemental air restraints. Another term used to describe an airbag system.

Saturation The point of maximum magnetic field strength of a coil.

SCR Silicon controller rectifier.

Screw jack assembly A screw jack that is used to raise or lower a power seat.

Sediment chamber A space below the cell plates of some batteries to permit the accumulation of sediment deposits flaking from the battery plates. A sediment chamber keeps the sediment from shorting the battery plates.

Self-induction The generation of an electric current in the wires of a coil created when the current is first connected or disconnected.

Semiconductor A material that is neither a conductor nor an insulator; it has exactly four electrons in the atom's outer shell.

Serial communication interface A type of serial data transmission used by Chrysler.

Serial data Data that is transmitted by a series of rapidly changing voltage signals.

Series circuit An electrical circuit that provides only one path for current to flow.

Series circuit laws Laws that were developed by Kirchhoff which pertain to series circuits.

Series-parallel circuits Any type of circuit containing resistances in both series and parallel in one circuit.

Series-parallel hybrid A hybrid vehicle design that can operate as a series hybrid, a parallel hybrid, or both series and parallel at the same time.

Series-wound field A typical starter motor circuit where the current through the field windings is connected in series with the armature before going to ground. Also called a series-wound starter.

SFI A fuel injection system in which injectors are pulsed individually in sequence with the firing order.

SHED Sealed housing for evaporative determination test.

Shims A thin metal spacer.

Short circuit A circuit in which current flows, but bypasses some or all the resistance in the circuit. A connection that results in a "copper-to-copper" connection.

Short to ground A short circuit in which the current bypasses some or all the resistance of the circuit and flows to ground. Because ground is usually steel in automotive electricity, a short to ground (grounded) is a "copper-to-steel" connection.

Short to voltage A circuit in which current flows, but bypasses some or all the resistance in the circuit. A connection that results in a "copper-to-copper" connection.

Shorted A condition of current not flowing due to a break in the system, such as a short circuit.

Shunt A device used to divert or bypass part of the current from the main circuit.

Shunt field A field coil used in a starter motor that is not connected to the armature in series but is grounded to the starter case.

Silicon A semiconductor material.

SIP State implementation plan.

SIR Supplemental inflatable restraints. Another term for airbags.

SKIS Sentry key immobilizer system. A type of antitheft system used in Chrysler vehicles.

SLA Abbreviation for short/long arm suspension.

SLI The battery that is responsible for starting, charging, and lighting in a vehicle's electrical system.

Slip-ring-end (SRE) housing The end of a generator (alternator) that has the brushes and the slip rings.

Socket A tool that fits over the head of a bolt or nut and is rotated by a ratchet or breaker bar.

Socket adapter An adapter that allows the use of one size of driver (ratchet or breaker bar) to rotate another drive size of socket.

Solar cells A device that creates electricity when sunlight hits a semiconductor material and electrons are released. About one kilowatt from a solar cell that is one square meter in size.

Solvent Usually colorless liquids that are used to remove grease and oil.

Spark knock Secondary rapid burning of the last 3% to 5% of the air–fuel mixture in the combustion chamber. Causes a second flame front that collides with the first flame front, causing a knock noise.

SPDT Single pole, double throw. A type of electrical switch.

Speakers A device consisting of a magnet, coil of wire, and a cone which reproduces sounds from the electrical signals sent to the speakers from a radio or amplifier.

Specific energy The energy content of a battery relative to the mass of the battery. Specific energy is measured in Watt-hours per kilogram (Wh/kg).

Specific gravity The ratio of the weight of a given volume of a liquid divided by the weight of an equal volume of water.

Spike protection resistor A resistor, usually between 300 and 500 ohms, that is connected in a circuit in parallel with the load. It helps reduce a voltage spike caused when a current following through a coil is turned off.

Splice pack A central point where many serial data lines jam together, often abbreviated SP.

Sponge lead Lead with many small holes used to make a surface porous or sponge-like for use in battery negative plates; the chemical symbol for lead is Pb.

Spontaneous combustion A condition that can cause some materials, such as oily rags, to catch fire without a source of ignition.

SPOUT Spark output.

SPST Single pole, single throw. A type of electrical switch.

Squib The heating element of an inflator module; it starts the chemical reaction to create the gas which inflates an airbag.

SRS Supplemental restraint system. Another term for an airbag system.

SST Special service tools.

Standard corporate protocol A type of serial data transmission used by Ford.

STAR Self-test automatic readout.

Starter drive A term used to describe the starter motor drive pinion gear with overrunning clutch.

Starter solenoid A type of starter motor that uses a solenoid to activate the starter drive.

State of health A signal sent by modules to all of the other modules in the network indicating that it is well and able to transmit.

Static electricity An electrical charge that builds up in insulators and then discharges to conductors.

Stator A name for three interconnected windings inside an alternator. A rotating rotor provides a moving magnetic field and induces a current in the windings of the stator.

Stiffening capacitor See powerline capacitor.

Strong hybrid Another term for "full hybrid." See full hybrid.

Stud A short rod with threads on both ends.

Subwoofer A type of speaker that is used to reproduce low frequency sounds.

Suppression diode A diode installed in the reverse bias direction. It is used to reduce the voltage spike created when a circuit that contains a coil is opened and the coil discharges.

SVR Sealed valve regulated. A term used to describe a type of battery that is valve regulated lead acid or sealed lead acid.

SWCAN An abbreviation for single wire CAN (controller area network).

TBI Throttle-body injection.

TED Thermoelectric device.

Tensile strength The maximum stress used under tension (lengthwise force) without causing failure.

Terminal The metal end of a wire which fits into a plastic connector and is the electrical connection part of a junction.

Terminating resistors Resistors placed at the end of a high-speed serial data circuit to help reduce electromagnetic interference.

Test light A light used to test for voltage. Contains a light bulb with a ground wire at one end and a pointed tip at the other end.

TFT Transmission fluid temperature.

THD Total harmonic distortion. A rating for an amplifier used in a sound system.

Thermistor A resistor that changes resistance with temperature. A positive-coefficient thermistor has increased resistance with an increase in temperature. A negative coefficient thermistor has decreased resistance with an increase in temperature.

Thermocouple Two dissimilar metals that, when connected and heated, create a voltage. Used for measuring temperature.

Thermoelectricity The production of current flow created by heating the connection of two dissimilar metals.

Threshold voltage Another name for barrier voltage or the voltage difference needed to forward bias a diode.

Through bolts The bolts used to hold the parts of a starter motor together. The long bolts go through field housing and into the drive-end housing.

Throws The term used to describe the number of output circuits in a switch.

TID Test identification.

Time base The setting of the amount of time per division when adjusting a scope.

Tone generator tester A type of tester used to find a shorted circuit that uses a tone generator. Headphones are used along with a probe to locate where the tone stops, which indicates where in the circuit the fault is located.

TOT Transmission oil temperature.

Total circuit resistance The total resistance in a circuit.

TP Throttle position.

Trade number The number stamped on an automotive light bulb. All bulbs of the same trade number have the same candlepower and wattage, regardless of the manufacturer of the bulb.

Transistor A semiconductor device that can operate as an amplifier or an electrical switch.

Trigger level The voltage level that a waveform must reach to start display.

Trigger slope The voltage direction that a waveform must have to start display. A positive slope requires the voltage to be increasing as it crosses the trigger level; a negative slope requires the voltage to be decreasing.

Troxler effect The Troxler effect is a visual effect where an image remains on the retina of the eye for a short time after the image has been removed. The effect was discovered in 1804 by Igney Paul Vital Troxler (1780–1866), a Swiss physician. Because of the Troxler effect, headlight glare can remain on the retina of the eye and create a blind spot.

TSB Technical service bulletin.

TTL Transistor-transistor logic.

Turns ratio The ratio between the number of turns used in the primary winding of the coil to the number of turns used in the secondary winding. In a typical ignition coil the ratio is 100:1.

TWC Three-way catalytic converter.

Tweeter A type of speaker used in an audio system that is designed to transmit high frequency sounds.

Twisted pair A pair of wires that are twisted together from 9 to 16 turns per foot of length. Most are twisted once every inch (12 per foot) to help reduce electromagnetic inference from being induced in the wires as one wire would tend to cancel out any interference pickup up by the other wire.

UART Universal asynchronous receive/transmit, a type of serial data transmission.

UBP UART-based protocol.

Ultracapacitor A specialized capacitor technology with increased storage capacity for a given volume.

UNC Unified national coarse.

Undercut A process of cutting the insulation, usually mica, from between the segments of a starter commutator.

UNF Unified national fine.

Universal joint A joint in a steering or drive shaft that allows torque to be transmitted at an angle.

Used oil Any petroleum-based or synthetic oil that has been used.

UST Underground storage tank.

Vacuum Any pressure less than atmospheric pressure (14.7 PSI).

VAF Vane airflow sensor.

Valence ring The outermost ring or orbit of electrons around a nucleus of an atom.

Vapor lock A lean condition caused by vaporized fuel in the fuel system.

Variable-delay wipers Windshield wipers whose speed can be varied.

Varistors Resistors whose resistance depends on the amount of voltage applied to them.

VATS Vehicle antitheft system. A system used on some General Motors vehicles.

VECI Vehicle emission control information. This sticker is located under the hood on all vehicles and includes emission-related information that is important to the service technician.

VIN Vehicle identification number.

VOC Volatile organic compounds. These compounds include gases emitted from paints, solvents, glass, and many other products.

Voice recognition A system which uses a microphone and a speaker connected to an electronic module which can control the operation of electronic devices in a vehicle.

Volt The unit of measurement for the amount of electrical pressure; named for Alessandro Volta (1745–1827).

Voltage drop Voltage loss across a wire, connector, or any other conductor. Voltage drop equals resistance in ohms times current in amperes (Ohm's law).

Voltmeter An electrical test instrument used to measure volts (unit of electrical pressure). A voltmeter is connected in parallel with the unit or circuit being tested.

VPW Variable pulse width, a type of data transmission to a scan tool.

VRLA Valve-regulated lead-acid battery. A sealed battery that is both spillproof and leakproof. AGM and gelled electrolyte are both examples of VRLA batteries.

Watt An electrical unit of power; 1 watt equals current (amperes) voltage (1/746 hp). Named after James Watt, a Scottish inventor.

Watt's law The formula for Watts is the voltage times the amperes in the circuit, which represents the electrical power in the circuit.

Wheel motors An electric motor that is mounted directly on the vehicle's wheel, eliminating the connecting drive shaft.

WHMIS Workplace hazardous materials information systems.

Wide band oxygen sensor An oxygen sensor design that is capable of detecting actual air–fuel ratios. This is in contrast to a conventional oxygen sensor that only changes voltage when a stoichiometric air–fuel ratio has been achieved.

Wind farms An area of land that is populated with wind-generating plants.

Window regulator A mechanical device that transfers the rotating motion of the window hand crank or electric motor to a vertical motion to raise and lower a window in a vehicle.

Windshield wipers The assembly of motor, motor control, and operating linkage, plus the wiper arms and blades which are used to remove rain water from the windshield.

Wiring schematic A drawing showing the wires and the components in a circuit using symbols to represent the components.

