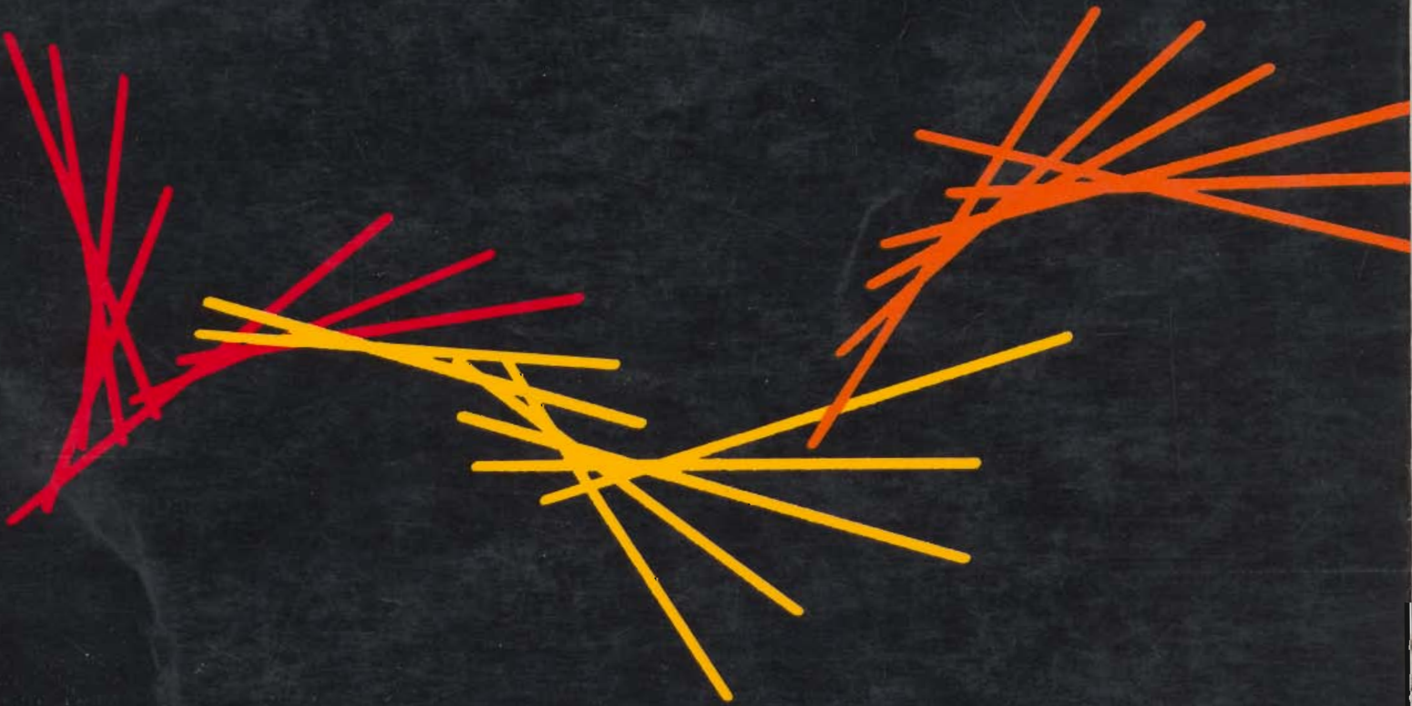
Lab Experiments For

MODERN ELECTRONICS: A FIRST COURSE

Victor F. Veley John J. Dulin



LAB EXPERIMENTS FOR MODERN ELECTRONICS
A First Course

VICTOR F. VELEY, Ph.D.
Assistant Dean and Associate Professor
Los Angeles Trade-Technical College

JOHN J. DULIN, Ph.D.
Assistant Professor
Los Angeles Trade-Technical College

PRENTICE-HALL, INC., Englewood Cliffs, New Jersey 07632

To
Joyce and Margy

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Preface

In the preface to *Modern Electronics: A First Course* we anticipated the groans that would greet the publication of yet another book on "basics." To alleviate the pain we are introducing a lab manual which will be a worthwhile companion to the text. This manual contains 40 experiments which are used to demonstrate and verify basic principles of electronics. The combination of theory text and related lab manual is comparatively rare at the present time and will benefit both the instructor and the student.

The highlights of the lab manual format are:

1. Through a reading assignment, each experiment is directly referenced to the text. The order of the experiments generally follows the sequence of the text and in the transition from dc to ac, we have again used the novel approach of introducing the square wave before the sine wave.
2. The experimental objectives are clearly stated and every effort has been made to ensure that the student derives the maximum benefit from each experiment.
3. The use of the test equipment is fully described. Only practical component values are used and the modern SI system of units is employed throughout. For the most part, calculations, as required by the experiment, are carried out with measured rather than rated values.
4. Each experiment is conducted through a careful step-by-step procedure with emphasis laid on correct laboratory practice in relation to the test equipment. The experimental results are entered in prepared tables and are also used to demonstrate a number of graphical relationships.
5. At the end of each experiment there are 10 questions that analyze the tabulated results, *communicate* with the student in terms of electronics, and suggest further avenues for experiment. In the conclusion the student is invited to *think* about the principles the experiment has demonstrated and to *communicate* these thoughts to the instructor.

All the experiments have been conducted by the authors themselves and also by a group of advanced-level students (in particular Mr. Hansil Bhadlawala) who are enrolled in the electronics department of our college. These students provided valuable help in arriving at the final version of the step-by-step procedure for each experiment.

We wish to acknowledge a considerable debt to our wives, Joyce and Margy, for typing the manuscripts of the laboratory manual and the theory text; without their valuable support and inspiration, the publication of these books would not have been possible.

Victor F. Veley
John J. Dulin

Introduction to DC Measurements; Soldering Techniques

INTRODUCTION TO METERS

In the dc chapters (1 through 9) of *Modern Electronics: A First Course*, we were concerned primarily with four electrical quantities: the voltage measured in volts, the current in amperes, the resistance in ohms, and the power in watts. Dc wattmeters are comparatively rare since the power may be calculated by multiplying the voltage by the current. We are therefore left with the requirements to measure voltage, current, and resistance. Chapter 10 describes in detail the VOM (voltmeter–ohmmeter–milliammeter), which uses a moving-coil (electromechanical) meter movement and depends on the motor effect to provide the necessary deflection torque. Such a multimeter does not need an external power source and contains only two primary cells to operate the instrument as an ohmmeter. Although under most circumstances the VOM is adequate for measuring the dc currents that normally occur in electronic circuits, it has limitations as far as the measurements of resistance and dc voltage are concerned. For such measurements it is preferable to use an electronic voltmeter (EVM); not only does this type of multimeter have a greater number of resistance ranges, it also has much less loading effect on a circuit when dc voltage measurements are being taken (see Experiment 20).

Although the EVM does take a variety of forms, in all cases the instrument, when acting as a voltmeter, needs an external power source or an internal battery. This supply is necessary to operate the solid-state devices or tubes which form part of the EVM circuitry. Because the theory of these active devices was not covered in *Modern Electronics: A First Course*, Chapter 10 did not describe the operation of the EVM.

According to the type of active device it contains, the EVM may be classified as a TVM (transistor voltmeter) or a VTVM (vacuum-tube voltmeter). Fig. 1 shows a TVM that uses field-effect transistors (FETs), so that there is an extremely small loading effect on a circuit when taking dc voltage measurements. The older VTVM (Fig. 2) has an input resistance of 11 MΩ on all dc voltage ranges and must be connected to the normal 120-V 60-Hz supply for its operation. Both these instruments would be described as analog meters in which the needle can move continuously across

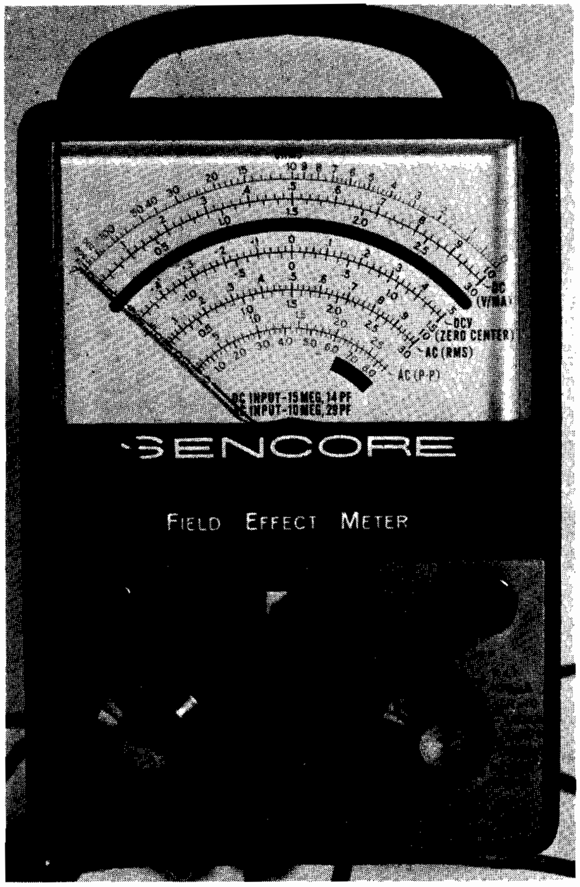


Fig. 1. Transistor (FET) voltmeter (TVM).

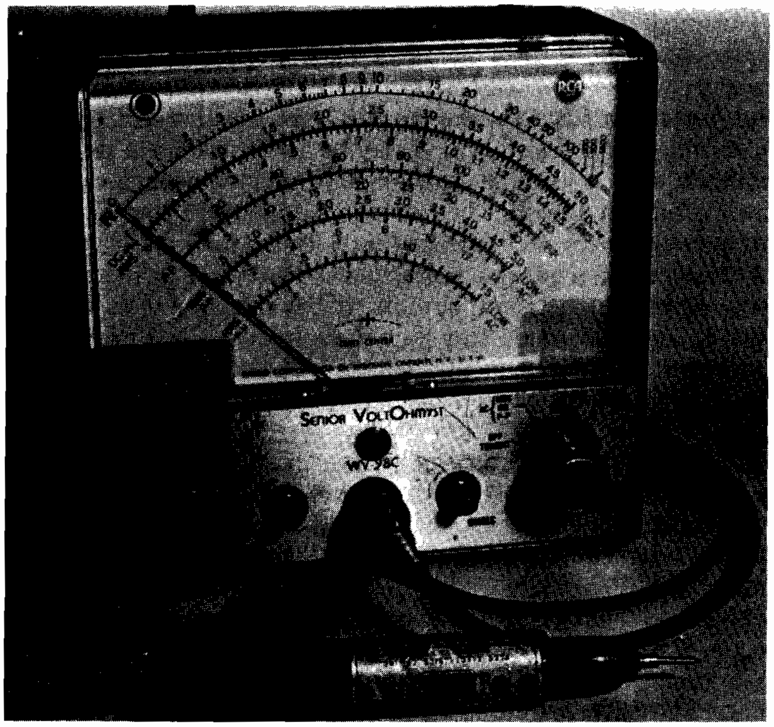


Fig. 2. Vacuum tube voltmeter (VTVM).

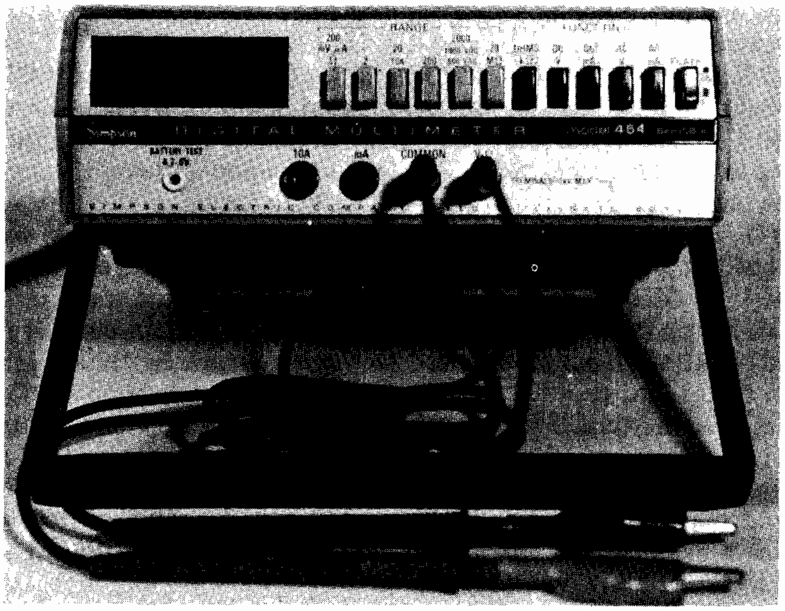


Fig. 3. **Digital multimeter (DMM).**

the scale and you are required to interpret the reading. By contrast, another type of EVM is the digital multimeter (DMM) of Fig. 3; with this type of multimeter there is a direct readout of the quantity being measured. Such an instrument contains integrated circuits (ICs) in which a large number of components and solid-state devices have been concentrated.

Like the VOM, many EVMs are equipped to measure voltage, current, and resistance. However, the VTVM, for example, has no current ranges, and therefore in the dc experiments (1 through 20) we will customarily use the EVM to measure voltage and resistance while the VOM will record the current.