Wrench A hand tool used to grasp and rotate a threaded fastener.

Xenon headlights Headlights that use an arc tube assembly; the assembly has a xenon gas inside which produces a bright bluish light.

Zener diode A specially constructed (heavily doped) diode designed to operate with a reverse-bias current after a certain voltage has been reached. Named for Clarence Melvin Zener.

ZEV Zero-emission vehicle. This rating is typically only achieved by battery-powered vehicles or those powered by fuel cells.

SPANISH GLOSSARY

Absorbente de calor Un termino que generalmente se refiere a una unidad de metal con planos de derive que se usa para mantener frescos los componentes electrónicos.

Aceite usado Cualquier aceite elaborado a base de petróleo que ya ha sido usado previamente en un motor.

Acoplación soldada fría Un tipo de acoplación soldada que no ha sido calentada a una temperatura lo suficientemente caliente como para formar una buena conexión eléctrica. A menudo tiene una apariencia gris opaca, al contrario de una buena conexión eléctrica que suele exhibir una coloración brillante y dorada.

Acoplamiento de corriente alterna Una señal que permite el paso del componente de corriente alterna de la señal en su trayecto al medidor, pero que bloquea el componente de corriente directa. Sirve para observar una señal de corriente alterna que típicamente viaja sobre una señal de corriente directa; por ejemplo, una ola cargante. *Véase también* Acoplamiento de corriente directa.

Acoplamiento de corriente directa Una señal que pasa tanto el componente de corriente alterna como el componente de corriente directa al medidor. *Véase también* Acoplamiento de corriente alterna.

Acoplamiento de goma Una conexión flexible entre el motor del asiento eléctrico y el cable de arranque.

Actuador Un aparato electromecánico que realiza movimientos mecánicos dirigidos por un controlador.

Acumulador Un depósito o recipiente temporal para fluidos bajo presión.

Adaptador de buje Un instrumento utilizado para adaptar un tamaño de un propulsor de bujes o dados para ser usado con otro propulsor de bujes o dados de distinto tamaño tal como un maneral o barra rompedora.

Aerómetro Un instrumento que se usa para medir la gravedad específica de un líquido. Un aerómetro de la batería se calibra para medir la gravedad específica esperada de electrólito de batería.

AFS Siglas en inglés de Sistema activo de faros delanteros. Un término utilizado para designar un sistema que causa que los faros se enciendan cuando el vehículo está doblando una esquina.

AGM Siglas en inglés para diseño de lámina de vidrio absorbente. Las baterías *AGM* son baterías de plomo-acido, pero usan un material absorbente entre sus placas para retener los electrolitos. Las baterías *AGM* se clasifican como baterías reguladas por válvula de plomo-acido (*VRLA* por sus siglas en inglés).

AGST Siglas en inglés para tanque de almacenamiento no subterráneo, utilizado para almacenar combustible usado.

AIR Siglas en inglés de sistema de control de emisiones por reacción de inyección de aire.

Aislante Franjas delgadas de plástico o goma dura utilizadas para separar las placas de un resorte plano.

Alambre fusible (eslabón fusible) Fusible que se derrite y abre el circuito protegido en caso de que haya un corto circuito que puede resultar en un flujo de corriente excesivo a través del alambre fusible. La mayoría de los alambres fusibles en realidad son alambres cuyas entrevías tienen un cuarto del diámetro o del tamaño que el alambre de los circuitos que protegen.

Alambre-fusible de cartucho o fusible *Pacific* Un tipo de fusible automotriz.

Alambre primario Alambre utilizado para circuitos de bajo voltaje, usualmente aquellos de 12 voltios.

Alambres de dirección Los cables que van desde el interruptor de control al motor de elevación de un circuito de ventanas eléctricas. La dirección en la que fluyen estos cables o alambres determina la dirección en la cual se mueve la ventana.

Alternador Un generador eléctrico que produce corriente alterna. También se lo conoce como un generador de corriente alterna.

Altoparlante de superfrecuencias Un tipo de parlante utilizado en un sistema de sonido que está específicamente diseñado para transmitir en alta frecuencia.

Amortiguador del alternador de rotación libre (*OAD* por sus siglas en inglés) Una polea de propulsión del alternador (generador) que tiene un embrague unidireccional y un resorte o muelle de amortiguación que se usa para amortiguar el funcionamiento del alternador y reducir el la tensión en la banda o correa.

Amperímetro Un instrumento de medición eléctrica usado para medir amperes (la unidad de la cantidad de flujo de corriente).

Amperímetro inductivo Un tipo de amperímetro que utiliza un sensor de efecto Hall en una tenaza que se usa para envolver un conductor que transporta una corriente.

Amperio La unidad de la cantidad de flujo de corriente. Nombrada en honor a André Ampére (1775–1836).

Amperio-vueltas La unidad de medida para la fuerza de un campo electromagnético.

Anchura de pulso Duración del tiempo de encendido/ funcionamiento de un inyector de combustible electrónico.

Anchura de pulso variable Un tipo de transmisión de datos que van hacia un instrumento de exploración o escáner.

Ánodo El electrodo positivo hacía el cual fluyen los electrones.

ANSI Siglas en inglés para Instituto nacional estadounidense de estándares. Una organización que publica y disemina estándares de seguridad para anteojos de seguridad y otro tipo de equipo de seguridad personal.

A.O. Una abreviación de amplificador operacional o OP-amps por sus siglas en inglés. Usado en circuitos para controlar y simplificar las señales digitales.

Asbestosis Una condición médica en la que el asbestos produce la formación de tejido cicatrizal en los pulmones lo cual conduce a la falta de aliento.

ASD Siglas en inglés de relé de apagado automático.

ASM Siglas en inglés de Modo de Aceleración Simulada.

Aspiradora de filtro APEE Aspiradora con filtro de aire particulado de elevada eficiencia utilizado para limpiar el polvo de freno.

ASTM Siglas en inglés de la Sociedad Americana para Materiales de Prueba.

Átomo La unidad más pequeña de la materia que aún mantiene su identidad y características propias.

Auto inducción La generación de una corriente eléctrica en los alambres de una bobina cuando una corriente comienza o deja de fluir a través de éstos.

Ayuda hidráulica de propulsión Configuración en vehículos híbridos que utiliza bombas hidráulicas y botellas acumuladores para la regeneración de energía.

Banda de valencia El intervalo o banda de electrones más alto que rodea el núcleo de un átomo.

Barra alargadora Un tubo, barra u otro instrumento utilizado para aumentar la cantidad de fuerza aplicada a una llave, matraca o maneral. No se recomienda su uso puesto que puede causar que la llave o matraca se rompa infligiendo daño personal a aquel que lo intente.

Barra rompedora Una herramienta de mano que se utiliza para girar un buje.

BAS Siglas en ingles de sistema de arranque de la correa del alternador. Un sistema de vehículo eléctrico híbrido que usa un generador de motor conectado al motor de combustión interna a través de una correa de transmisión accesoria.

Base El nombre para la sección del transistor que controla el flujo de corriente a través del transistor.

Batería de arranque o tipo *SLI* La batería que se encarga del arranque el alumbrado y el encendido del sistema eléctrico de un automóvil.

Batería de baja perdida de agua Un tipo de batería que normalmente utiliza poca agua para su funcionamiento regular. La mayoría de las baterías utilizadas en automóviles y camiones ligeros son de este tipo.

Batería de gel Una batería de plomo-ácido sellada que se le añade silicio o dióxido de silicio y que actúa no solo contra los derrames pero también cuenta con protección en contra goteras.

Batería libre de mantenimiento Un tipo de batería que no requiere un aumento regular de agua a sus celdas. La mayoría de las baterías utilizadas en los automóviles y camionetas son de este tipo.

Batería recombinante Un diseño de batería que no libera los gases durante la operación normal. Las baterías tipo AGM son baterías tipo recombinantes.

BCI Siglas en inglés de Consejo Internacional de la Batería.

BEV Siglas en inglés de vehículo eléctrico de batería.

Bluetooth Un protocolo de comunicación inalámbrico con baja cobertura así llamado en honor a un rey nórdico que tenía un diente azul.

BMAP Siglas en inglés para presión de admisión barométrica absoluta.

BOB Siglas en inglés para caja de desconexión.

Bobina de choque Una bobina de escaso tamaño instalada en la guía de poder que se conecta con una unidad pulsatoria, tal como un regulador de voltaje de instrumentos, para prevenir la interferencia de ondas radioeléctricas.

Bobina de tracción Una de dos bobinas electromagnéticas dentro de un solenoide que se usa para mover un núcleo movible.

Bobina del encendido Aparato eléctrico que consta de dos bobinas distintas de alambre: un bobinado primario y uno secundario. El objetivo de un encendido es producir una corriente de alto voltaje (entre 20,000 y 40,000 V) y bajo amperaje (cerca de 80 mA) necesaria para producir el encendido de la chispa.

Bobinado de sujeción Uno de dos embobinados electromagnéticos dentro de un solenoide; se usa para fijar el núcleo movible del solenoide.

Bobinas de inducción Bobinas o alambre enroscado en superficies polares de metal para crear un campo magnético dentro de un motor eléctrico.

Bocina Un aparato electromecánico que produce un fuerte sonido al activarse.

Bolsa de aire Un saco de tela inflable que se activa y despliega en cuanto ocurre un choque lo suficientemente grave como para causar daño personal.

Bolsas de aire de dos etapas Bolsas de aire que se pueden activar ya sea con una fuerza mínima o con la fuerza máxima o ambas juntas dependiendo de la información recabada por el controlador de las bolsas de aire respecto a las fuerzas dinámicas presentes en la colisión.

Botella de Leyden Un aparato utilizado para almacenar una carga eléctrica por primera vez. El primer tipo de condensador o capacidor.

Buje, casco o casquillo Un instrumento utilizado con el objetivo de retener el cabezal de un perno o tuerca para posteriormente girarlo por medio de un maneral o barra rompedora.

Bus de datos Un termino utilizado para describir una red de comunicación.

CAA Siglas en inglés para *Clean Air Act.* Legislación federal adoptada en 1970, y actualizada en 1990, que introdujo estándares de calidad de aire a nivel nacional.

Cables de batería Los cables que se adhieren a los terminales negativos y positivos de la batería.

Cables de control Los cables utilizados en los circuitos de las ventanas eléctricas y que son utilizados para controlar el funcionamiento de las ventanas del vehículo.

Cables *HV* Cables en un vehículo que traen un alto voltaje.

Cables para paso de corriente Cables eléctricos pesados (4 a 00) con abrazaderas grandes que se usan para conectar un vehículo con una batería descargada a otro que tiene una batería cargada.

Caída de tensión Pérdida de voltaje a través de un alambre, conector o cualquier otro conductor cuando fluye una corriente a través de un circuito. La caída de voltaje equivale a la resistencia en ohmios por la corriente en amperios (la Ley de Ohm).

Caja de extremo de arranque El puntal de un motor de arranque que contiene el piñón satélite de arranque.

Caja del extremo de las escobillas La punta de un arrancador o generador (alternador) donde se ubican los escobillones.

Caja final del colector El extremo o parta trasera de un motor de arranque que contiene el colector o conmutador y las escobillas. También conocido como la caja del extremo de las escobillas.

Calor de baja energía Temperaturas en sistemas de refrigeración, las cuales son muy parecidas a la temperatura del aire ambiente, lo cual produce una eficiencia reducida de la transferencia de calor.

Cámara del sedimento Un espacio debajo de los platos de la célula de algunas baterías que se utiliza para recolectar la acumulación de sedimento que se desprende de los platos de la batería. El uso de una cámara de sedimento previene que el sedimento cause un corto circuito en las placas de la batería.

Camino de retorno a tierra El camino de retorno a través del cual fluye la corriente en un circuito cerrado.

Camino HOV Camino de vehículos de muchos pasajeros. A veces se llama el camino *carpool,* o de coches compartidos, en las carreteras urbanas.

Campaña Una llamada de atención mediante la cual los dueños de un vehículo son contactados para devolver el vehículo a una concesionaria de venta de vehículos para que dicho vehículo se pueda reparar.

Campo de arrollado en serie Un típico circuito de encendido de motor donde la corriente que atraviesa el campo embobinado está conectado en serie con el inducido antes de salir a tierra. También llamado un encendido arrollado en serie.

Campo derivado Una bobina de campo usada en un motor de arranque que no está conectada al inducido de forma serial y, al contrario, está puesta en tierra a través de la caja de encendido.

CAN Siglas en inglés de red de control de área. Un tipo de transmisión de datos en serie.

CANP Siglas en inglés para purga del cánister.

Capacidad de reserva El número de minutos que una batería puede producir 25 amperios y aun así mantener un voltaje de 1.75 voltios por celda (10.5 voltios para una batería de 12 voltios).

Capacidor tipo Stiffening™ *Véase* Condensador de alto voltaje.

Capacitancia La capacitancia eléctrica es un término usado para medir o describir la cantidad de carga que se puede almacenar en un capacitor (condensador) para un cierto diferencial potencial de voltaje. La capacitancia se mide en faradios o en incrementos menores de faradios tal como los microfaradios.

Carcasa o casco del arrancador El componente de un arrancador que sostiene las bobinas de campo.

Carga Un termino usado para describir un aparato cuando una corriente eléctrica fluye a través de el.

Carga eléctrica La acción de aplicar una carga a un componente tal como una batería a fin de medir su desempeño.

Carga neutral Un átomo que tiene el mismo número de electrones y protones.

Casco Un gorro plástico y duro que protege la cabeza de potenciales golpes.

CAT III Una medida para equipos de medición eléctrica creada por la Comisión Electrotécnica Internacional (*IEC* por sus siglas en inglés). El modelo CAT III indica el nivel más bajo de protección instrumental que debería estar implementada cuando se realizan medidas electrónicas en vehículos eléctricos híbridos.

Cátodo El electrodo negativo.

CCA Siglas en inglés de capacidad de amperaje de arranque en frío. Una clasificación de batería probada a –18°C (0°F).

CCM Siglas en inglés para monitor de componente integral.

Célula de combustible o energética Un dispositivo electroquímico que convierte la energía almacenada en gas hidrogeno a electricidad, agua y calor.

Célula fotovoltaica Un aparato que produce electricidad como resultado de la liberación de electrones cuando la luz solar choca contra un material semiconductor. Se produce aproximadamente un kilovatio de electricidad en una célula fotovoltaica de un metro cuadrado de tamaño.

Células Un grupo de placas negativas y positivas que forman una célula capaz de producir 2,1 V.

CEMF Siglas en inglés para fuerza contraelectromotriz.

CFR Siglas en inglés para el Código de Regulaciones Federales.

Chip de doble línea de pines (*DIP* por sus siglas en inglés) Un tipo de chip electrónico que contiene dos líneas paralelas de pines.

CHMSL Siglas en inglés para luz montada al centro superior; la tercera luz de freno.

CHT Siglas en inglés para temperatura del cabezal del cilindro.

Ciclado o ciclaje completo La descarga completa de una batería seguida de una recarga completa.

Ciclo de duración Porcentaje de tiempo en el que una señal se mantiene encendida durante un ciclaje completo.

Circuito El trayecto por el que viajan los electrones desde una fuente de poder, a través de una resistencia, y de regreso a la fuente de poder.

Circuito abierto Cualquier circuito que no esta cerrado y en el cual no fluye la corriente.

Circuito combinado Otro nombre para un circuito eléctrico en serie paralelo.

Circuito completo Un tipo de circuito eléctrico que tiene continuidad y en el que la corriente fluiría si es que estuviese conectado a la corriente y puesto a tierra.

Circuito compuesto Otro nombre para un circuito eléctrico en serie paralelo.

Circuito en paralelo Un circuito eléctrico que sigue más de un trayecto desde la fuente de poder hasta el puesto a tierra. Tiene más de un brazo o pata.

Circuito en serie Un circuito eléctrico que proporciona sólo un camino para que fluya la corriente.

Circuito en serie paralelo Cualquier circuito que contenga resistencias tanto en serie como en paralelo en un solo circuito.

Circuito integrado (CI) Un circuito electrónico que a su vez contiene múltiples circuitos en un solo chip.

Clase 2 Un tipo de protocolo de comunicación Bus utilizado por los vehículos de *General Motors*.

CMOS Siglas en inglés para oxido de metal complementario.

Códigos de calibración Códigos usados en muchos de los módulos de control del tren de fuerza.

Colector El nombre que se da a una sección del transistor.

Combustión espontánea Un fenómeno por el cual un incendio comienza espontáneamente en trapos llenos de aceite o grasa sin que éste tenga una fuente de ignición aparente.

Compensador de gasolina Una función de la computadora vehicular que ajusta la provisión de combustible durante la fase de operación de ciclo cerrado para que la mezcla aire/combustible se aproxime lo más posible a una proporción de 14.7:1.

Comprobador de generador de audiofrecuencia Un tipo de aparato de pruebas usado para encontrar un cortocircuito mediante el uso de un generador de audiofrecuencia. Se utilizan audífonos y una sonda para comprobar dónde termina la audiofrecuencia lo cual indica dónde se encuentra la falla en el circuito.

Compuesto orgánico volátil Estos compuestos incluyen los gases emitidos por pinturas, disolventes, vidrio y muchos otros productos.

Computadora digital Una computadora que solo usa señales de encendido y apagado. Usa un convertidor A a D para transformar las señales analógicas antes de comenzar a procesarlas.

Condensador Un componente del sistema de aire condicionado localizado en la parte delantera del radiador que retira el calor del refrigerante y causa que éste sufra un cambio de un estado gaseoso a uno líquido.

Condensador de alto voltaje Un condensador utilizado para reforzar la salida de un sistema de sonido que mueve los parlantes especialmente cuando reproduce las frecuencias bajas.Conductor Un material que conduce la electricidad y el calor. Un metal que tienen menos de cuatro electrones en el aro exterior de su átomo.

Conductor doble retorcido Un par de cables trenzados en una ratio de 9 a 16 vueltas por pie longitudinal. La mayoría de estos cables se trenzan una vez cada pulgada (12 vueltas por cada pie longitudinal) para ayudar a reducir la interferencia electromagnética que podría resultar al ser inducidos en el alambrado.

Conector *BNC* Un mini conector de entrada estándar de tipo coaxial. Nombrado por sus inventores Paul Neill y Carl Concelman.

Conector de presión y de sello Un tipo de conector eléctrico que contiene pegamento en su cara interior lo cual le proporciona un sellado a prueba de agua después de que éste ha sido calentado.

Control de crucero Un sistema que mantiene la velocidad deseada del vehículo. También conocido como *control de velocidad.*

Control eléctrico de ventana Un dispositivo mecánico que transforma el movimiento giratorio del manivela manual de la ventana o del motor eléctrico en un movimiento vertical para subir o bajar una de las ventanas en un vehículo.

Controlador Un término utilizado para referirse a una computadora vehicular o unidad de control electrónico (*ECU* por sus siglas en inglés).

Controlador de Interconexión Programable (*PCI* por sus siglas en inglés) Un tipo de protocolo de comunicación de red utilizado en vehículos marca *Chrysler*.

Convertidor Aparato electrónico que se usa para convertir CD (corriente directa) en CA (corriente alterna).

Convertidor catalítico Un mecanismo de control de emisiones ubicado en el sistema de escape que convierte el HC y el CO en H_2O y CO_2 inocuos. En un catalizador de tres vías, el NOx también se divide en nitrógeno (N_2) y oxígeno (O_2).

Convertidor de análogo a digital (*ADC* por sus siglas en inglés) Un circuito electrónico que convierte señales análogas en señales digitales que pueden ser usadas por una computadora.

Corriente de diseño Flujo de corriente en la dirección normal.

Corto a tierra Circuito corto por lo cual la corriente fluye pero evita algo de o toda la resistencia en el circuito y fluye a tierra. Porque el suelo es generalmente acero en la electricidad automotriz, un corto a tierra (puesto a tierra) es una conexión cobre a acero.

Cortocircuito Circuito en que la corriente fluye pero evita un poco de o toda la resistencia en el circuito; una conexión que tiene como resultado una conexión cobre a acero.

Cortocircuito al voltaje Circuito en que la corriente fluye pero evita un poco de o toda la resistencia en el circuito; una conexión que tiene como resultado una conexión 'cobre a cobre.

Coulomb Una unidad de medida de los electrones. Un coulomb consta de 6.28×10^{18}, es decir, seis mil doscientos ochenta (6,280) millones de electrones.

CPA Siglas en inglés para clip de conector de posición. Un clip utilizado para ayudar a mantener juntas los dos componentes de un conector eléctrico.

CPU Siglas en inglés para unidad de procesamiento central.

Cresta El diámetro externo de un tornillo medido de rosca a rosca.

Cristal oscilante Un cristal que determina la velocidad de los circuitos electrónicos.

Crossover activo Un tipo de circuito divisor de frecuencias que usa componentes electrónicos para bloquear ciertas frecuencias.

CRT Siglas en inglés para tubo de rayo catódico.

Cuadrícula Conjunto de cuadrados en la cara de un osciloscopio. Usualmente de entre 8 a 10 en una pantalla.

dB Símbolo de decibelio.

DDS Siglas en inglés para sistema de provisión por demanda.

Densidad de la energía Una medida de la cantidad de energía que puede ser almacenada en una batería relativa al volumen del contenedor de la batería. La densidad de la energía es medida en términos de Watts por hora por litro (Wh/L).

Densidad del flujo La densidad de las líneas de fuerza magnética que rodean un imán u otro objeto.

Derivación Artefacto que se usa para desviar parte de la corriente del circuito principal.

Derivación Partes eléctricas de un circuito eléctrico paralelo.

Detonación Una explosión violenta en la cámara de combustión creada por una incineración incontrolada de la mezcla aire y combustible; generalmente causa un golpeteo fuerte y audible. También conocido como golpeteo o ping.

Diagrama de conexiones eléctricas Un diagrama que consiste en una serie de símbolos y líneas que representan el alambrado y los componentes de un circuito eléctrico.

Dieléctrico La resistencia a la conducción eléctrica.