DESCRIPTION OF THE EVM

The step-by-step procedures for measuring voltage and resistance will be outlined when they are first required by the experiments. At this stage we are only going to describe the switches and controls that you will normally encounter when operating an analog EVM.

The face of an analog EVM can present a variety of appearances, but in all cases there will be a function switch and a range switch. In the case of the VTVM (Fig. 2) the function switch is located at the lower right-hand corner and is controlled by a knob with five positions. The position on the left side is marked "OFF TRANSIT," so that when the knob is moved to any one of the other four positions, the instrument is automatically switched ON. Reading clockwise the other positions of the function switch are

1. "AC, RMS or P-P" for measuring ac voltage
2. "– DC VOLTS" for the measurement of *negative* dc potentials with respect to ground
3. "+ DC VOLTS" for the measurement of *positive* dc potentials with respect to ground
4. "R OHMS" for measuring resistance

The range switch is positioned at the lower left-hand corner of the front panel and its control knob has eight positions. The fully counterclockwise position is used for the 0–0.5 V range, which applies only to dc voltage measurements. Moving clockwise, the next position of the range switch is marked "1.5 V, R X 1, 4.0 V." [At this stage we will ignore the meaning of the "4.0 V" marked on the figure since it applies only to ac voltage measurements and will be explained in the introductory section (pages 126–127) prior to Experiment 21.] This position will be used for the dc voltage measurements in the 0–1.5 V range and also for resistance readings on the R X 1 scale. The other six positions in clockwise order are (1) 0–5 V, R X 10; (2) 0–15 V, R X 100; (3) 0–50 V, R X 1000; (4) 0–150 V, R X 10 K; (5) 0–500 V, R X 100 K; and (6) 0–1500 V, R X 1 MEG.

Next to and slightly to the right of the range switch is the ZERO control, which is used to set the needle at the zero marks on the left-hand side of the meter scales. When the function switch is set to any one of the three voltage positions, the needle may not settle on the zero marks. It is then possible to move the needle to the zero mark by the ZERO control.

After the ZERO control has been correctly set, the knob on the function switch can be moved to the "R OHMS" position prior to taking resistance measurements. With the meter leads apart and the probe set to the "AC OHMS" position (Fig. 2), the needle should travel up the scale and settle on the last mark, which represents the infinite (∞) ohms of an open circuit. If the needle does not settle in the correct position, it may be moved to the "∞" mark by the OHMS control, which is next to the function switch and slightly to its left.

The TVM (Fig. 1) is battery operated and has similar controls and switches to the VTVM. However, this instrument is capable of measuring dc current so that, reading clockwise, the four positions of the function switch (bottom left-hand corner) are (1) - DC V/mA, (2) + DC V/mA, (3) AC V/Ohms, and (4) BATT. CHK. There is a separate ON/OFF switch for the battery and neither lead contains a switch-operated probe. The range switch (bottom right-hand corner) has 12 positions, which include the following ranges:

DC Voltage: 0-1 V, 0-3 V, 0-10 V, 0-30 V, 0-100 V, 0-300 V, 0-1000 V (0-3kV, 0-10 kV, and 0-30 kV ranges are also available with the use of an additional high-voltage probe)

DC Current: 0-100 μA, 0-1.0 mA, 0-10 mA, 0-100 mA, 0-1 A

Resistance: R X 1, R X 10, R X 100, R X 10 K, R X 1 MEG

On this instrument the zero control is located at the top left-hand corner and is marked "ZERO ADJ"; the ohms control in the top right-hand corner is shown as "OHMS ADJ." Both of these controls operate in a similar manner to the corresponding controls of the VTVM.

In Fig. 3 the DMM is operated from the normal 120-V 60-Hz supply, with the power switch located on the extreme right of the front panel (some models can also be powered from an internal battery). The function switch is pushbutton controlled and has the following five positions: OHMS (kΩ), DC V, DC mA, AC V, and AC mA. The range switch is also pushbutton controlled with six positions. Reading from left to right:

1. 0 to ±200 mV dc, 0 to 200 mV ac, 0 to ±200 μA dc, 0 to 200 μA ac, 0 to 200 Ω
2. 0 to ±2 V dc, 0 to 2 V ac, 0 to ±2 mA dc, 0 to 2 mA ac, 0 to 2 kΩ
3. 0 to ±20 V dc, 0 to 20 V ac, 0 to ±20 mA dc, 0 to 20 mA ac, 0 to 20 kΩ (0 to ±10 A dc, 0 to 10 A ac if the 10-A jack is used)
4. 0 to ±200 V dc, 0 to 200 V ac, 0 to ±200 mA dc, 0 to 200 mA ac, 0 to 200 kΩ
5. 0 to ±1000 V dc, 0 to 600 V ac, 0 to ±2 A dc, 0 to 2 A ac, 0 to 2 MΩ
6. 0 to 20 MΩ

In the DMM there are no zero and ohms controls. With the VTVMs, TVMs, and DMMs there is a wide variety of appearances, switches, and controls; you are therefore advised to study the manual of the EVM that you will be using for your experiments.

SOLDERING TECHNIQUES

Soldering Tools

There are two ways in which you can connect the experiments contained in this manual. Either you can lay the components on a bench and use connecting leads or, preferably, you can mount the smaller components on a vector board as shown in Fig. 4. Because of the limited space available

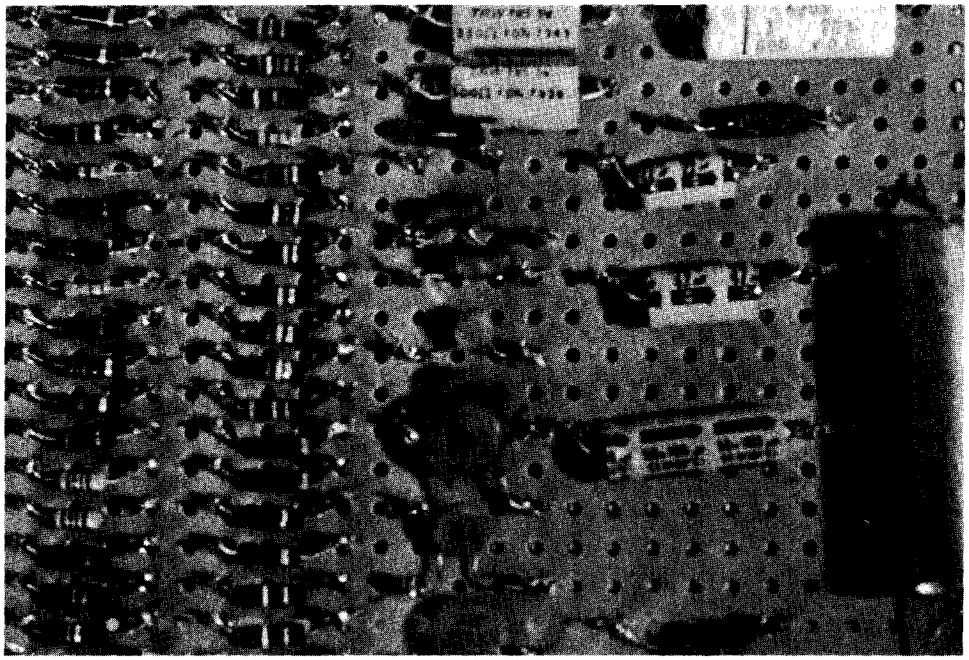


Fig. 4. Vector board with components assembled.

on a standard vector board ($8\frac{1}{2}$ in. by $4\frac{1}{4}$ in.), we suggest that you use one board for the dc experiments and a separate board for the ac experiments. To assist in building up these boards, the components required are listed on pages 10–12 and 126–127. We recommend the use of vector boards since you will rapidly learn not only the most effective way of wiring up the various circuits but also the basic techniques of soldering, which is a vital part of electronic maintenance procedures. Soldering is a manual skill that can and must be learned by all personnel who work in the field of electronics. To develop proficiency in the techniques of soldering requires practice, which should be accompanied by a thorough understanding of the basic principles involved.

Let's begin by looking at the main tools that you will use. These are shown in Fig. 5 and include:

1. The *soldering iron*, which operates in the approximate temperature range 250 to 300° Celsius. When leads are soldered to terminals, it is common practice to use a 100-W iron, but for working on a printed circuit board the 25-W midget iron or soldering pencil is preferred since it is lighter, easier to handle, and has a miniature tip which can operate in difficult places. Both the standard iron and the pencil work at the same temperature, but the pencil does not have the capacity to transfer large quantities of heat.
2. *Dykes* or *diagonal pliers*, which are made for cutting copper or aluminum wires as well as component leads. Some dykes can also be used for stripping No. 22 copper wire, which is commonly used in electronics circuitry.
3. *Needlenose pliers*, to hold the wire ends which have been stripped to their insulation. These wires can then be steered and pushed through a terminal eye or partially wrapped around a terminal post. The long, thin jaws allow you to reach into difficult positions where there is little room to maneuver.
4. The *wire stripper*, whose purpose is to bare the ends of connecting wires by removing their insulation. The simplest type of stripper will operate effectively only on one particular diameter, such as No. 22 wire, but the more sophisticated versions can be used with wires of differing diameters.
5. The *soldering aid*, which has one pointed end to clear away unwanted solder from terminal lugs, eyes, and forks. The other end is slotted and can grip wire as it is being unwrapped and disconnected from terminals during the desoldering process.

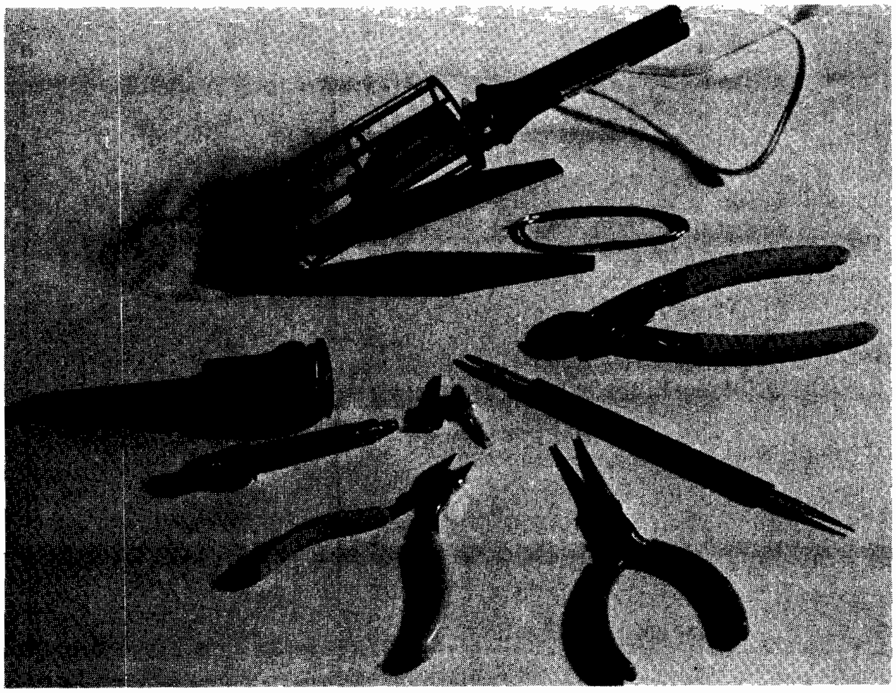


Fig. 5. Soldering tools and aids.

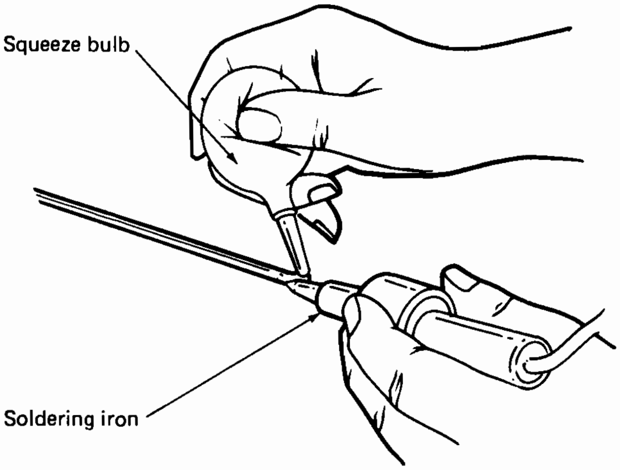


Fig. 6. Use of the "solder sucker."

6. The *"solder sucker" syringe* (Fig. 6), whose purpose is to suck up excess solder from a joint and whose tip must be able to withstand the temperature of molten solder. Apart from these five tools, other aids, such as brushes, probes, scrapers, and knives, are frequently used in the soldering process.

Solder and the Soldering Process

The three grades of solder generally used for electronics work are 40–60, 50–50, and 60–40. The first figure is the percentage of tin; the second is the percentage of lead. The higher the percentage of tin, the lower is the temperature required for melting. Also, the higher the tin content, the easier the flow, the less time required to harden, and generally the easier it is to do a good soldering job.