Diferencial de presión La diferencia de presión entre un circuito de frenos y otro.

Digital Un método de visualización que utiliza números en vez de recurrir a una aguja o un aparto parecido.

Diodo Un aparato electrónico que permite que la corriente eléctrica fluya en una sola dirección mientras que la bloquea en otra dirección.

Diodo de supresión de voltaje Un diodo ubicado en dirección de la corriente de retorno y utilizado para reducir el pico de voltaje generado cuando un circuito que contiene una bobina se abre y dicha bobina se descarga.

Diodo despuntador Otro nombre para un *diodo de bloqueo.*

Diodo protector Un diodo instalado en un circuito con el cátodo hacia el positivo. El diodo adquiere una polarización negativa frontal cuando el circuito se apaga lo cual reduce el aumento de alto voltaje creado por la acción de una corriente que fluye por un cable.

Diodo Zener Diodo especialmente construido (muy dopado) y diseñado para operar con una corriente de retorno después de que se alcanza un cierto nivel de voltaje. Llamado así en honor a Clarence Melvin Zener.

DIS Siglas en inglés para sistema de encendido sin distribuidor.

Disparo externo Un modo de disparo de un osciloscopio en el cual el inicio del despliegue en pantalla del mismo es activado a través de un circuito externo al que está siendo medido.

Dispositivo de inflado El elemento inflamable de un módulo inflable que comienza la reacción química que genera el gas que infla las bolsas de aire.

Distancia entre roscas El número de roscas por pulgada de un sujetador enroscado.

Disyuntor (Fusible interruptor de circuito) o interruptor automático Un dispositivo mecánico que abre un circuito eléctrico en caso de que ocurra un flujo excesivo de corriente.

División Un segmento especifico de la configuración de la onda, tal cual esta definido por la matriz en la visualización.

Divisiones Particiones entre las células de una batería. Las divisiones se hacen del mismo material que el casco o cuerpo exterior de la batería.

DLC Siglas en inglés para conector para extraer datos.

DMM Siglas en inglés para multímetro digital. Un multímetro digital tiene la capacidad de medir simultáneamente la corriente eléctrica, la resistencia y el voltaje.

Dopar Añadir impurezas al silicio o al germanio puro para crear materiales de tipo P o N.

DOT Siglas en inglés de Departamento o Ministerio de Transporte.

DPDT Siglas en inglés para un interruptor de polo doble y tiro doble.

DPFE Siglas en inglés para sensor EGR de retroalimentación de presión delta.

DPST Siglas en inglés para un interruptor de polo doble y tiro sencillo.

DRL Siglas en inglés de faros diurnos. Luces ubicadas en la parte posterior del vehículo y que se encienden al mismo tiempo que el encendido del motor. En algunos vehículos, el vehículo en cuestión debe estar en movimiento antes de que estas luces se enciendan. Utilizado como un dispositivo de seguridad en muchos vehículos y de uso obligado en muchos países tales como el Canadá desde 1990.

DSO Siglas en inglés para osciloscopio de almacenamiento digital.

DVOM Siglas en inglés para un miliamperímetro de voltios ohmios digital.

E & C Siglas en inglés para entretenimiento y confort.

EAC Siglas en inglés para control electrónico de aire.

ECA Siglas en inglés para módulo de control electrónico. El nombre utilizado por *Ford* para describir la computadora vehicular utilizada para controlar la chispa y el combustible en modelos antiguos.

ECM Siglas en inglés para módulo de control electrónico en un vehículo.

ECT Siglas en inglés para temperatura del refrigerante del motor.

ECU Siglas en inglés para unidad de control electrónico.

EDR Siglas en inglés para registro de información de sucesos. Los componentes electrónicos y los programas de computación utilizados para registrar la información vehicular antes, durante y después de la activación de las bolsas de aire.

EEPROM Siglas en inglés para memoria de sólo lectura electrónicamente borrarle y programable.

Efecto de atenuación de Troxler El efecto de atenuación de Troxler, conocido como el efecto Troxler describe un efecto visual mediante el cual la retina del ojo retiene una imagen por un corto periodo después de que dicha imagen haya desparecido del campo visual. Este efecto visual fue descubierto por un médico suizo llamado Ignaz Paul Vital Troxler (1780–1866). Debido al efecto Troxler el brillo causado por la luz delantera de un vehículo puede permanecer por unos momentos en la retina, lo que puede ocasionar un punto ciego.

Efecto Peltier Jean Charles Peltier, un científico francés, descubrió que los electrones que fluyen a través de un material solidó pueden transportar el calor al otro lado del objeto. A este efecto se le denomina el efecto Peltier.

EI Siglas en inglés para encendido electrónico.

EIS Siglas en inglés para sistema de encendido electrónico.

El menisco/meniscal El fruncimiento o la curvatura de un líquido en un tubo. Una batería esta correctamente llenada de agua cuando un electrólito comienza a encorvarse por primera vez.

Electricidad Movimiento de electrones libres de un átomo a otro.

Electricidad estática Una carga eléctrica que se sobrecarga en un cuerpo aislante y se descarga en un material conductor.

Electroimán Un electroimán esta compuesto de un núcleo de hierro suave envuelto por un cable conductor de forma espiral. La corriente eléctrica que fluye a través del conductor genera un campo magnético alrededor del núcleo.

Electrólisis El proceso mediante el cual la corriente eléctrica pasa a través del agua para convertirse en hidrógeno y oxígeno gaseoso.

Electrolito Cualquier sustancia que al disolverse o diluirse se descompone en iones y, de esta manera, adquiere la capacidad de conducir una corriente eléctrica; La solución ácida de una batería de ácido-plomo.

Electromagnetismo Un campo magnético creado por el flujo de corriente a través de un conductor.

Electrones libres Los electrones en la capa exterior de un átomo que contiene menos de cuatro electrones en su orbita exterior.

Electrones ligados Electrones que están cerca del núcleo de un átomo.

Electroquímica El termino utilizado para describir la reacción química que ocurre al interior de una batería para producir electricidad.

Elemento Cualquier sustancia que no pude subdividirse en dos o más substancias.

Elemento fusible (fusible de cartucho) Un dispositivo de seguridad, que se derretirá y causara que la tapa se cierre en caso de incendio. Un tipo de fusible usado para controlar la corriente máxima al interior de un circuito.

Embrague de sobremarcha Parte de un ensamblaje del piñón del motor de arranque que permite que el motor gire más rápido que el motor de arranque a fin de proteger el arranque de daños que podría sufrir en caso de que el interruptor de encendido se mantenga en la posición de arranque después de que el motor se haya encendido. También conocido como un embrague unidireccional.

Emisora Nombre de un componente de un transistor. La flecha que se usa en un símbolo para un transistor se encuentra en la emisora e indica la parte negativa del transistor.

En cortocircuito El estado en el cual un objeto está cortocircuitado tal como cuando ocurre un cortocircuito.

Encendido de compresión con carga homogénea Proceso de combustión a bajas temperaturas en el que se queman mezclas de aire y combustible sin el uso del encendido de chispa.

Encendido sensor de iones Sistema electrónico de encendido que utiliza la bujía como sensor para determinar la posición del árbol de levas, el fallo de encendido y el golpeteo.

Energía específica El contenido de energía de una batería en relación a la masa de la batería. La energía específica se mide en vatiohoras por kilogramo (Vh/kg).

Enlace automático Un tipo de fusible automotriz.

Ensamblaje de empalme Un término utilizado por *General Motors* para describir la interconexión de los módulos en una red. A menudo se abrevia SP.

Ensamblaje de gato de rosca Un gato de rosca o husillo que se usa para levantar o bajar un asiento eléctrico.

Ensamblaje de membrana y electrodo (*MEA* por sus siglas en inglés) Aquella parte de la célula combustible PEM que contiene la membrana, las capas de catalizadores y los electrodos.

Entrada (de datos o información) A la información recolectada por los sensores enviada a un controlador electrónico se le llama datos de entrada.

Entretuerca Un diseño especial de sujetador de tuerca que se deforma levemente o que tiene otras propiedades que permiten que la tuerca permanezca unida al sujetador sin soltarse.

EPA Siglas en inglés para Agencia de Protección Ambiental.

EPM Siglas en inglés para manejo de la potencia eléctrica. Un término utilizado por *General Motors* para describir un sistema de carga de sensor de control y la salida del control del generador (alternador) basado en las necesidades del vehículo.

Equipo de protección personal (*PPE* por sus siglas en inglés) Prendas que los trabajadores llevan o utilizan a fin de protegerse de peligros en el lugar de trabajo, incluyendo los anteojos de seguridad, los guantes y otros elementos de protección.

Escobillas Conexiones de carbón o carbón-cobre utilizadas para pasar una corriente eléctrica a un ensamblaje rotante como un inducido en un motor de arranque o un rotor en un generador (alternador).

Escobillas aislantes Escobillas utilizadas en un motor de arranque que conectan a la fuente de poder de la batería a través del solenoide.

Escobillas puestas a tierra Las escobillas en un motor de arranque que transportan la corriente al encendido o al puesto a tierra.

ESD Siglas en inglés para descarga electrostática. Otro nombre para el ESD es electricidad estática.

Espárrago Vara corta con roscas de tornillo a ambos extremos.

Esponja de plomo Plomo elaborado con un alto nivel de porosidad a fin de que su superficie tenga una consistencia o textura esponjosa para su uso en los platos negativos de batería; el símbolo químico para el plomo es Pb.

EST Siglas en inglés para sincronización electrónica de chispa.

Estación de lavado de ojo Una unidad dispensadora de agua diseñada para enjuagar los ojos con un gran volumen de agua.

Estator Nombre utilizado para un conjunto de tres bobinados interconectados dentro de un alternador. Un inducido giratorio proporciona un campo magnético móvil e induce una corriente en los bobinados del estator.

ETC Siglas en inglés para control electrónico de la mariposa. La placa de la mariposa del sistema de entrada es controlada por un servo motor en vez de un varillaje mecánico. También conocida como un *drive-by-wire.*

ETR Siglas en inglés para radio electrónicamente sintonizada.

EV Vehículo eléctrico. Un término para describir vehículos propulsados por baterías eléctricas.

EVP Siglas en inglés para sensor de la válvula EGR.

EVRV Siglas en inglés para válvula electrónica reguladora de vació.

Extensión Una herramienta de llave de cubo o dado utilizada entre una matraca o mango articulado (maneral) y un dado o cubo.

Extinguidor, tipos de incendios Tipos de incendios que un extinguidor de fuego está diseñado para manejar.

Extremo del anillo de deslizamiento El extremo de un generador (alternador) que contiene escobillas y anillos de deslizamiento.

Faradio Unidad de capacidad, llamada así en honor del físico inglés Michael Faraday (1791–1867). Un faradio es la capacidad de almacenar 1 Coulomb de electrones a 1 voltio de diferencia de potencial.

Faros delanteros compósitos Clase de faro que utiliza una lámpara distinta y reemplazable.

Faros delanteros de xenón Luces delanteras que usan un ensamblaje de tubo arqueado lleno de gas xenón, el cual produce una iluminación intensa de color azuleado.

FCHV Vehículo híbrido de pila de combustible.

FCV Vehículo de pila de combustible.

FET Siglas en inglés para transistor de efecto de campo.

Fidelidad de medición El porcentaje de exactitud de un medidor.

Filtro de cruce o circuito crossover Un circuito electrónico divisor de frecuencias que separa las frecuencias en un sistema de sonido (audio).

Filtro de paso alto Un filtro en un sistema de audio que bloquea las frecuencias bajas y solo permite que las frecuencias altas lleguen a los parlantes.

Filtro de paso bajo Un aparato utilizado en un sistema de audio que bloquea la frecuencia alta y sólo permite que la frecuencia baja llegue a los parlantes.

Flujo magnético Las líneas de fuerza producidas por un campo magnético.

FM Siglas de Frecuencia Modulada.

Fotodiodo Un tipo de diodo utilizado como un sensor de carga de energía solar. Cuando se conecta con polarización inversa, el flujo de la corriente es proporcional a la intensidad de luz.

Fotoelectricidad Cuando algunos metales son expuestos a la luz, parte de la energía luminosa se transfiere a los electrones libres del metal. Esta energía excedente libera a los electrones de su adhesión a la superficie del metal. Como consecuencia, estos pueden ser recolectados y alistados para fluir al interior de un conductor. A este fenómeno se le denomina fotoelectricidad.

Fotones La luz se emite desde los diodos fotoemisores por medio de la liberación de la energía en forma de fotones.

Fotorresistor Un semiconductor que cambia su resistencia ante la presencia o ausencia de la luz.

Fototransistor Un dispositivo electrónico que puede detectar la presencia de la luz y encenderse o apagarse como efecto de aquello. Se utiliza en algunos sensores de altura de la suspensión.

Frazada antiincendios Una frazada de lana a prueba de incendios que se utiliza para apagar el fuego al envolverla alrededor de una víctima.

Frecuencia Número de veces o ciclos que una onda se repite en un segundo, lo cual se mide en Hertzios (Hz) en una banda.

FTP Siglas en inglés para Procedimiento Federal de Evaluaciones.

Fuente de poder En términos eléctricos la batería o el generador (alternador).

Fuerza de tensión La resistencia máxima utilizada bajo tensión (fuerza longitudinal) sin causar un fallo.

Fuerza electromotriz La fuerza (presión) que tiene la capacidad de mover electrones a través de un conductor.

Función de parado Fase en la operación de un vehículo eléctrico híbrido en la cual el motor de combustión interna se apaga durante la operación en función de parado.

Fusible Una unidad de seguridad eléctrica que se fabrica a partir de un conductor de estaño u hojalata fina que se derrite y abre el circuito en caso que un flujo de corriente sea excesivo.

Galga americana para alambres Un método usado para determinar el diámetro de los cables y alambres eléctricos.

GAWR Abreviación en inglés para Peso bruto nominal por eje. Una valuación o medición de la capacidad de carga de un vehículo que figura en los afiches y planillas del vehículo y en el manual del conductor.

GDI Siglas en inglés de inyección directa de gasolina. Diseño del sistema de inyección de combustible en el cual se inyecta la gasolina directamente a la cámara de combustión.

Generador Artefacto que convierte la energía mecánica en energía eléctrica.

Germanio Un material semiconductor.

GMLAN Siglas en inglés para Red de Área Local de General Motors. Un tipo de transmisión de datos en serie utilizado por la General Motors.

GMM Siglas en inglés para multímetro gráfico.

Golpeteo Quemado rápido secundario de los últimos 3% a 5% de la mezcla de aire/combustible en la cámara de combustión que causa un segundo frente de llama que choca con el primer frente de flama causando un ruido de golpeteo. También llamado detonación o *ping.*

Grado La medida de la fuerza o calidad de un perno o sujetador de tuercas.

Granja de viento Un área de terreno destinada a la instalación de plantas de energía eólica.

Guantes de *lineman* Tipo de guantes usados por técnicos al trabajar alrededor de circuitos de alto voltaje. Usualmente incluyen un guante interior forrado de goma que se clasifica para 1.000 voltios y un guante exterior protector de cuero cuando se usan para trabajar en vehículos eléctricos híbridos.

GVWR Siglas en inglés de nivel de peso total del vehículo. El peso total del vehículo incluyendo la carga máxima.

HCNM Hidrocarburos no metano.

HEI Siglas en inglés para encendido de alta energía.

HEI Siglas en inglés para la marca de encendido electrónico utilizada en los vehículos de *General Motores Corporation*.

Hertzio Unidad de la medida de la frecuencia, abreviada Hz. Un Hertzio es un ciclo por segundo. Llamado en honor de Heinrich R. Hertz, físico alemán del siglo diecinueve.

***HEV* (Vehículo eléctrico híbrido)** Siglas en inglés para cualquier vehículo que utiliza más de un modo de propulsión, tal como un motor de combustión interna y un motor eléctrico.

Híbrido Abreviación de vehículo eléctrico híbrido (*HEV* por sus siglas en inglés). Un tipo de vehículo que utiliza dos tipos de propulsión.

Híbrido completo Un vehículo eléctrico híbrido que utiliza altos voltajes (200 voltios o mas), y es capaz de propulsar el vehículo utilizando la función todo eléctrico a bajas velocidades. También conocido como un híbrido fuerte.

Híbrido fuerte Otro término para un híbrido completo. *Véase* Híbrido completo.

Híbrido mediano Diseño de un vehículo eléctrico híbrido que usa voltajes medianos (entre 50 y 200 voltios). Los híbridos medianos usan el freno regenerativo y el parado libre pero no pueden encender el motor cuando el automóvil está inmóvil usando el modo eléctrico.

Híbrido moderado Un diseño de vehículos eléctricos híbridos que usa el freno regenerativo y el parado pero no puede propulsar el vehículo en la función solamente eléctrica. Una propulsión de híbrido moderado opera típicamente a un voltaje menor de 50 voltios.

Híbrido paralelo Diseño de vehículos híbridos en el que la máquina eléctrica (u otra fuente de energía) ayuda el motor de combustión interna a propulsar el vehículo.

Híbrido paralelo de serie Un diseño de vehículo híbrido que puede operar como un híbrido de serie, un híbrido paralelo, o como tanto de serie y paralelo al mismo tiempo.

HO_2S Sensor Calentado de oxígeno.

HomeLink® La marca registrada de un sistema utilizado e incluido en muchos vehículos nuevos para operar la puerta de garaje automática.

HSD Siglas en inglés de circuito manejador (*driver*) controlable por el lado de alta tensión (*high side*).

HV Siglas en inglés de alto voltaje. Se refiere a cualquier voltaje que exceda los 50 voltios.

IAC Siglas en inglés para control de aire de ralentí.

IAT Siglas en inglés para temperatura de aire de admisión.

IC Siglas en inglés para control de encendido.

ICE Siglas en inglés para motor de combustión interna.

ICM Siglas en inglés para Modulo de control de encendido.

IEC Siglas en inglés para la Comisión Electrotécnica Internacional.

Impedancia La resistencia de una bobina o alambre, que se mide en ohmios.

Impurezas Elementos de dopaje.

Inducción electromagnética La generación de una corriente en un conductor que se pasa a través de un campo magnético. La inducción electromagnética fue descubierta en 1831 por Michael Faraday.

Inducción magnética La transferencia de las fuerzas magnéticas a un objeto cercano, bobina o alambre.

Inducción mutua La generación de una corriente eléctrica debido a un campo magnético cambiante de un bobinado adyacente.

Inducido o rotor La unidad rotante dentro de un generador de corriente continua o un arrancador compuesta de una serie de bobinas de material aislante enrolladas alrededor de un núcleo de hierro laminado.

Intercambio en serie de datos Datos transmitidos en serie por medio de señales de voltaje altamente variable.

Interfaz de comunicación serial (*SCI* por sus siglas en inglés) Un tipo de transmisión de datos en serie utilizado por la marca *Chrysler*.

Interferencia electromagnética o *EMI* por sus siglas en inglés Una señal electrónica indeseada, causada por la expansión y colapso de un campo magnético, lo cual genera una interferencia eléctrica no deseada en un circuito eléctrico cercano.

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Interruptor de cierre eléctrico Un cierre eléctrico ubicado en un Fusible interruptor de circuito para asegurarse de que nadie prenda el circuito eléctrico mientras se llevan a cabo las reparaciones del automóvil.

Interruptor de control maestro El interruptor de control para las ventanas eléctricas ubicado cerca del conductor del vehículo quien puede operar todos las ventanas.

Interruptor de efecto Hall Un semiconductor moviéndose en relación a un campo magnético, creando así una salida de voltaje variable. Utilizado para determinar una posición. Un tipo de sensor electromagnético utilizado en el encendido electrónico y otros sistemas. Llamado así en honor a Edwin H. Hall, el descubridor del efecto Hall en 1879.

Interruptor de seguridad neutral Un interruptor eléctrico que permite que el encendido se recargue solo si el selector de engranaje esta en neutro o estacionado.

Interruptor oscilante Un tipo de interruptor que oscila entre prendido y apagado.

Interruptores independientes Interruptores ubicados en cada puerta del vehículo y utilizados para bajar la ventana eléctrica solo de aquella puerta a la cual están conectados.

IOD Siglas en inglés para consumo de corriente en apagado. Un término utilizado por la compañía *Chrysler* para describir el fenómeno de descarga parasítica de la batería cuando el encendido está apagado.

Ión Un átomo con un exceso o deficiencia de electrones que como consecuencia forma ya sea una partícula positivamente o negativamente cargada (aniones o cationes).

ISC Siglas en inglés para control de velocidad de marcha mínima.

ISO Abreviación de la Organización Internacional para la Estandarización.

Junta de recursos atmosféricos de California Agencia gubernamental estatal del estado de California que regula los estándares de calidad de aire para el estado de California.

Junta o unión El extremo donde dos tipos de materiales se unen.

KAM Siglas en inglés para memoria siempre activa.

Kelvin (K) Una escala de temperatura donde el cero absoluto equivale a cero grados. No existe nada más frió que el cero absoluto.

Kilo Del griego 9 (chiloi) que significa 1,000; se abrevia *k* o *K.*

KOEO Siglas en inglés para prueba de llave en motor.

KOER Siglas en inglés para prueba de encendido con llave en motor.

LAF Siglas en inglés para sensor de ratio de mezcla pobre de aire combustible.

Lámina de ajuste Espaciador de metal delgado.

Lámpara indicadora de mal funcionamiento Luz de advertencia en el tablero que puede estar rotulada con *check engine* (revisar motor) o *service engine soon* (mantenimiento del motor necesario).

LDP Siglas en inglés para bomba de detección de fuga.

LED Siglas en inglés para diodos fotoemisores. Una fuente de luz de alta eficiencia que utiliza muy poca electricidad y produce muy poco calor.

Ley de circuito en serie de Kirchhoff Ley o lema desarrollado por Kirchhoff en relación con los circuitos en serie.

Ley de corrientes de Kirchhoff Un principio científico-matemático que afirma que: La corriente que fluye a cualquier nodo de un circuito eléctrico equivale a la corriente que sale de dicho nodo.