In addition to the solder, there must be flux to remove any oxide film on the metals being

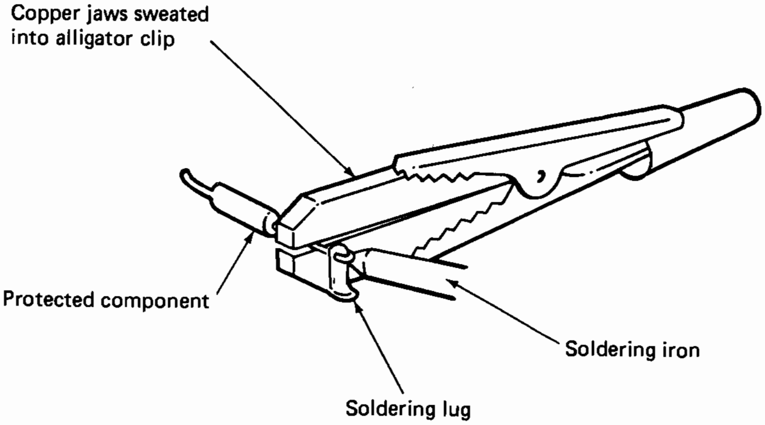


Fig. 7. Use of the heat shunt.

joined; otherwise, they cannot fuse. The flux enables the molten solder to wet the metals so that the solder can stick. Rosin flux is always used for the light soldering work involved in making wire connections. Generally, the rosin is in the hollow core of solder intended for electronics work, so that a separate flux is unnecessary. It should be noted, though, that the flux is not a substitute for cleaning the metals to be soldered. The metal must be shiny clean for the solder to stick.

Cleanliness is a prime prerequisite for efficient, effective soldering. Solder will not adhere to dirty, greasy, or oxidized surfaces. Heated metals tend to oxidize rapidly, and the oxide must be removed prior to soldering. Oxides, scale, and dirt can be removed by mechanical means (such as scraping or cutting with an abrasive) or by chemical means. Grease or oil films can be removed by a suitable solvent. Cleaning should take place immediately prior to the actual soldering operation.

Items to be soldered should normally be tinned before making a mechanical connection. Tinning is the coating of the material to be soldered with a light coat of solder. When the surface has been properly cleaned, a thin, even coating of flux may be placed over the surface to be tinned to prevent oxidation while the part is being heated to soldering temperature.

The tinning on a wire should extend only far enough to take advantage of the depth of the terminal or receptacle. Tinning or soldering on wires subject to flexing causes stiffness, and may result in breakage.

The tinned surfaces to be joined should, if necessary, be shaped and fitted, then mechanically joined to make good mechanical and electrical contact. They must be held still with no relative movement of the parts. Any motion between parts will probably result in a poor connection.

Some type of thermal shunt is essential in all soldering operations that involve heat-sensitive components. Pliers or tweezers may be used for some applications, but their effectiveness is limited. A superior heat shunt or sink, as shown in Fig. 7, permits soldering the leads of component parts without overheating the part itself.

For maximum effectiveness, any protective coating should be removed before applying the heat shunt. The shunt should be attached carefully to prevent damage to the leads, terminals, or component parts. The shunt should be clipped to the lead between the joint and the part to be protected. As the joint is heated, the shunt absorbs the excess heat before it can reach the part and cause damage.

At the end of the operation the heat source should be removed immediately, but the shunt should be left in place. Premature removal of the heat shunt permits unrestricted flow of heat from the melted solder into the component. The shunt should be allowed to remain in place until it cools to room temperature. A slip-on type of shunt is preferred because it requires positive action to remove the shunt but does not require that you maintain pressure to hold it in place.

Solder Connections

In making soldered connections to the various types of terminal, it is essential to provide maximum mechanical support and strength, so that the parts to be joined cannot move in relation to one

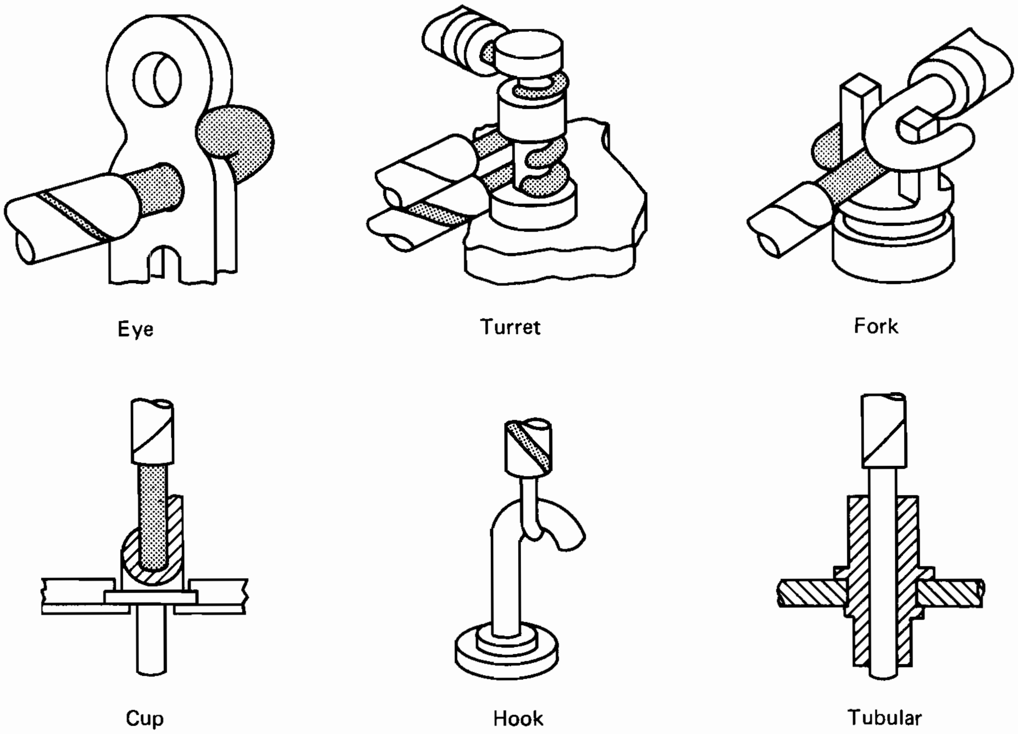


Fig. 8. **Examples of soldered joints.**

another during the soldering process. Subsequently, the joint must not be disturbed until the solder has completely solidified.

Typical examples of joints are shown in Fig. 8. Wire wrappings of three-eights to three-quarters turn are usually recommended so that the joint need not be held during the application and cooling of the solder.

Excessive wrappings of leads results in increased heat requirements, more strain on parts, greater difficulty of inspection, greater difficulty of assembly and disassembly of the joints, and increased danger of breaking the parts or terminals during the desoldering operations. Insufficient wrapping may result in poor solder joints due to any movement of the lead during the soldering operation.

The areas to be joined must be heated to or slightly above the flow temperature of the solder. The application of heat must be carefully controlled to prevent damage to components in the assembly, insulation, or nearby materials. Solder is then applied to the heated area. Only enough solder should be used to make a satisfactory joint.

Solder should not be melted with the soldering tip and allowed to flow onto the joint. The joint should be heated and the solder applied to the joint. When the joint is adequately heated, the solder will flow evenly. Excessive temperature tends to carbonize flux and hinders the soldering operation.

No liquid should be used to cool a solder joint. By using the proper tools and soldering techniques, a joint should not become so hot that rapid cooling is needed.

If for any reason, a satisfactory joint is not initially obtained, the joint must be taken apart, the surface cleaned, excess solder removed, and the entire soldering operation (except tinning) repeated.

After the joint has cooled, all flux residues should be removed. Any flux residue remaining on the surface of electrical contacts may collect dirt and cause arcing at a later time. This cleaning is necessary even when rosin-core solder is used.

Connections should never be soldered or desoldered while equipment power is on or while the circuit is under test. Always discharge any capacitors in the circuit prior to any soldering operation.

DC EXPERIMENTS 1 THROUGH 20: COMPONENTS AND EQUIPMENT REQUIRED

Resistors

5% tolerance	100 Ω	2 W
	200 Ω	
	100 Ω	1 W
	1 kΩ	
	100 Ω	$\frac{1}{2}$ W
	Two 200 Ω	
	390 Ω	
	1 kΩ	
	2 kΩ	
	Two 10 kΩ	
	20 kΩ	
	91 kΩ	
	Two 200 kΩ	
	910 kΩ	
	1.1 MΩ	
	2 MΩ	
10% tolerance	18 Ω	2 W
	56 Ω	1 W
	100 Ω	
	180 Ω	$\frac{1}{2}$ W
	330 Ω	
	470 Ω	
	820 Ω	$\frac{1}{2}$ W
	1 kΩ	
	1.2 kΩ	
	1.5 kΩ	
	1.8 kΩ	
	2.2 kΩ	
	2.7 kΩ	
	3.3 kΩ	
	Two 3.9 kΩ	
	4.7 kΩ	
	5.6 kΩ	
	6.8 kΩ	
	8.2 kΩ	
	Two 10 kΩ	
	12 kΩ	
	18 kΩ	
	180 kΩ	
20% tolerance	470 Ω	$\frac{1}{2}$ W
	680 Ω	
	3.3 kΩ	
	4.7 kΩ	
	6.8 kΩ	
	47 kΩ	
	68 kΩ	
	1 MΩ	
	680 Ω	2 W

500 Ω, 20 W or greater
960 Ω, 15 W or greater
10 Ω, 5 W
4 Ω, 10 W
5 Ω, 10 W

Potentiometers
10 kΩ, 2 W
15 Ω, 12½ W

Inductor
4-H choke, 50 mA

Capacitors
200 pF (mica)
250 pF max (variable, air)
0.01 μF (paper)
0.01 μF (ceramic)
0.1 μF (ceramic)
0.47 μF (paper)
1 μF (oil)
10 μF (oil or paper)
20 μF (electrolytic)

Switches
Four single-pole single-throw
One single-pole double-throw
One double-pole single-throw

Cells and Power Supplies
Four 1½-V dry cell (Eveready 1S6 or equivalent)
One 6-V (lighting) cell (Eveready 510S or equivalent)
Four variable low-voltage regulated dc power supplies, 0-30 V (0-400 mA)
One variable high-voltage regulated dc power supply, 0-300 V (0-150 mA)

Insulators
1-m lengths of string, paper, wood, plastic, rubber, and glass

Test Equipment
EVM
Two VOMs: (20,000 Ω/V); (1000 Ω/V)
Capacitor checker

Miscellaneous
1N4002 silicon diode (or equivalent)
Incandescent lamp: 12 W, 12 V [GE 12S8/93T or equivalent (high intensity lamp)]
Incandescent lamp: 15 W, 120 V
(Alternative: incandescent lamp 28 V, 0.04 A, No. 1819)
Decade resistor box

Experiment 1

The Ohmmeter; Color-Coded and Variable Resistors

READING ASSIGNMENT

Modern Electronics: A First Course, pages 51–58

Topics: Color-Coded Resistors; The Potentiometer and the Rheostat

OBJECTIVES OF EXPERIMENT

1 To become familiar with the operation of an ohmmeter in the measurement of resistance
2. To measure the resistances of a number of composition resistors
3. To examine experimentally the potentiometer and the rheostat as examples of variable resistors

COMPONENTS AND EQUIPMENT REQUIRED

1. Color-coded resistors as listed on pages 10 and 11
2. Variable resistor: 10-kΩ 2-W potentiometer
3. Meters: analog EVM; analog VOM

PROCEDURE

Operation of the Analog EVM as an Ohmmeter

The following procedure is common to many types of analog EVMs and applies to the VTVM shown in Fig. 1-1. Should there be significant differences for the particular EVM you are using, you must consult the operator's manual regarding the measurement of resistance.

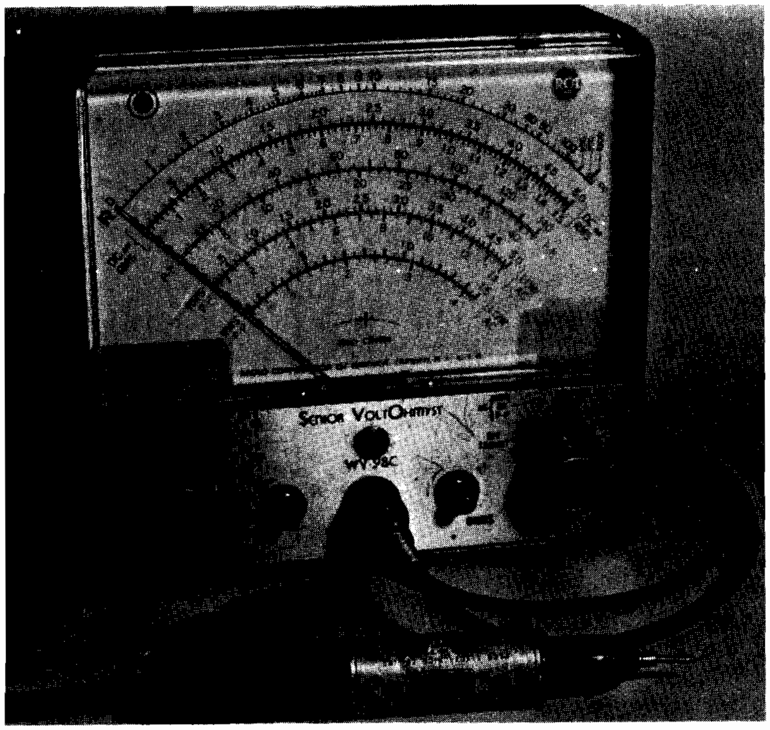


Fig. 1-1. Vacuum tube voltmeter (VTVM).