Ley de Lenz La variación del flujo magnético entre un conductor y un campo magnético es contrario a sentido de la corriente inducida que ha producido.

Ley de Ohm Ley que propugna que se requiere un voltio de voltaje para mover un amperio de corriente a través de un ohmio de resistencia.

Ley de tensiones de Kirchhoff Un principio científico-matemático en relación a los circuitos eléctricos que afirma que: El voltaje que rodea cualquier circuito cerrado es igual a la suma total de las resistencias.

Ley de Watt Fórmula o principio científico matemático que establece que un vatio equivale a un amperio multiplicado por un voltio en un circuito, lo cual representa la potencia eléctrica en dicho circuito.

Leyes de divulgación de información sobre materiales peligrosos Una serie de leyes que afirman que los empleados tienen el derecho de enterarse cuando los materiales que usan en el trabajo constituyen un peligro.

Limpiaparabrisas El ensamblaje de motor, controlador de motor, y varillaje así como los limpiadores o escobillas y raquetas que se utilizan para retirar la lluvia excesiva que se acumula en el parabrisas.

Limpiaparabrisas de accionamiento intermitente Limpiaparabrisas que operan intermitentemente. También conocidos como limpiaparabrisas de acción demorada.

Limpiaparabrisas intermitente variable Limpiaparabrisas cuya velocidad puede variar.

Llave Instrumento manual usado para girar pernos y tuercas.

Llave de boca abierta Un tipo de llave que permite el acceso lateral a la parte plana de una tuerca o tornillo.

Llave de boca ajustable Una llave que tiene una quijada móvil, lo cual le permite adaptarse a diferentes tipos de medida de sujetadores de tuerca.

Llave para tuercas cónicas Un tipo de llave utilizada para retirar líneas de combustible, de frenos o del aire acondicionado.

Llavero o fob de llave Un elemento decorativo adherido a las llaves. A menudo incluye un control remoto para abrir o cerrar un vehículo.

LOC Siglas en inglés para convertidor tipo Light-off.

LSD Siglas en inglés de circuito manejador (*driver*) controlable por el lado de baja tensión (*low side*).

Luces de descarga de alta intensidad (luces HID) Tipo de luz delantera que hace uso de un lato nivel de voltaje para generar un arco de luz al interior del ensamblaje de tubo arqueado, el cual produce una luz blanquecina azuleada.

Lumbar Perteneciente a la sección baja de la espalda.

Luz de entrada Un término genérico para describir todas la luces al interior del vehículo.

Luz de prueba Una luz utilizada para comprobar el nivel de voltaje. Contiene un foco conectado, en un extremo, a un cable puesto a tierra y a un puntal en el otro extremo.

Luz de prueba de continuidad Una luz de prueba que contiene una batería y que se enciende si es que detecta la presencia de la continuidad (corriente eléctrica) entre los dos polos que están conectados al probador.

Luz trasera Luz que ilumina la pantalla de cristales líquidos de una herramienta de prueba por atrás.

MA Modulación de Amplitud.

MAF Siglas en inglés para sensor de circulación de masa.

Magnetismo Un tipo de energía reconocida por la atracción que un objeto ejerce sobre otro.

Magnetismo residual Magnetismo remanente que queda después que la fuerza magnetizante ha sido retirada.

MAP Siglas en inglés para Sensor detector de presión absoluta de admisión.

Mapeo de motor Un programa de computadora que utiliza la información de las pruebas de motor para determinar la mejor relación aire/combustible y la velocidad apropiada de avance de chispa para el desempeño ideal del motor.

Material del tipo N Silicio o germanio dopado con fósforo, arsénico o antimonio.

Material del tipo P Silicio o germanio dopado con boro o indio.

MCA Siglas en inglés para amperios de arranque en aplicaciones marinas. Un indicador para batería.

Mecanismo de seguridad del conector eléctrico (tapa) Una lengüeta mecánica que se utiliza para afianzar el extremo de una Terminal a un conector eléctrico. Este mecanismo debe deprimirse con la presión a fin de liberar la Terminal del conector.

Medida de cable métrica El método métrico para medir el tamaño de un cable o alambre en milímetros cuadrados. Esta es la medida del núcleo del alambre sin incluir el material aislante.

Medida dinámica del estado de salud (SOH) Una señal enviada por uno de los módulos a los demás módulos en la red informándoles que está funcionando correctamente y que mantiene su habilidad de transmitir señales.

Medidor de alta impedancia Un medidor digital que tiene por lo menos 10 millones de ohmios de resistencia interna medida entre los conductores de pruebas cuando el medidor esta programado para leer voltios.

Mega Millón. Termino utilizado para referirse a números muy grandes o para la medición de una gran cantidad de resistencia eléctrica.

Mercurio Un metal pesado.

Micro Una millonésima parte de un voltio o un amperio.

Mili Una milésima parte de un voltio o un amperio.

Modo de auxilio de fuerza Una fase de operaciones de un vehículo híbrido en el cual el motor de combustión interna es auxiliado por la maquinaria eléctrica (u otra fuente de energía) para impulsar al vehículo.

Modo de motor Fase de la operación de un vehículo híbrido BAS en la que el motor-generador arranca el motor ICE con una manivela para encenderlo.

Modulación de la anchura de pulso (*PWM* por sus siglas en inglés) Operación de un artefacto por medio de una señal digital binaria que se controla variando la duración de tiempo que el artefacto está conectado y desconectado.

Modulación La combinación de frecuencias de onda larga y de onda corta comúnmente se conoce como modulación.

Módulo de control del tren de fuerza La computadora de manejo del motor que controla el motor y las funciones de la transmisión.

Módulo de control del tren de poder (*PCM* por sus siglas en ingles) Módulo de control electrónico para el motor y la transmisión.

MOSFET Siglas en inglés para transistor de efecto de campo del semiconductor de óxido de metal. Un tipo de transistor.

Motor de rueda Un motor eléctrico que esta montado directamente sobre la rueda del vehículo, eliminando de esta manera el árbol de transmisión conectante.

Motor eléctrico de imanes permanentes Motores eléctricos que utilizan imanes permanentes en el campo magnético en vez de electroimanes.

MOV Siglas en inglés de varistor de oxido metálico. Un dispositivo electrónico que opera como dos diodos zener conectados en serie.

MRFS Siglas en inglés de sistema mecánica de combustible sin devolución. Sistema de entrega de combustible sin devolución que usa un regulador mecánico de la presión ubicado en el depósito de combustible.

MSDS Siglas en inglés de hoja de datos de seguridad física.

Muda de color Un término utilizado para describir el cambio de coloración que sufre un tubo arqueado HID con el transcurso del tiempo.

Muelle de reloj Un resorte metálico plano utilizado bajo el cable de la dirección para transferir señales eléctricas de las bolsas de aire. Dependiendo del diseño y del modelo del vehículo, también podría incluir circuitos electrónicos de control de la bocina y del volante.

Multímetro digital de corriente alterna y directa con sujetador Un tipo de medidor que tiene una tenaza, o clip, que se sujeta al cable para medir la corriente.

Multiplexación Un proceso de enviar múltiples señales de información a la misma vez utilizando un solo cable.

N.C. Siglas en inglés para normalmente cerrado.

N.O. Siglas en inglés para normalmente abierto.

NEDRA Siglas en inglés de la Asociación Nacional de los Arranque de Vehículos Eléctricos.

NiMH Hidruro de níquel y metal. Diseño de baterías de alto voltaje que se usan en la mayoría de los vehículos eléctricos híbridos.

Nivel de disparo El nivel de voltaje al cual debe llegar una configuración de onda para activar la visualización en la pantalla.

Nodo Un modulo y una computadora que forman parte de una red de comunicaciones.

Notificación de campaña Una notificación efectuada al dueño de un vehículo que le informa que él debe atender y corregir algún asunto que está atentando contra la seguridad vehicular.

NTC Siglas en inglés para coeficiente de temperatura negativa. Usualmente utilizado en referencia a los sensores de temperatura (de refrigerante o de temperatura ambiente). A medida que la temperatura aumenta, la resistencia del sensor disminuye.

Número de comercio Número estampado en un bombillo automotor. Cada bombillo del mismo número de comercio tiene la misma potencia lumínica y vatiaje, independiente del fabricante de la bombilla.

Número de fundición Un número de identificación fundido al bloque del motor y otras fundiciones o placas metálicas grandes.

OAD *Véase* Amortiguador del alternador de rotación libre.

OAP *Véase* Polea del alternador de rotación libre.

OBD Siglas en inglés para diagnósticos a bordo.

Ohmio Unidad de la resistencia eléctrica, llamada así en honor de Georg Simon Ohm (1787–1854).

Ohmiómetro Instrumento de prueba eléctrico que se usa para medir los ohmios (unidad de la resistencia eléctrica).

OL Siglas en inglés para sobrecarga o sobre límite.

Operación de circuito abierto Fase de la operación computarizada del motor en la cual la mezcla de aire y combustible se calcula en la ausencia de las señales del sensor de oxígeno. Durante esta fase, los cálculos se basan principalmente en la posición del acelerador, las RPM del motor y la temperatura del refrigerante del motor.

ORVR Siglas en inglés para sistemas de diagnóstico a bordo y recuperación de vapores.

OSC Siglas en inglés para capacidad de almacenamiento de oxígeno.

Osciloscopio Un medidor que muestra una visualización de los niveles de voltaje en una pantalla.

OSHA Siglas en inglés de la Administración de la Seguridad y Salud Ocupacionales.

OSHA La agencia federal principal que se ocupa de la seguridad en el lugar de trabajo y de la legislación de salud ocupacional.

Ozono Gas rico en oxígeno (O_3) formado por la combinación de hidrocarburos (HC) sin quemar y óxidos de nitrógeno (NOx) en la presencia de la luz solar. También llamado niebla tóxica o esmog.

Palabra clave Un tipo de comunicación en red usada en muchos vehículos de General Motors.

Par Darlington Dos transistores eléctricamente conectados para formar un amplificador. Esto permite que una muy pequeña corriente controle el flujo de una corriente mucho mayor. Nombrada así en honor a Sidney Darlington, físico de los laboratorios Bell desde 1929 hasta 1971.

Parlantes Un aparato que consiste en un imán, una bobina de alambre y un cono que reproduce los sonidos generados por señales eléctricas que se envían a los parlantes desde una radio o un amplificador.

Passkey I y II Un tipo de sistema antirrobo utilizado en los vehículos de General Motors.

Patas Otro nombre para las ramas de un circuito en paralelo.

Pico de voltaje inverso (PVI) La medición de resistencia para el voltaje diagonal inverso. También conocido como el voltaje inverso culminante designado (VIC o PRV por sus siglas inglés).La medición de resistencia para el voltaje diagonal inverso. También conocido como el voltaje inverso culminante designado (VIC o PRV por sus siglas inglés). *PECF* Siglas en inglés para Célula Combustible de Polímero Electrolítico.

PCV Siglas en inglés para válvula de control de presión.

PEM Siglas en inglés para célula combustible con membrana de intercambio de protones. Una célula combustible de bajas temperaturas conocida por su arranque rápido y su construcción relativamente sencilla.