The ohms scale of the VTVM is shown in Fig. 1-2. It is a nonlinear scale with the zero or short-circuit mark on the left side and the infinite (∞) or open-circuit mark on the right side. The graduations are widely spaced for low readings, but for any reading above 100 the graduations are extremely close and an accurate measurement is impossible. The best results are obtained when the needle is somewhere near the *middle* of the scale; this is achieved by the correct setting of the range switch, for example R × 1000. In this case you would then find the actual resistance after multiplying the reading on the ohms scale by 1000. One example for each position of the range switch is shown in Figs. 1-3(a) through (g). It is strongly recommended that you familiarize yourself with the ohms scale as much as possible so that you can interpret readings without making mistakes.

General Caution (EVM and VOM)

If you are measuring the value of a resistor that is connected into a circuit, all power *must* be removed from the circuit and all capacitors *must* be discharged. A low voltage applied to the ohmmeter will cause incorrect resistance readings and a high voltage will damage the instrument.

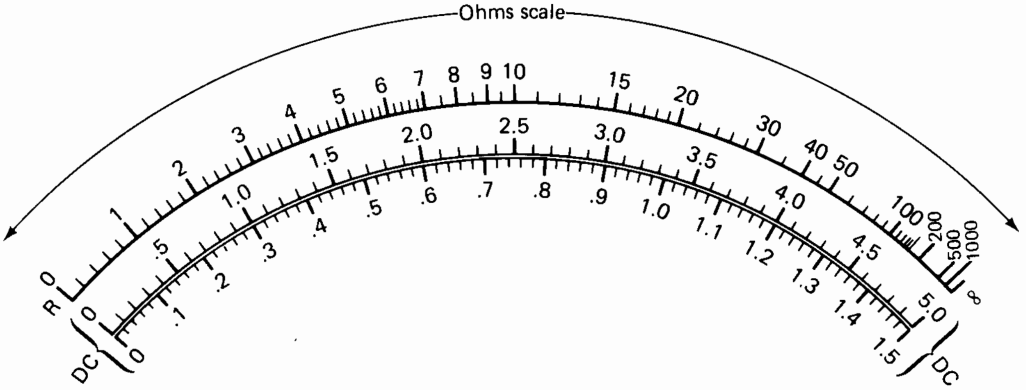
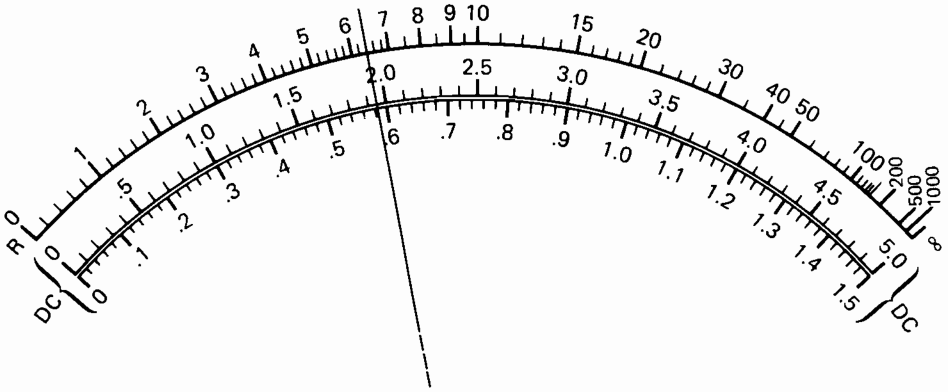
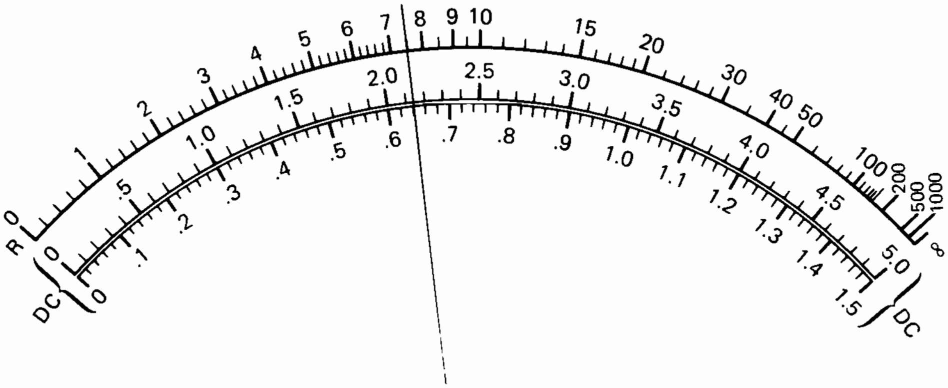


Fig. 1-2. Ohms scale of the VTVM.



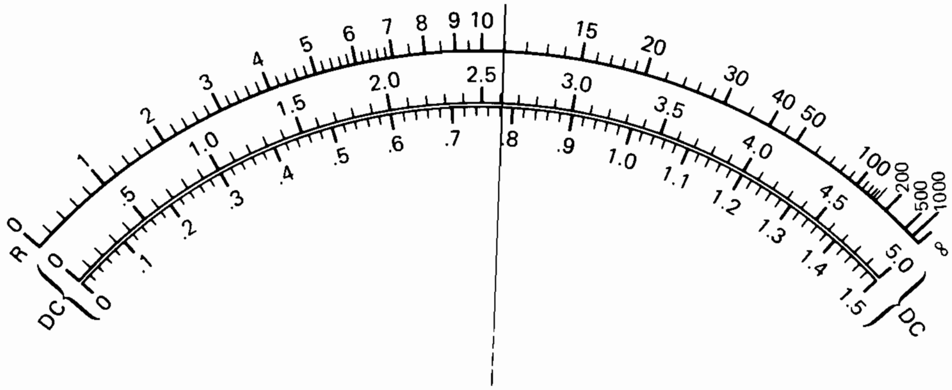
Scale reading: 6.4
Range switch: R X 1
Measured resistance: 6.4 Ω

(a)



Scale reading: 7.5
Range switch: R X 10
Measured resistance: 75 Ω

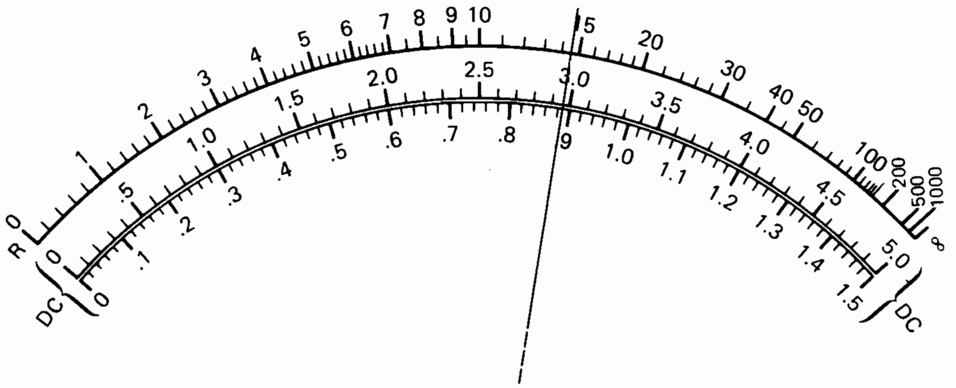
(b)



Scale reading: 11.0
Range switch: R X 100
Measured resistance: 1100 Ω or 1.1 kΩ

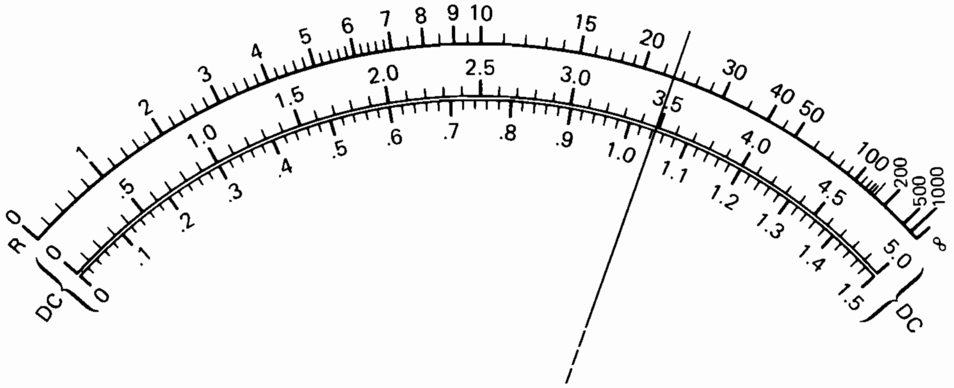
(c)

Fig. 1-3



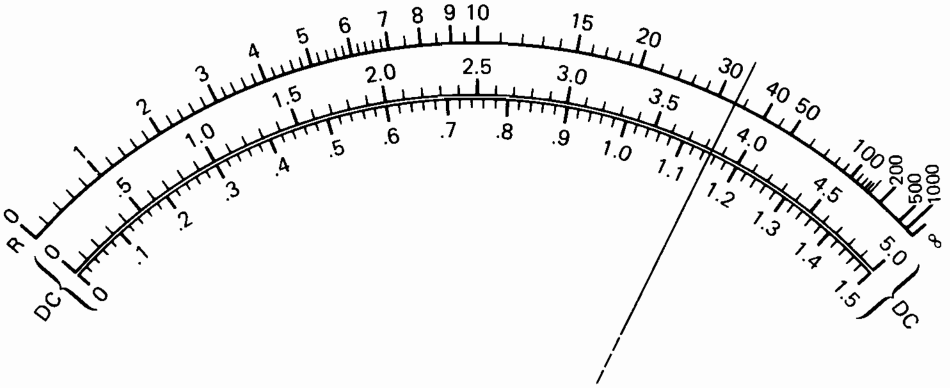
Scale reading: 14.5
Range switch: R X 1000
Measured resistance: 14500 Ω or 14.5 kΩ

(d)



Scale reading: 23.0
Range switch: R X 10 K
Measured resistance: 230 kΩ

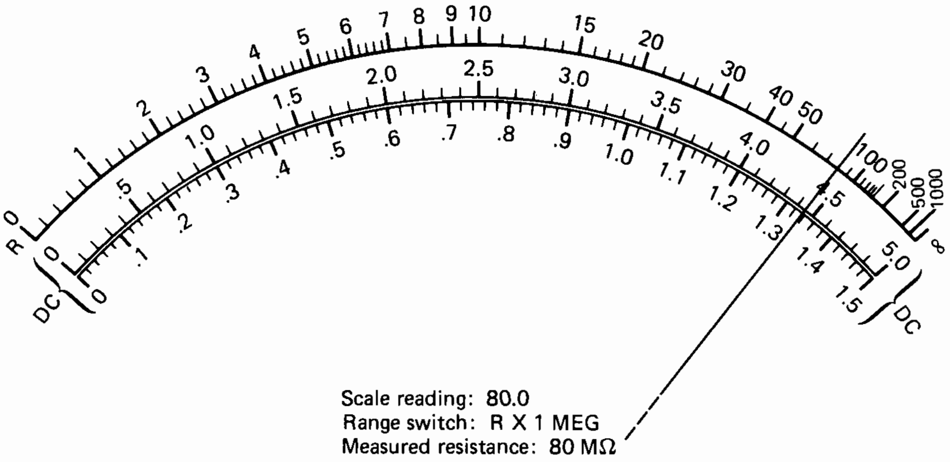
(e)



Scale reading: 33.0
Range switch: R X 100 K
Measured resistance: 3300 kΩ or 3.3 MΩ

(f)

Fig. 1-3 Continued



Scale reading: 80.0
Range switch: R X 1 MEG
Measured resistance: 80 MΩ

(g)

Fig. 1-3 Continued

Check whether there are other resistance paths across the resistor whose value you are measuring. If such paths exist, the measured value will be lower than the actual value of the resistor.

The procedure for measuring the value of a resistor with the VTVM is as follows:

1. Set the function switch to "R OHMS" and the sliding switch on the probe to "AC OHMS."
2. Set the range switch to the "R X 10" position.
3. Connect the tip of the probe to the common or ground lead so that the two are shorted. If necessary, adjust the ZERO control to bring the needle to the zero mark on the left side of the ohms scale.
4. Separate the tip of the probe from the common lead to create an open circuit (infinite ohms). The needle should now deflect full scale and should lie on the final infinite (∞) mark. If necessary, adjust the OHMS control to bring the needle to the required mark. (*Note:* After separating the probe tip from the common lead, lay both down and do not hold on to their metal parts. This is to avoid connecting your body resistance across the ohmmeter.)
5. Repeat steps 3 and 4 as necessary. Whenever the position of the range switch is changed, steps 3 and 4 should be rechecked.
6. Connect the clip of the common or ground lead to one end of the resistor and the probe's metal tip to the other end.
7. If necessary, change the setting of the range switch so that the deflection is approximately at the middle of the ohms scale. Multiply the reading by the factor shown on the chosen position of the range switch.

Note: When measuring a totally unknown resistance, start with the range switch in the "R X 1 MEG" position and then move the switch counterclockwise until a suitable deflection is obtained. This avoids applying up to 1.5 V to the unknown resistance on the R X 1 and R X 10 ranges; such a voltage might damage the component whose resistance you are measuring.

Operation of the Analog VOM as an Ohmmeter

The typical appearance of an analog VOM is shown in Fig. 1-4. The range switch is in the center of the control panel and has 12 positions. The three resistance ranges are located at the lower right-hand side of the switch; these three ranges compare with the seven ranges available on the EVM.

The ohms scale of the VOM is shown in Fig. 1-5. Notice that, unlike the EVM, the zero or short circuit mark is now on the right side and the infinite (∞) or open-circuit mark on the left side; therefore, the ohms scale reads from right to left for increasing values of resistance. However the scale again is nonlinear and must be carefully interpreted. Examples of reading the scale for each position of the resistance range switch are shown in Figs. 1-6(a) through (f).

Fig. 1-4. Voltmeter-ohmmeter-milliammeter (VOM).

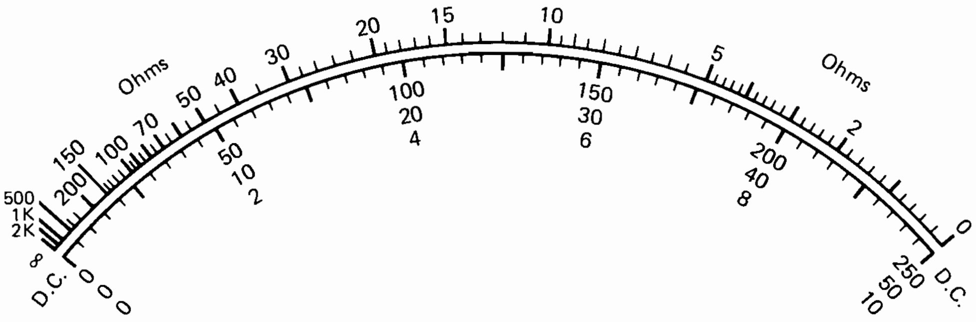
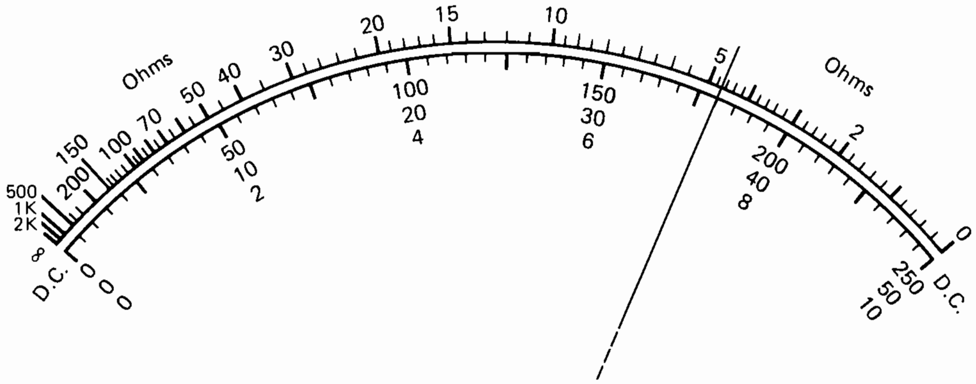


Fig. 1-5. Ohms scale of the VOM.

After observing the rules in the "General Caution," the procedure for measuring resistance with the VOM is as follows:

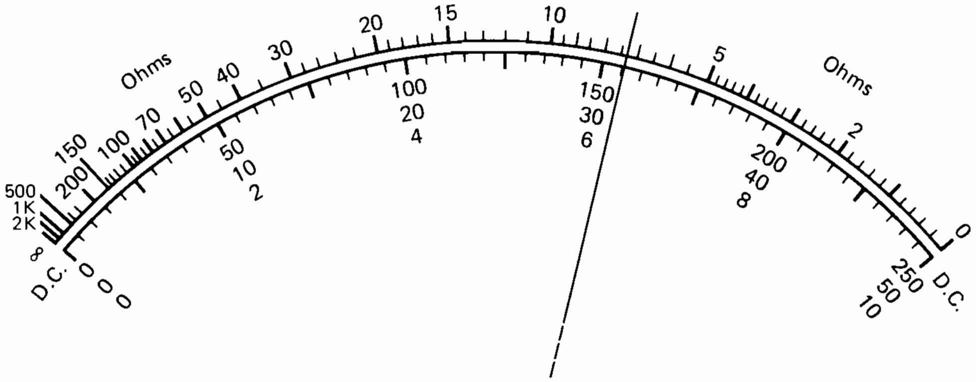
1. Plug the black lead into the "COMMON" jack and the red lead into the "+" jack. These jacks are located at the bottom left-hand corner of the panel.
2. Set the function switch (left-hand side of the panel) to the "+ DC" position. This means that the red lead will have a positive polarity and the black lead a negative polarity from the internal cell(s) which are used for measuring resistance. The polarity will be reversed if the switch is set to the "– DC" position; however, the procedure is the same for either position unless a semiconductor diode action is involved (Experiment 6).
3. Set the range switch to the appropriate position. If the resistance is known approximately, the correct settings are:
   a. R × 1 range for resistances between 0 and 200 Ω
   b. R × 100 range for resistances between 200 and 20,000 Ω
   c. R × 10,000 range for resistances greater than 20,000 Ω

   If the resistance is unknown, start with the "R × 10,000" range.



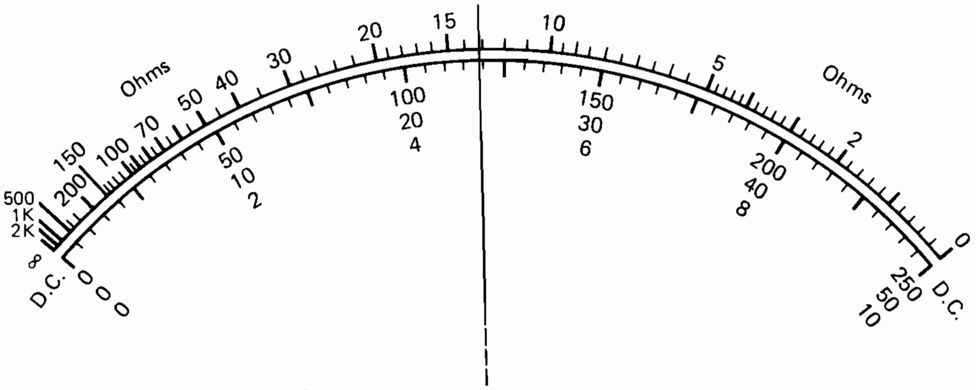
Scale reading: 4.7
Range switch: R X 1
Measured resistance: 4.7 Ω

(a)



Scale reading: 7.3
Range switch: R X 1
Measured resistance: 7.3 Ω

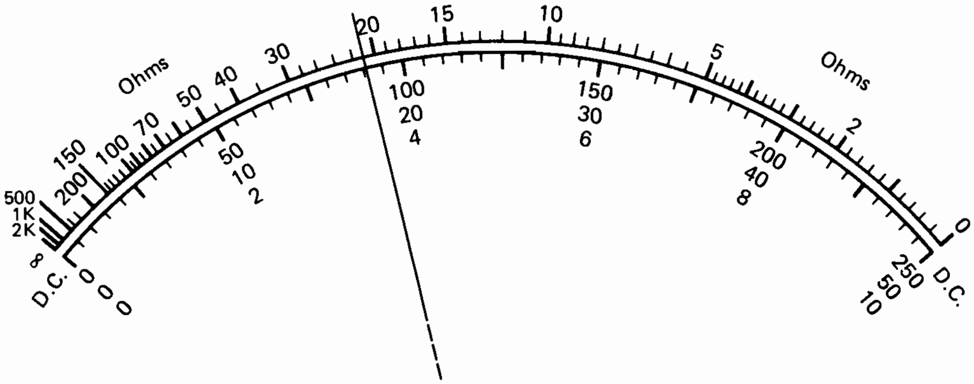
(b)



Scale reading: 13.2
Range switch: R X 100
Measured resistance: 1320 Ω or 1.32 kΩ

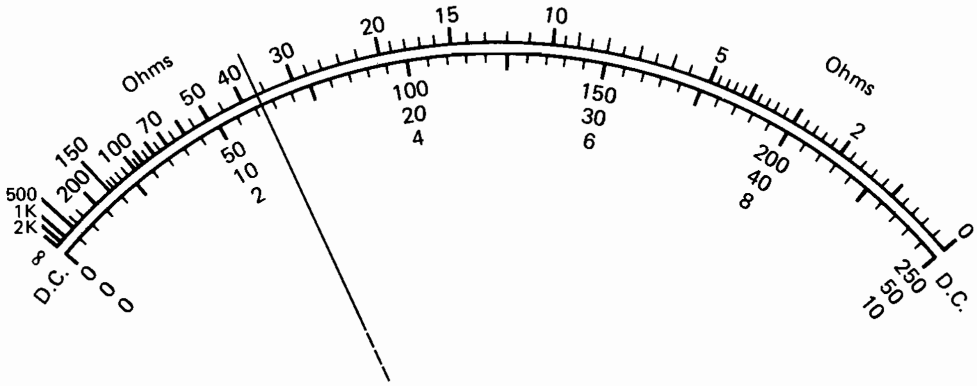
(c)

Fig. 1-6



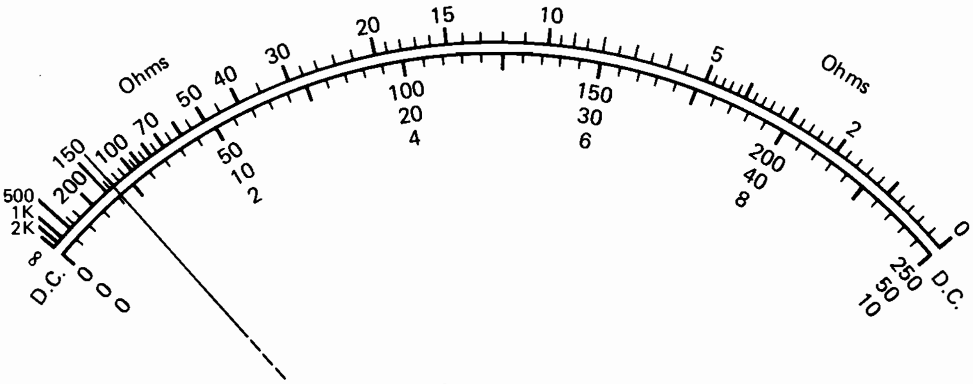
Scale reading: 21.0
Range switch: R X 100
Measured resistance: 2100 Ω or 2.1 kΩ

(d)



Scale reading: 37.0
Range switch: R X 10000
Measured resistance: 370000 Ω or 370 kΩ

(e)



Scale reading: 130.0
Range switch: R X 10000
Measured resistance: 1300000 Ω or 1.3 MΩ

(f)

Fig. 1-6 Continued

4. If the needle is not on the infinite (∞) mark with the leads apart, use a small screwdriver to adjust the screw located in the cover below the center of the dial.
5. Connect the test leads together to create a short circuit. If necessary, adjust the "ZERO OHMS" control (right side of the panel) to bring the needle to the zero mark on the right side of the ohms scale. If you find that this is not possible, one or both of the internal cells must be replaced.
6. Disconnect the leads. Clip the red lead to one end of the resistor (or component whose resistance you want to find) and the black lead to the other end.
7. Observe the reading on the ohms scale. To obtain the actual resistance, multiply the reading by the factor shown on the chosen position of the range switch.

Note: When measuring a totally unknown resistance, start with the "R X 10,000" position of the range switch. If necessary, move the switch counterclockwise until a suitable deflection is obtained. When changing range, the setting of the "ZERO OHMS" control should be rechecked.

EXPERIMENTAL PROCEDURE

Measuring the Resistance of Color-Coded Resistors

1. Collect together all the color-coded resistors listed on pages 10 and 11. Separate them into three groups according to their tolerances (20, 10, and 5%). In ascending order of their resistances, enter the rated values of each group into Table 1-1. Calculate the permitted upper and lower resistance limits for each resistor and then measure its value with both the EVM and the VOM; enter the computed results and measured readings in Table 1-1. Confirm that switching the leads across a resistor with either instrument does not affect the measured value of the resistance.

Measuring the Resistance of an Open Circuit

2. With the EVM measure the resistance of a 10-kΩ resistor. Cut one of the pigtail wires to create an open circuit (Fig. 1-7). Measure the new resistance and record the reading in Table 1-2. Repeat the procedure with the VOM.

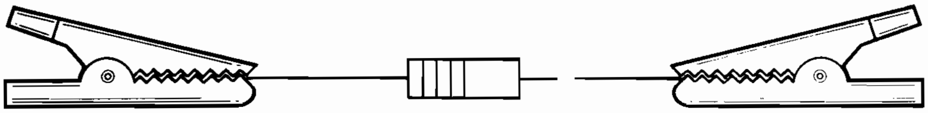


Fig. 1-7. Measurement of the open circuit.

Measuring the Resistance of a Short Circuit

3. With the EVM measure the resistance of a 1-kΩ resistor. Bend the pigtail wires so that they just touch across the resistor (Fig. 1-8). Measure the new resistance between the ends of the resistor and record the reading in Table 1-2. Repeat the procedure with the VOM.