Pendiente de disparo Dirección de voltaje que una onda debe tener para comenzar visualización en la pantalla. Una cuesta positiva requiere que el voltaje se aumente mientras cruza el nivel del disparado; una cuesta negativa requiere que el voltaje se disminuya.

Permeabilidad Una medida de la habilidad de una materia para conducir las líneas magnéticas de fuerza.

Perno pasante Los pernos utilizados para mantener unidas las diversas partes del motor de arranque. Estos pernos largos atraviesan la caja de campo hasta ingresar al cuerpo del extremo de arranque.

Pernos métricos Pernos que se fabrican y diseñan en base al sistema métrico.

Peso específico Ratio del peso del volumen de un líquido dividido entre el peso de un volumen equivalente de agua.

PHEV Siglas en inglés para un vehículo eléctrico híbrido con conexión de clavija o Vehículo Híbrido-Eléctrico que se Enchufa.

PID Siglas en inglés para identificación de parámetro.

Pila electroquímica Un conjunto de celdas de combustible individuales apiladas y concatenadas, de principio a fin, de forma similar a unas rebanadas de pan.

Ping Quemado rápido secundario de los últimos 3% a 5% de la mezcla de aire/combustible en la cámara de combustión que causa un segundo frente de llama que choca con el primer frente de flama causando un ruido de golpeteo.

PIV Siglas en inglés para pico de voltaje inverso. Un tipo de medición o valuación de un diodo.

Plano puesto a tierra El componente metálico de una antena que forma parte del cuerpo del vehículo.

Plomo poroso Plomo con muchos poros diminutos utilizado para crear una superficie porosa para su uso en platos negativos de la batería; el símbolo químico para el plomo es Pb.

Polaridad La condición positiva o negativa en relación con un polo magnético.

Polarización inversa El flujo de la corriente en dirección opuesta a la normal.

Polea del alternador de rotación libre (*OAP* por sus siglas en inglés) Una polea de propulsión del alternador (generador) que tiene un embrague unidireccional y un resorte o muelle de amortiguación que se usa para amortiguar el funcionamiento del alternador y reducir el la tensión en la banda o correa.

Polo El lugar donde las líneas de fuerza magnética ingresan o salen de un imán.

Polos en forma de garras Los polos magnéticos del inductor o rotor de un dinamo (alternador).

Potencia en candelas Una clasificación de la cantidad de luz producida por una fuente de luz tal como un foco.

Potencial eléctrico Otro término para voltaje.

Potenciómetro Un resistor variable de tres terminales que incide en la variación de la baja de voltaje en un circuito.

Pretensioners Aparatos explosivos utilizados para disminuir la holgura derivada de un cinturón de seguridad cuando se activan y despliegan las bolsas de aire.

Probador de continuidad Instalación de un instrumental para medir el cableado, los circuitos y los conectores o interruptores para verificar la existencia de brechas (circuitos abiertos) o cortocircuitos (circuitos cerrados).

Probador de inducidos Un medidor o probador eléctrico diseñado para probar un encendido y las armaduras de los generadores de corriente directa.

Procesamiento de datos o información Los cambios que una computadora ejecuta sobre las señales de entrada a fin de convertirlas en información útil. Estos procesos usualmente requieren un convertidor de análogo a digital y otros circuitos electrónicos que eliminan la interferencia.

Proceso de gaseado El proceso de liberación de hidrógeno y oxígeno de los platos de una batería durante la carga o la descarga de dicha batería.

PROM Siglas en inglés de memoria de sólo lectura programable.

Propulsión microhíbrida Término que describe el encendido de alternador de cinta (*BAS* por sus siglas en inglés) y otros sistemas de híbridos moderados.

Protocolo SCP Un protocolo de red utilizado por *Ford*.

Prueba de banco La prueba de un componente, tal como un arrancador, antes de ser instalado en el vehículo.

Prueba de capacidad de carga Un tipo de prueba de la batería donde una carga eléctrica se aplica a la batería y se monitorea el voltaje para determinar el estado de la batería.

Prueba de carga voltaica Una prueba eléctrica que se lleva a cabo utilizando un voltímetro y un amperímetro para comprobar el estado del circuito de carga.

Prueba de descarga parásita de la batería Una prueba que mide el nivel de descarga de corriente (en amperios) de la batería con el encendido apagado y con todas las cargas eléctricas apagadas.

Prueba de fuga eléctrica de la batería Una prueba para determinar si un componente o circuito está causando que la batería se agote.

Prueba *SHED* Prueba para determinar las emisiones por evaporación en vehículos a motor.

PRV *Véase* Pico de voltaje inverso (*PIV* por sus siglas en inglés).

Puente rectificador Grupo de seis diodos, tres positivos (+) y tres negativo (−) que a menudo se utiliza en los alternadores.

Pulsador híbrido Un tipo de unidad emisora de destellos que puede operar dos o más bombillas eléctricas a un ritmo constante.

Pulsera trenzada puesta a tierra Cables a tierra trenzados y sin aislamiento para ayudar a incrementar la flexibilidad y reducir la interferencia electromagnética.

PVV Siglas en inglés para válvula de puerto de ventilación a presión. Una válvula ubicada en el tanque de combustible para prevenir una sobrepresión debido a la expansión térmica del combustible.

Radio frecuencia Un tipo de frecuencia EMI que existe en la banda de radio frecuencia.

RAM Siglas en inglés para memoria de acceso aleatorio.

Rango La distancia que un vehículo puede recorrer con una carga completa o tanque lleno sin recargar o reabastecerse de combustible. El rango se mide en millas o kilómetros.

Ranura de soldadura de pinza Una sección en la parte inferior del vehículo donde dos paneles del cuerpo del automóvil se juntan y se enroscan para posteriormente soldarse.

RCRA Siglas en inglés para Ley de Conservación y Recuperación de Recursos.

Reactancia inductiva Una corriente opuesta que se genera en un conductor de electricidad cuando existe una corriente que fluye por dicho conductor.

Rebajado de micas Un proceso de cortar el aislante, usualmente de mica, de entre el medio de los segmentos de un conmutador de encendido.

Recirculación de los gases de escape (*EGR* por sus siglas en inglés) Un dispositivo de control de emisiones que sirve para reducir las temperaturas de combustión y la formación de NOx (óxidos de nitrógeno).

Reconocimiento automático de voz Un sistema que hace uso de un micrófono y un parlante conectados a un módulo electrónico con el objetivo de controlar el funcionamiento de los dispositivos electrónicos de un vehículo por medio de comandos de voz.

Red Un sistema de comunicaciones utilizado para conectar múltiples computadoras o módulos entre si.

Regla de mano izquierda Un método utilizado para determinar la dirección del movimiento de las líneas magnéticas de fuerza que rodean un conductor. La regla de la mano izquierda se usa en coordinación con la teoría del flujo de electrones (− fluye hacia el +).

Regla de mano derecha Un método para determinar la dirección de las líneas magnéticas de fuerza en un conductor de corriente. La regla de mano derecha se utiliza con la teoría convencional de flujo de corriente (+ fluyendo hacia el negativo).

Rejilla Armazón (apoyo), de aleación de plomo, que sostiene los materiales activos de una batería automotriz.

Relación de vueltas La ratio o relación entre el número de vueltas que se dan en un bobinado primario y el número de vueltas en un bobinado secundario. Un típico bobinado de encendido tiene una ratio de 100:1.

Relé Un interruptor electromagnético que utiliza un brazo giratorio.

Reluctancia Resistencia al movimiento de las líneas magnéticas de la fuerza.

Reóstato Un resistor variable de dos terminales.

Reóstato o resistor de protección de alza de potencia (sobretensión) Un resistor, usualmente de entre 300 y 500 ohmios, que está conectado a un circuito en paralelo con una carga para ayudar a reducir los picos de tensión causados cuando se corta la corriente que fluye a través de un alambre.

Reposo de leva Medición en grados, de la rotación de la leva o flecha del distribuidor en el cual los puntos descritos por el punto trazador están cerrados.

Resistencia Oposición al flujo de la corriente medida en ohmnios.

Resistencia total del circuito (R_T) El valor de la resistencia total de un circuito.

Resistor terminal Un resistor colocado en el extremo de un circuito de transmisión de datos en serie de alta velocidad a fin de reducir la interferencia electromagnética.

Resolución del medidor Las especificaciones de un medidor que indican a qué grado de precisión puede detectar y mostrar una medida el medidor.

Resorte de acoplamiento Un resorte usado detrás del piñón de arranque en un mecanismo de arranque para engranar el piñón satélite con el engranaje anular en el motor.

Resorte de compresión Un resorte que es parte de la transmisión de arranque que actúa sobre el piñón satélite de la transmisión.

Retroalimentación Flujo inverso de la corriente eléctrica por un circuito o unidad eléctrica que normalmente no debería estar funcionando. Esta corriente de retroalimentación (flujo de corriente de retorno) muchas veces se atribuye a un contacto a tierra defectuoso para el ya mencionado circuito que normalmente funciona de forma regular.

RMS Siglas en inglés de raíz cuadrada de la media de los cuadrados de los valores instantáneos.

Rodaje El proceso mediante el cual se opera un aparato electrónico por un periodo prolongado que puede durar desde varias horas hasta varios días.

ROM Siglas en inglés para memoria de sólo lectura.

Rotor El elemento rotante de un generador donde se produce un campo magnético.

RVS Siglas en inglés para encendido remoto del vehículo. Un término de General Motors para un sistema que le permite al conductor encender el motor de su vehículo utilizando un control remoto.

SAE Siglas en inglés para la Sociedad de Ingenieros Automotrices.

SAI Siglas en inglés para Inyección de aire secundaria.

SAR Siglas en inglés de sistema de bolsas de aire suplementarias. Otro nombre para un sistema de bolsas de aire.

Saturación El punto en que el nivel de fuerza de un campo magnético alcanza el máximo.

SCR Siglas en inglés para rectificador de controlador de silicona.

Semiconductor Un material que no es ni conductor ni aislador y que tiene exactamente cuatro electrones en el nivel exterior de átomo.

Sensor BARO Un sensor que mide la presión barométrica.

Sensor de desaceleración Un sensor montado al cuerpo o armazón de un vehículo que detecta y mide la desaceleración de un vehículo. Utilizado para controlar la activación de las bolsas de aire y los sistemas de estabilidad del vehículo.

Sensor de golpeteo Sensor que puede detectar el golpeteo de chispa del motor.

Sensor de oxígeno de banda ancha Un diseño de sensor de oxígeno capaz de detectar ratios actuales y reales de aire-combustible, a diferencia de los sensores de de oxígeno convencionales que solamente cambian de voltaje cuando el ratio estequiométrico ha sido alcanzado.

Sensor de seguridad Un sensor usado en un circuito de bolsas de aire que es muy sensible y completa el circuito. Es el primero de dos sensores que se necesitan para activar y desplegar una bolsa de aire.

Sensor integral Un termino utilizado para describir a un sensor de impacto integrado al modulo de control de las bolsas de aire.

Sensor O_2 Una sonda lambda o sensor de oxígeno.

Sensor PFE Sensor de retroalimentación de presión EGR.