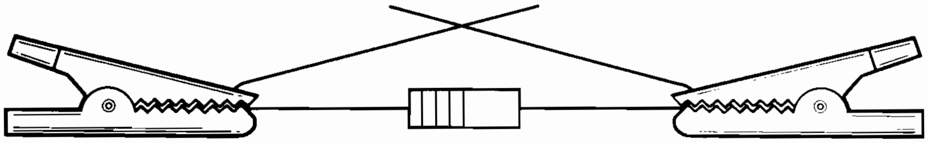


Fig. 1-8. Measurement of the short circuit.

Measuring the Resistance of a Variable Resistor

4. Lay the potentiometer on a flat sheet of white paper with the shaft *S* pointing toward you and the three terminals *X*, *Y*, *Z* on the right side [Fig. 1-9(a)]. Wrap a piece of flexible wire around the shaft and leave one end free to act as a pointer. Rotate the shaft fully counterclockwise and move the pointer to any

Table 1-1

Rated Value	*Tolerance*	*Permitted Upper Limit of Resistance*	*Permitted Lower Limit of Resistance*	*EVM Measurement*	*VOM Measurement*	*Is the Resistor within Its Tolerance? (Yes or No)*

Table 1-2

Resistance	*EVM Measurement*	*VOM Measurement*
Of open circuit		
Of short circuit		

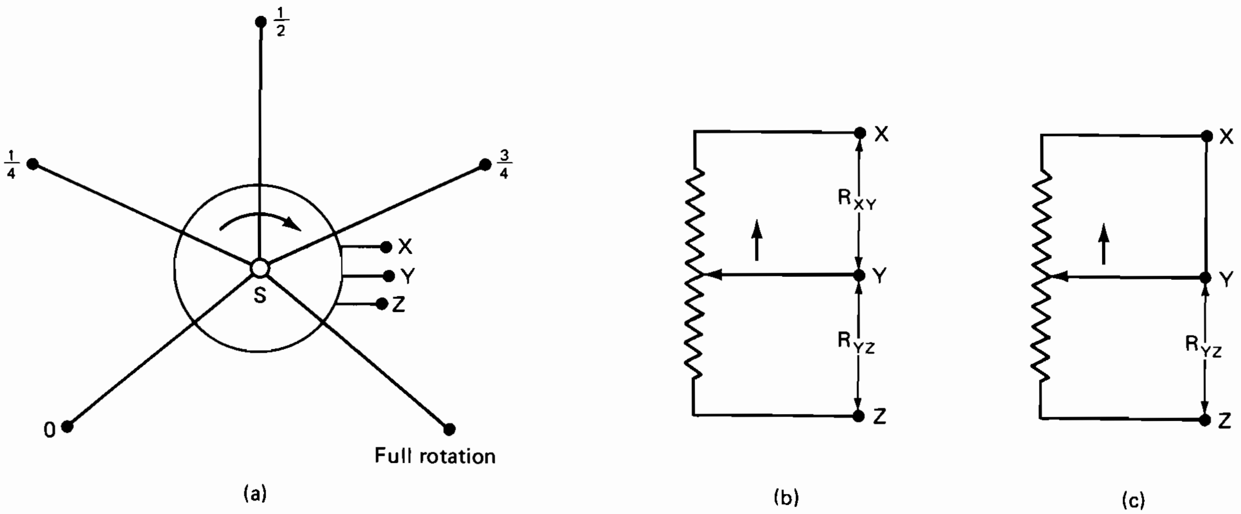
convenient position, for example SO. Mark the position SO on the sheet of paper. Rotate the shaft clockwise through its entire travel and mark the position corresponding to full rotation. Determine and mark the positions for $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ rotation.

5. Using the EVM as an ohmmeter on the R X 1000 range, measure the resistance R_{XZ} between terminals X and Z and enter the reading in Table 1-3. Rotate the shaft through its entire travel and confirm that the measured value of R_{XZ} does not change.

Table 1-3

Amount of Rotation	*Measured* R_{XY} (kΩ)	*Measured* R_{YZ} (kΩ)	R_{XZ} (kΩ)
Zero		0	(Measured)
$\frac{1}{4}$			(Computed)
$\frac{1}{2}$			(Computed)
$\frac{3}{4}$			(Computed)
Full			(Computed)

6. Rotate the potentiometer shaft to the full counterclockwise position; Y and Z of Fig. 1-9(b) are now together. With the EVM measure the resistances R_{YZ} and R_{XY} and record the readings in Table 1-3. Rotate the shaft to the $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full rotation positions and measure the values of R_{YZ} and R_{XY} in each case. Enter all readings in Table 1-3. Add together the corresponding values of R_{YZ} and R_{XY} and enter the results in the R_{XZ} column.
7. Rotate the potentiometer shaft to the fully counterclockwise position. Short together the terminals X and Y with a piece of bare copper wire so that the potentiometer is connected as a rheostat [Fig. 1-9(c)]. Measure the resistance R_{YZ} with the EVM and record the reading in Table 1-4. Rotate the shaft to the



(a) (b) (c)

Fig. 1-9. The potentiometer as a variable resistor.

Table 1-4

Amount of Rotation	*Measured* R_{YZ}
Zero	
$\frac{1}{4}$	
$\frac{1}{2}$	
$\frac{3}{4}$	
Full	

$\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full rotation positions and measure the value of R_{YZ} in each case. Enter all the readings in Table 1-4.

QUESTIONS

1. What is the accuracy of your VOM when used as an ohmmeter? (*Hint:* Look for the answer in the operator's manual.)
2. Is the VOM suitable for measuring high resistances of several megohms? Explain your answer.
3. For what percentage of the resistors was the measured resistance outside the tolerance limits?
4. What is the basic reason for the EVM and VOM ohms scales being nonlinear?
5. From your readings in Table 1-3, what is the relationship between the resistance R_{YZ} and the fraction of the shaft's rotation? In step 6, what is the relationship between R_{XY}, R_{YZ}, and R_{XZ}?
6. What is the difference in purpose between a rheostat and a potentiometer?
7. What is the color coding of the first three bands for the following rated resistances? (a) 0.22 Ω; (b) 2.2 Ω; (c) 22 Ω; (d) 220 Ω; (e) 2200 Ω; (f) 22 kΩ; (g) 220 kΩ; (h) 2.2 MΩ; (i) 22 MΩ. Which range would you use to measure the 220-kΩ resistor with the EVM?
8. You are measuring a resistance on the R X 100 range and the needle is at the crowded end of the scale. Would you switch to the R X 10 or the R X 1000 range?
9. Can a current flow through an open circuit? Can a voltage be developed across an open circuit? Can any power be dissipated in an open circuit?
10. Can a current flow through a short circuit? Can a voltage be developed across a short circuit? Can any power be dissipated in a short circuit?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 2

DC Voltage Measurements; Cells in Series and Parallel; Low-Voltage Regulated DC Power Supply

READING ASSIGNMENT

Modern Electronics: A First Course, pages 100–104, 195–197, 419–421

Topics: Dry Cell; Cells in Series and Parallel; DC Voltmeter

OBJECTIVES OF EXPERIMENT

1. To become familiar with the operation of the EVM and the VOM as dc voltmeters
2. To measure the voltages obtained from various series and parallel combination of cells
3. To become familiar with the controls of a low-voltage regulated dc power supply

COMPONENTS AND EQUIPMENT REQUIRED

1. Four general-purpose $1\frac{1}{2}$-V dry cells (Eveready 1S6 or equivalent)
2. Variable regulated dc power supply 0–30 V
3. Meters: analog EVM; analog VOM
4. Resistor: $\frac{1}{2}$ W, 10%, 1 kΩ

PROCEDURE

Operation of the Analog EVM as a DC Voltmeter

The following procedure is common to many types of analog EVM and applies to the VTVM of Fig. 2-1. Should there be any significant differences for the particular EVM you are using, you must consult the operator's manual regarding the measurement of dc voltage.

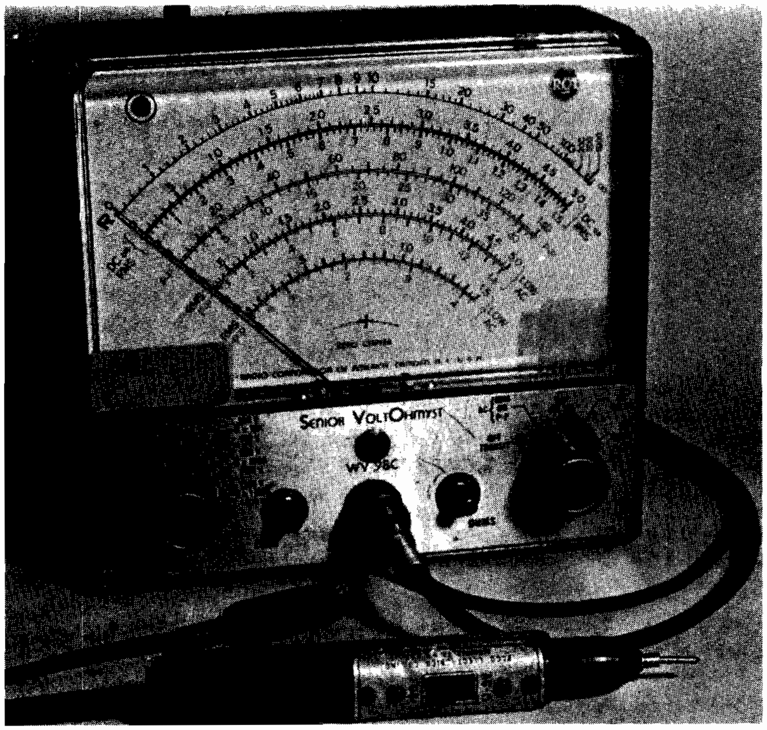


Fig. 2-1. Vacuum tube voltmeter (VTVM).

The dc voltage scales (Fig. 2-2) of the VTVM are linear with the graduations evenly spaced and have the zero marks on the left side. The upper of the two scales is graduated from 0 to 5.0 (each division = 0.1) and is used with the dc voltage ranges 0–0.5 V, 0–5.0 V, 0–50 V, and 0–500 V. The lower scale is graduated from 0 to 1.5 (each division = 0.02) and applies to the ranges 0–1.5 V, 0–15 V, 0–150 V, and 0–1500 V. Examples of calculating the actual dc voltages for each position of the range switch are shown in Figs. 2-3(a) through (h).

The procedure for taking dc voltage measurements with the EVM is as follows:

1. Set the sliding switch on the probe to "DC" and the function switch to "+ DC VOLTS" or "− DC VOLTS" according to whether you intend to measure a positive or negative potential with respect to ground.
2. To protect the meter, set the range switch to one position higher than the anticipated voltage. If the voltage is entirely unknown, use the highest setting and then switch to lower ranges as required.
3. If necessary, adjust the "ZERO" control to move the needle to the left-hand "0" marks.
4. Clip the common or ground lead to the ground of the circuit.

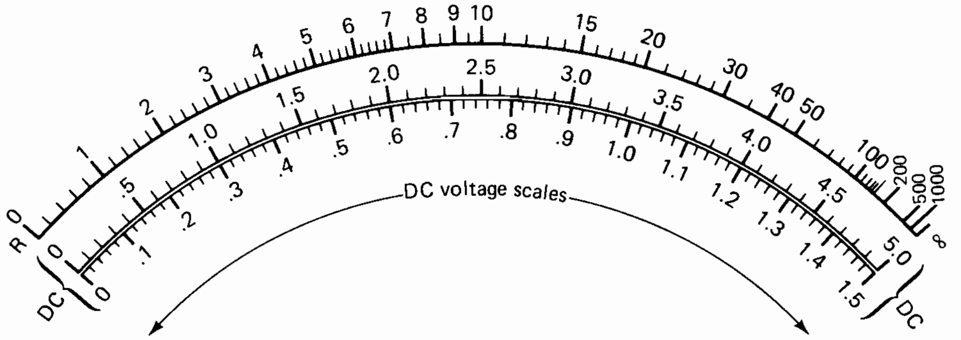
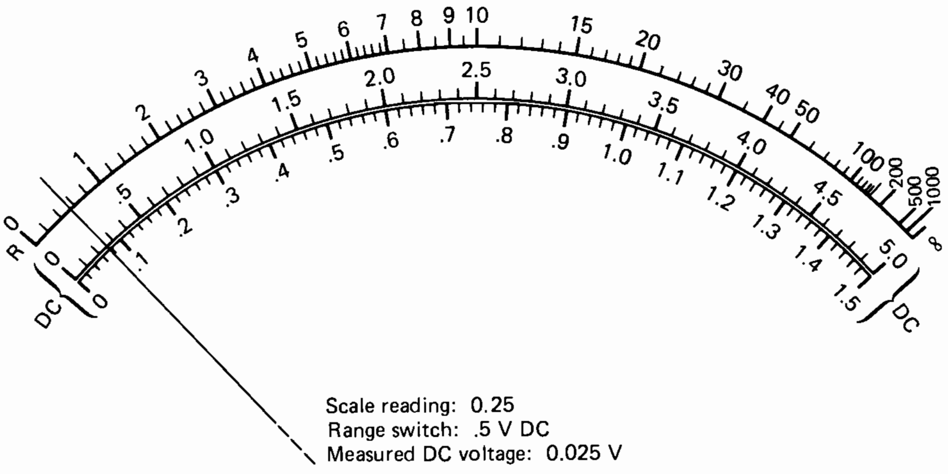
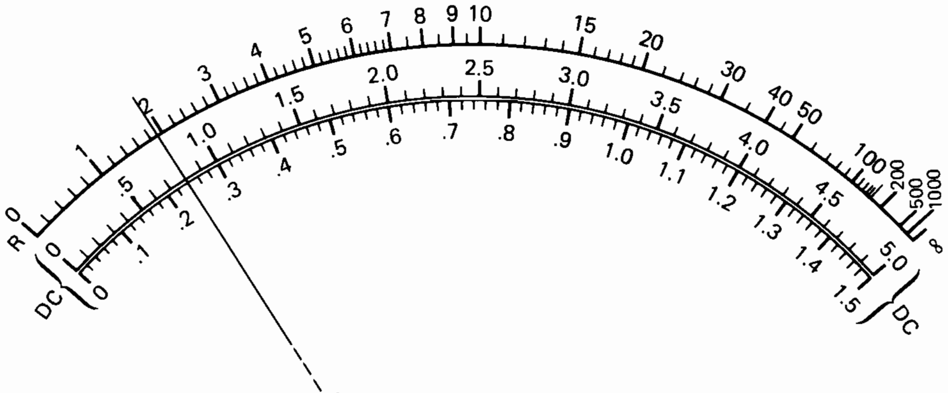


Fig. 2-2. DC voltage scales of the VTVM.



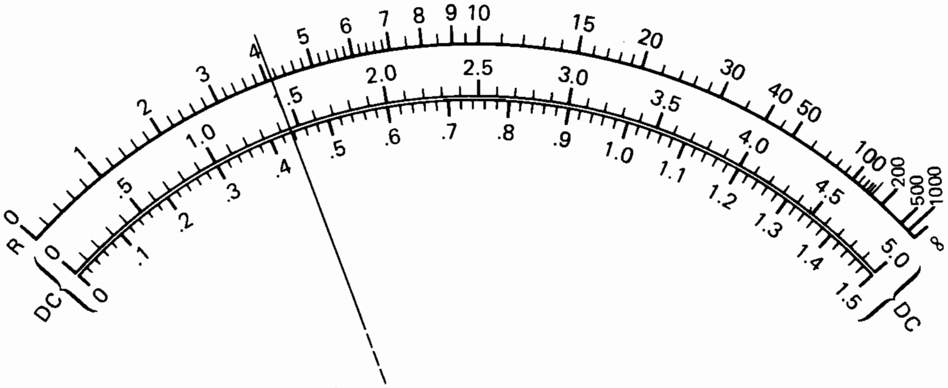
Scale reading: 0.25
Range switch: .5 V DC
Measured DC voltage: 0.025 V

(a)



Scale reading: 0.24
Range switch: 1.5 V
Measured DC voltage: 0.24 V

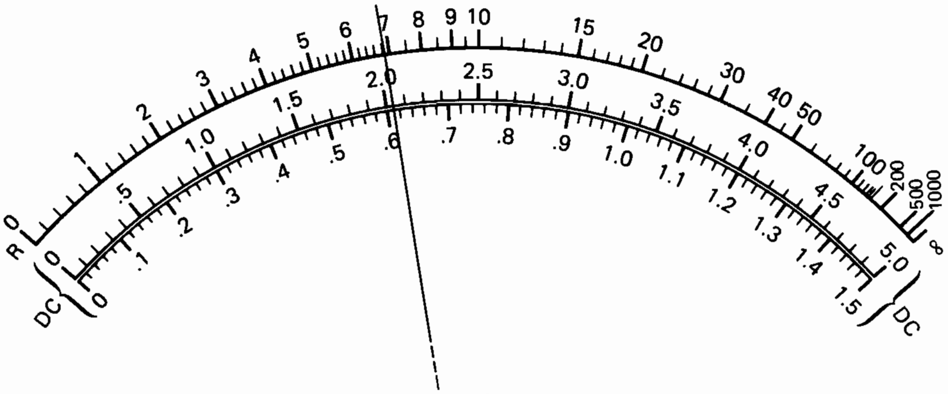
(b)



Scale reading: 1.45
Range switch: 5.0 V
Measured DC voltage: 1.45 V

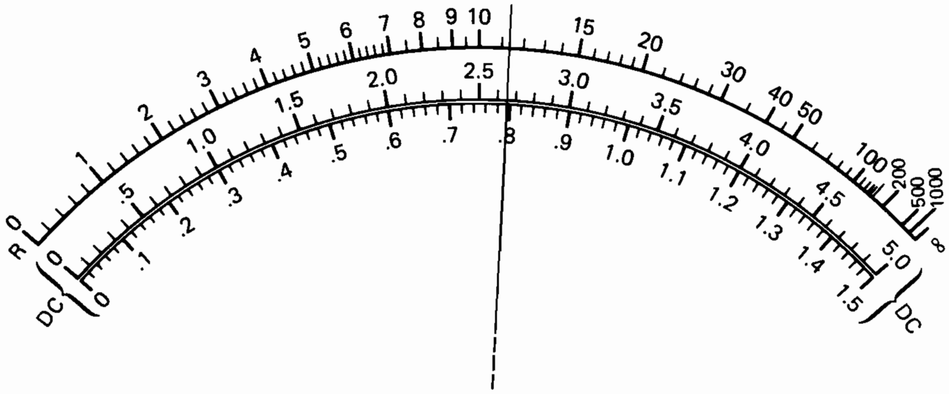
(c)

Fig. 2-3



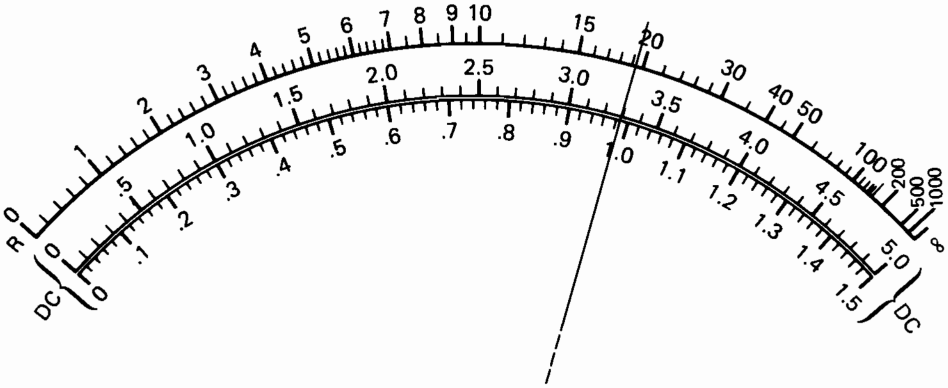
Scale reading: 0.61
Range switch: 15 V
Measured DC voltage: 6.1 V

(d)



Scale reading: 2.65
Range switch: 50 V
Measured DC voltage: 26.5 V

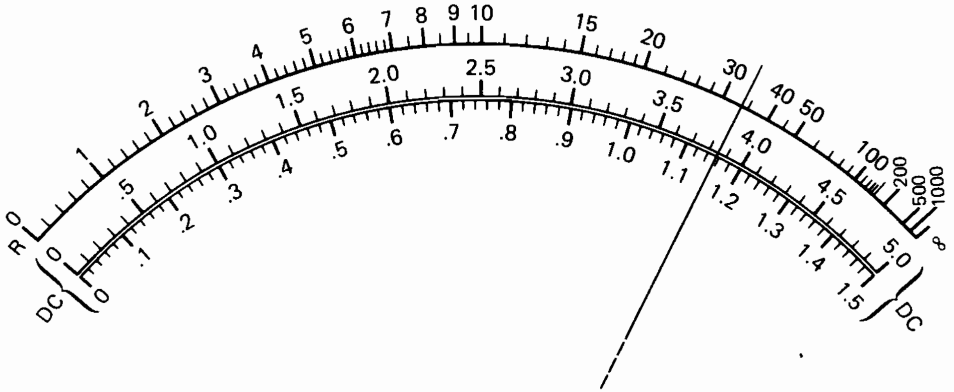
(e)



Scale reading: 0.985
Range switch: 150 V
Measured DC voltage: 98.5 V

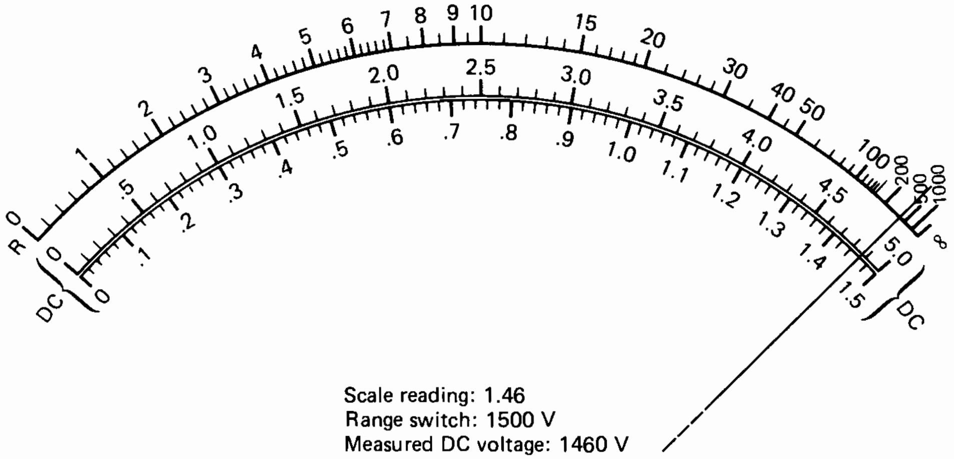
(f)

Fig. 2-3 Continued



Scale reading: 3.85
Range switch: 500 V
Measured DC voltage: 385 V

(g)



Scale reading: 1.46
Range switch: 1500 V
Measured DC voltage: 1460 V

(h)

Fig. 2-3 Continued

5. Connect the metal tip of the probe to the live side of the dc voltage to be measured.
6. If necessary, reset the range switch to a position that causes the needle to deflect toward the high side of the scale. This is important because the accuracy of your EVM as a voltmeter is expressed as a percentage of a *full-scale* deflection. Consequently, the accuracy of a reading on the high side of the scale is greater than on the low side. (*Note;* When switching from one dc voltage range to another, it is normally not necessary to reset the ZERO control.)
7. Measure the dc voltage from the scale reading and the setting of the range switch.

Operation of the Analog VOM as a DC Voltmeter

The typical appearance of an analog VOM is shown in Fig. 2-4. The dc voltage ranges are located on the left-hand side of the switch; although there are only five positions concerned with the voltage measurement, there are three additional jack positions (panel's top left, right jack; top right, left jack; bottom right, right jack), which increase the number of ranges to eight: 0–250 mV (0.25 V), 0–1 V, 0-2.5 V, 0-10 V, 0-50 V, 0–250 V, 0–500 V, 0–1000 V.

The dc voltage (and current) scale (Fig. 2-5) of the VOM is linear with the divisions evenly spaced. The scale is graduated (1) from 0 to 250 (each division = 5) for the ranges 0–250 mV, 0–2.5 V, and 0–250 V; (2) from 0 to 50 (each division = 1) for the ranges 0–50 V and 0–500 V; and

Fig. 2-4. Analog VOM.

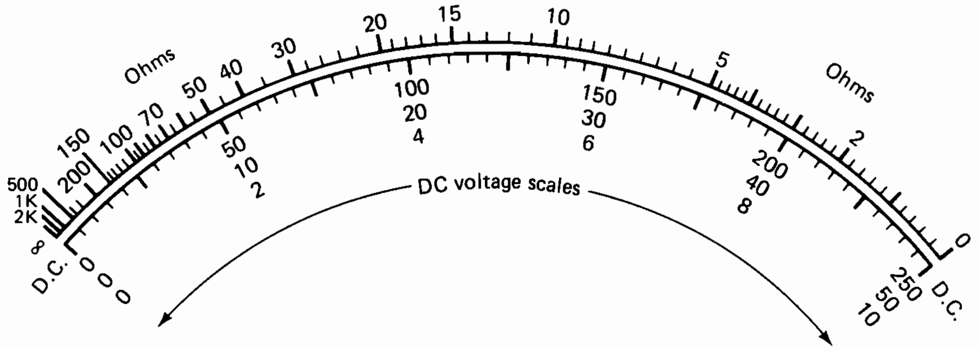
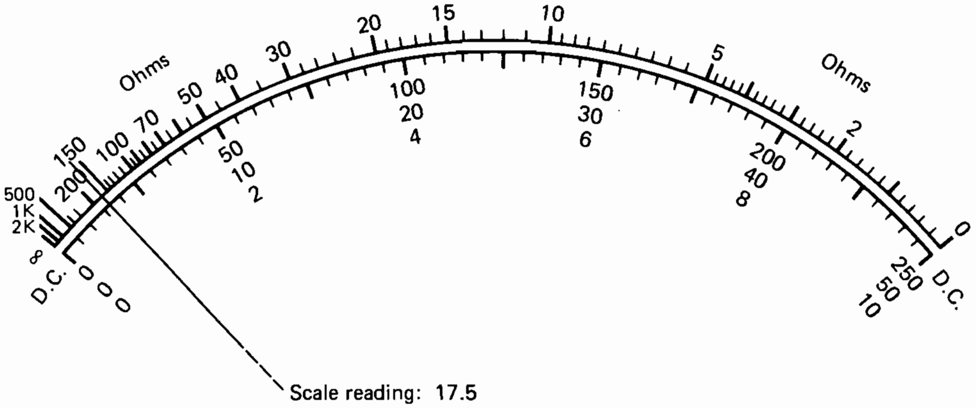


Fig. 2-5. DC voltage scales of the VOM.