Señal de peligro Una señal de peligro en una pegatina, adhesivo (*sticker*) o calcomanía que indica la proximidad de un peligro.

SFI Siglas en inglés para inyección secuencial de combustible. Un sistema de inyección de combustible en la cual los inyectores son pulsados de manera individual en vez de en grupos.

Silicona Material semiconductor.

SIP Siglas en inglés para plan de implementación estatal.

SIR Siglas en inglés para elementos de seguridad inflables auxiliares. Otro nombre para bolsas de aire.

Sistema binario Un sistema de computadora que usa una serie de ceros y unos para representar la información.

Sistema de detección de pasajeros Un sistema de bolsas de aire que incluye un sensor en el asiento de pasajeros que se utiliza para detectar si es que el pasajero esta o no esta sentado en el lado del pasajero así como el rango de peso de dicho pasajero.

Sistema de encendido de bobina en bujía Un sistema de encendido sin distribuidor (estático) en el cual cada bobina de encendido está integrada con un bobinado de encendido.

Sistema de presencia de pasajeros (*PPS* por sus siglas en inglés) Un sistema de bolsas de aire que incluye un sensor en el asiento de pasajeros utilizado para detectar si un pasajero está o no está sentado en el lado del pasajero y el rango de peso de dicho pasajero.

Sistema electrónico de combustible sin retorno Un sistema de provisión de combustible que no devuelve el combustible al tanque.

Sistema no puesto en tierra Un sistema eléctrico en el cual ni los circuitos puestos en tierra ni la potencia están conectados al chasis.

SKIS Siglas en inglés para sistema inmovilizador electrónico de llave centinela. Un tipo de sistema antirrobo utilizado en los vehículos marca *Chrysler*.

SLA Siglas en inglés de suspensión de brazo corto y largo.

Soldadura con núcleo de resina Un tipo de soldadura usada en las reparaciones eléctricas. Al interior de la soldadura hay una resina que actúa como un flujo lubricante-limpiador para limpiar la soldadura y ayudarla a fluir.

Solenoide del arrancador Un tipo de motor de arranque que utiliza un solenoide para activar la transmisión del motor de arranque.

Solvente Un líquido, usualmente incoloro, que se utiliza para quitar el aceite y la grasa.

Sonda lógica Un tipo de medidor que puede detectar tanto la presencia de energía eléctrica como una conexión a tierra. La mayoría de los medidores pueden detectar un voltaje pero la mayoría no puede detectar la presencia de una conexión a tierra sin la necesidad de llevar a cabo pruebas adicionales.

SPDT Siglas en inglés para interruptor de polo sencillo y tiro doble. Un tipo de interruptor eléctrico.

SPOUT Siglas en inglés para *spark output*.

SPST Siglas en inglés para un interruptor de polo sencillo y tiro sencillo. Un tipo de interruptor eléctrico.

SRS Siglas en inglés de sistema auxiliar de seguridad. Otro nombre para un sistema de bolsas de aire.

SST Siglas en inglés de herramientas especiales de servicio.

STAR Siglas en inglés para lectura automática de autoprueba.

Subwoofer Un tipo de altavoz activo usado para reproducir sonidos de baja frecuencia.

Superficies magnéticas La parte mecánica de una bobina de campo en un motor de arranque.

SVR Siglas en inglés de acumuladores de plomo-ácido sellados, regulados por válvula. Un término utilizado para describir un tipo de batería de plomo-ácido o de tecnología de gel sellado que son reguladas por válvula.

SWCAN Siglas en inglés de alambre sencillo de protocolo de comunicaciones CAN o CAN bus (*controller area network*—red CAN tipo ISO 11898-2 o ISO 11519-2/ISO 11898-3).

Tabique deflector Una placa o pantalla utilizada para dirigir el flujo de un líquido o de un gas.

Tamaño del propulsor El tamaño en fracciones de pulgada del propulsor cuadrado para soquetes.

Tapón de motor u obstrucciones por vapores del líquido Una condición de combustión pobre causada por la vaporización de combustible en el sistema de combustible.

TBI Siglas en inglés para inyección de cuerpo de la mariposa/ válvula de admisión.

Tecnología de doble capa tecnología utilizada para fabricar ultra capacitadores Dicha técnica involucra el uso de dos electrodos de carbón separados por una membrana.

TED Siglas en inglés para dispositivo termoeléctrico.

Tensión de polarización En términos eléctricos, una tensión de polarización es un voltaje que se aplica a un aparato o componente para establecer un punto de referencia para su operación.

Teoría convencional Aquella teoría que propugna que la electricidad fluye del positivo (+) al negativo (–).

Teoría convencional del flujo de corriente Una teoría que afirma que a medida que un electrón fluye de lo negativo (−) a lo positivo (+), el flujo de electrones que se va formando, deja a su paso por el conductor un espacio o hueco. De acuerdo a esta teoría, dicho hueco viajaría en sentido opuesto al flujo de estos, es decir de lo positivo (+) a lo negativo (−) y se puede interpretar a esta corriente como positiva.

Teoría de electrones Teoría que propugna que la electricidad fluye desde el negativo (−) al positivo (+).

Terminal La punta metálica de un alambre o cable que encaja en un conector de plástico y constituye el componente conector de una junta.

Termistor Resistor que varía su resistencia según la temperatura. Un termistor de coeficiente positivo aumenta la resistencia ante el aumento de la temperatura. Un termistor de coeficiente negativo aumenta la resistencia ante la disminución de temperatura.

Termoelectricidad La creación de un flujo de corriente por medio del calentamiento de la conexión entre dos metales disímiles.

Termopar Dos metales disímiles que al unirse y calentarse producen un voltaje. Utilizados para medir la temperatura.

TFT Siglas en inglés de sensor de temperatura del fluido de la transmisión.

THD Siglas en inglés para distorsión harmónica total. Una medida de evaluación utilizada con equipos y sistemas de sonido.

TID Siglas en inglés para identificación de trabajo.

Tiempo base/unidad de tiempo La cantidad fija de tiempo por división cuando se regula un osciloscopio.

Tiempo de encendido Punto exacto del encendido con relación a la posición del pistón.

Tiros El término utilizado para describir el número de circuitos de salida (posiciones) que tiene un interruptor eléctrico.

Tornillo de tope Un perno que se enrosca en una fundición.

TOT Siglas en inglés para temperatura del aceite de la transmisión.

TP Siglas en inglés de sensor de posicionamiento de la mariposa.

Transistor Dispositivo semiconductor que puede funcionar como un relé o un amplificador.

Transistor bipolar Un tipo de transistor que tiene una base, es decir, un emisor y un colector.

Transistor NPN Un tipo de transistor bipolar que utiliza material del tipo P en su base y material del tipo N en su emisor y colector.

Transistor PNP Un tipo de transistor bipolar que utiliza material del tipo N en su base y material del tipo P en su emisor y colector.

Transmisión del motor de arranque Término que se usa para describir el piñón satélite de propulsión del motor de arranque con acoplamiento libre.

Transmisión por fibra óptica Transmisión de luz por medio de un plástico especial que mantiene los rayos paralelos aún cuando el plástico se anuda.

Transportador eléctrico Cualquier medio que es utilizado para almacenar o transportar energía. Por ejemplo, el hidrógeno es un transportador de energía porque la energía debe ser utilizada para generar gas hidrógeno el cual es usado como combustible.

Trayecto eléctrico aislado El lado potenciado de un circuito eléctrico.

Tren de pulso Voltaje de corriente directa que se conecta y se desconecta en una serie de pulsos.

TSB Siglas en inglés de boletín de servicio técnico.

TTL Siglas en inglés para lógica transistor-transistor®.

Tubo aislante termocontraíble revestido con adhesivo Un tipo de tubo aislante termocontraíble que se contrae a un tercio de su diámetro original y tiene pegamento en su interior.

Tubo aislante termocontraíble Un tipo de tubo de goma que se contrae y reduce su diámetro por la mitad cuando se calienta. Utilizado sobre un empalme durante la reparación de un cable o alambre eléctrico.

TWC Siglas en inglés para convertidor catalítico de triple acción.

UART Siglas en inglés de Receptor-Transmisor Asíncrono Universal. Un tipo de transmisión de datos en serie.

UBP Siglas en inglés de protocolo basado en UART.

Ultracapacitador Una tecnología de capacitador especializado con capacidad de almacenamiento aumentada para un volumen dado.

UNC Siglas en inglés de Estándar Nacional Unificado de Roscas.

UNF Siglas en inglés de estándar de lámina fina (delgada) del tornillo.

Unión universal Una unión o junta en un eje de propulsión o transmisión que permite que se transmita fuerza de torsión en un ángulo.

UST Siglas en inglés de depósito de almacenamiento subterráneo.

Vacío Cualquier presión menor a la presión atmosférica (14.7 psi a nivel de mar).

VAF Siglas en inglés para sensor de circulación.

Varistores Resistores cuya resistencia depende de la cantidad de voltaje que se les aplica.

Vatio Unidad eléctrica de poder; un vatio equivale al voltaje de la corriente (amperios) − (1/746 hp). Llamado así en honor de James Watt, un inventor escocés.

VATS Siglas en inglés para sistema antirrobos de vehículos utilizado en algunos vehículos de General Motors.

VECI Siglas en inglés para información de control de emisiones de vehículos. Esta etiqueta o calcomanía se encuentra debajo del capo de todos los vehículos e incluye aquella información relativa al control de emisiones importante para el mecánico o técnico automotriz.

Velocidad de línea en baudios La velocidad a la que se transmite bits de información en un flujo de datos en serie. Se mide en bits por segundo (bps).

VIN Siglas en inglés para número de identificación de vehículo.

Voltaje de circuito abierto El nivel de voltaje que se mide cuando el circuito no esta funcionando.

Voltaje de entrada Otro nombre para tensión umbral o la diferencia de voltaje necesaria para polarizar negativamente un diodo.

Voltaje de rizado Voltaje de corriente alterna excesivo producido por un generador (alternador) usualmente como consecuencia de un diodo defectuoso.

Voltaje dinámico El voltaje medido cuando el circuito está cargado y la corriente fluye a través del circuito.

Voltímetro Instrumento eléctrico de prueba que se usa para medir voltios (la unidad de la presión eléctrica). El voltímetro se conecta en paralelo con la unidad o el circuito que se está probando.

Voltio Unidad de medición de la cantidad de presión eléctrica; llamado así en honor a Alessandro Volta (1745–1827).

VRLA Siglas en inglés de batería de plomo-ácido sellados, regulados por válvula. Una batería sellada que protege contra los derrames y también contra goteras. Las baterías AGM y los acumuladores de plomo-ácido sellados, regulados por válvula de gel electrolítico son claros ejemplos de este tipo de batería.

WHMIS Siglas en inglés para sistema de información sobre materiales peligrosos en el lugar de trabajo.

Zapatas polares Los imanes utilizados en una bobina de campo de un arrancador.

ZEV Siglas en ingles de vehículo de cero emisiones. Esta calificación solo se logra típicamente por vehículos propulsados por baterías o aquellos propulsados por células de combustible.

Zumbido del alternador El ruido que hace un alternador que tiene un diodo(s) defectuoso.

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