(3) from 0 to 10 (each division = 0.2) for the ranges 0–1 V, 0–10 V, and 0–1000 V. Examples of obtaining the actual voltage for each range are shown in Figs. 2-6(a) through (h).

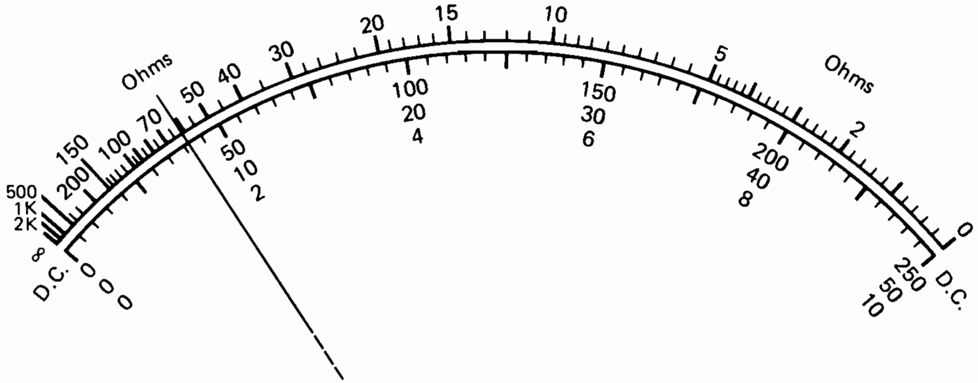
The procedure for taking a dc voltage measurement is as follows:

1. Set the function switch to "+ DC." The "– DC" position will not reverse the polarity for the ranges involving the three additional jacks. For these three ranges the polarity can be changed only by reversing the leads.
2. Plug the black lead into the "COMMON" jack and the red lead into the "+" jack. For any one of the additional ranges, the red lead is plugged into the appropriate jack.
3. To protect the meter, set the range switch to one position higher than the anticipated voltage. If the voltage is entirely unknown, use the highest setting and then switch to that lower range which causes the needle to deflect to the high side of the scale. This is important because the accuracy of the meter is expressed as a percentage of the *full-scale* deflection. Consequently, the accuracy on the high side of the scale is greater than on the low side.



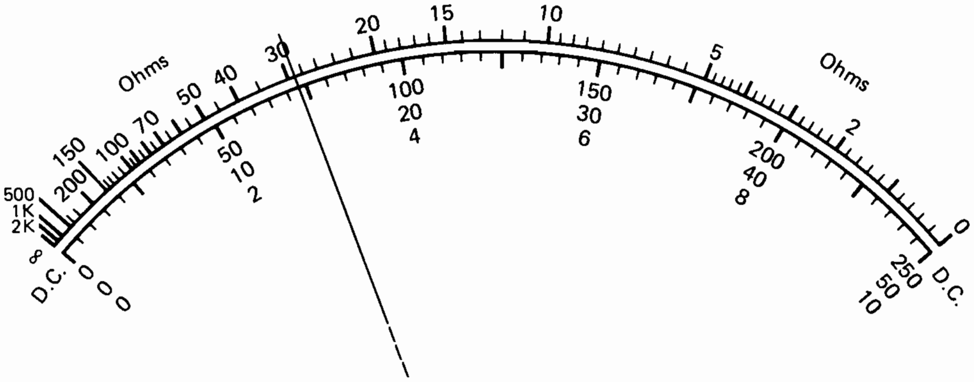
Scale reading: 17.5
Range switch: 250 mV
Measured DC voltage: 17.5 mV (0.0175 V)

(a)



Scale reading: 1.65
Range switch: 1.0 V
Measured DC voltage: 0.165 V

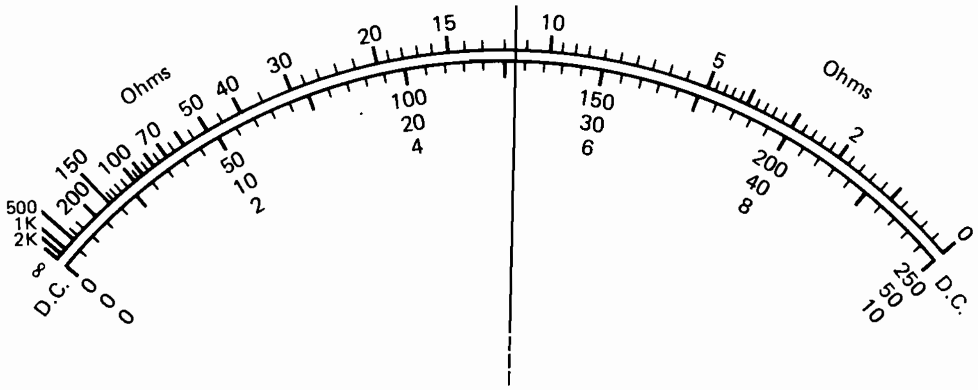
(b)



Scale reading: 73.0
Range switch: 2.5 V
Measured DC voltage: 0.73 V

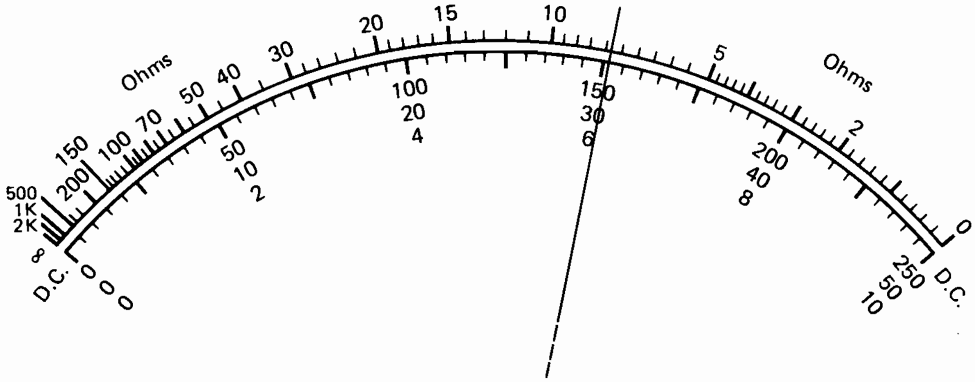
(c)

Fig. 2-6



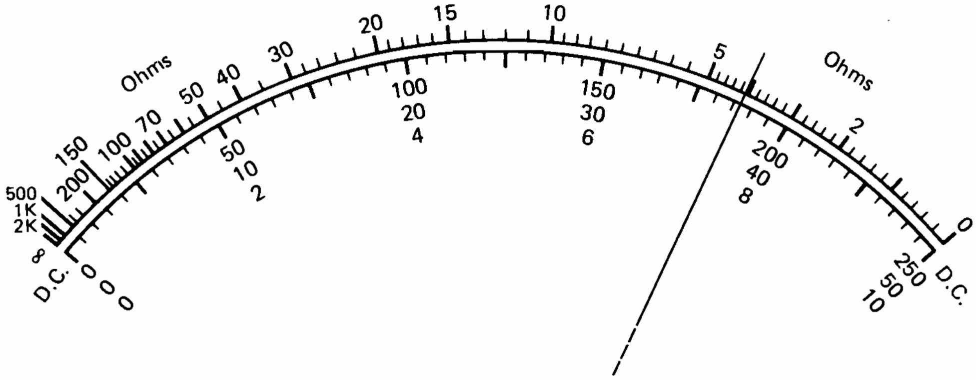
Scale reading: 5.1
Range switch: 10 V
Measured DC voltage: 5.1 V

(d)



Scale reading: 30.25
Range switch: 50 V
Measured DC voltage: 30.25 V

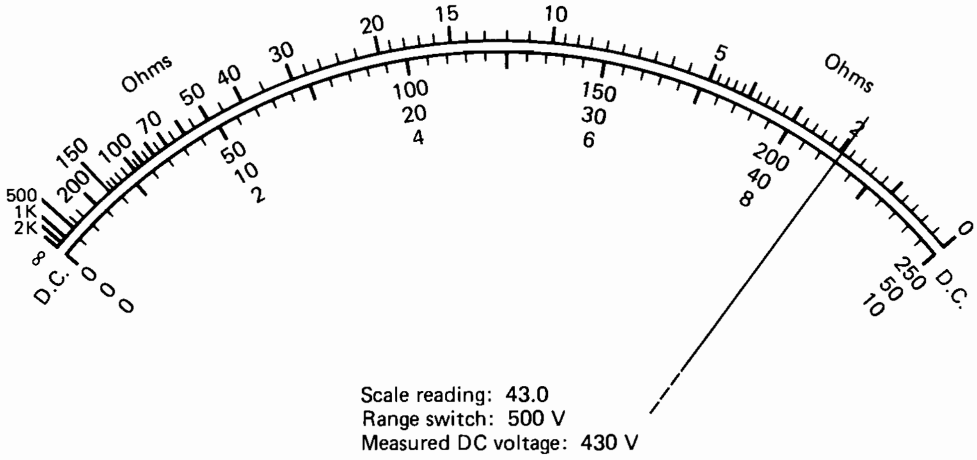
(e)



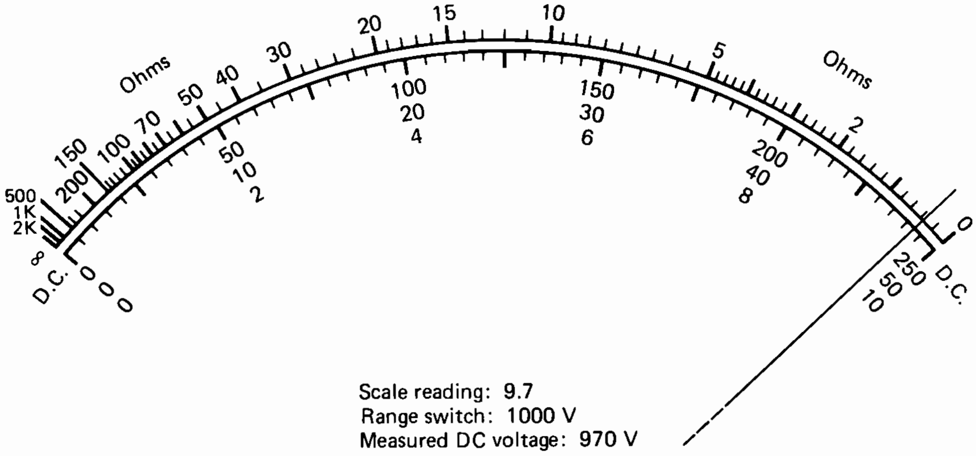
Scale reading: 187
Range switch: 250 V
Measured DC voltage: 187 V

(f)

Fig. 2.6 Continued



(g)



(h)

Fig. 2.6 Continued

4. If the needle is not on the zero mark, use a small screwdriver to adjust the screw located in the cover below the center of the dial.
5. Connect the black test lead to the negative side of the dc voltage being measured and the red lead to the positive side.
6. Apply power to the circuit that is being monitored by the VOM.
7. Read the dc scale, then multiply the reading by the appropriate range factor to obtain the actual voltage.
8. Remove power from the circuit and do not disconnect the leads until the needle indicates zero.

Warning: To avoid damage to the instrument, *never* attempt to take a dc voltage measurement when the VOM is switched to a current range.

EXPERIMENTAL PROCEDURE

Individual Cells and Cells in Series

1. Identify the four cells as 1, 2, 3, and 4. Measure each of their terminal voltages E_1, E_2, E_3, and E_4 with both the EVM and the VOM. Record the readings in Table 2-1.

Table 2-1

	E_1 (V)	E_2 (V)	E_3 (V)	E_4 (V)
EVM				
VOM				

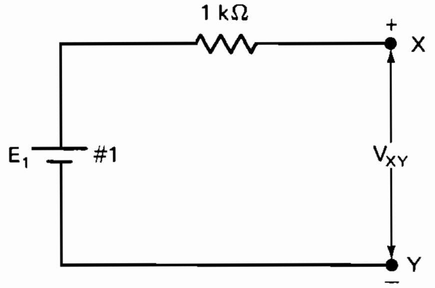


Fig. 2-7. **Single cell under open circuit conditions.**

Table 2-2

	V_{XY} *Cell 1* (V)	V_{XY} *Cell 2* (V)	V_{XY} *Cell 3* (V)	V_{XY} *Cell 4* (V)
EVM				
VOM				

2. Connect a 1-kΩ resistor to cell 1 as shown in Fig. 2-7. Measure the voltage V_{XY} with both the EVM and the VOM. Repeat this step for cells 2, 3, and 4 and record the readings in Table 2-2.
3. Connect the cells in the series formations of Figs. 2-8(a) through (g). For each formation calculate the value of the total voltage E_T between points X and Y. Measure the values of E_T with the EVM and the VOM. Enter the calculated values and the measured readings in Table 2-3.

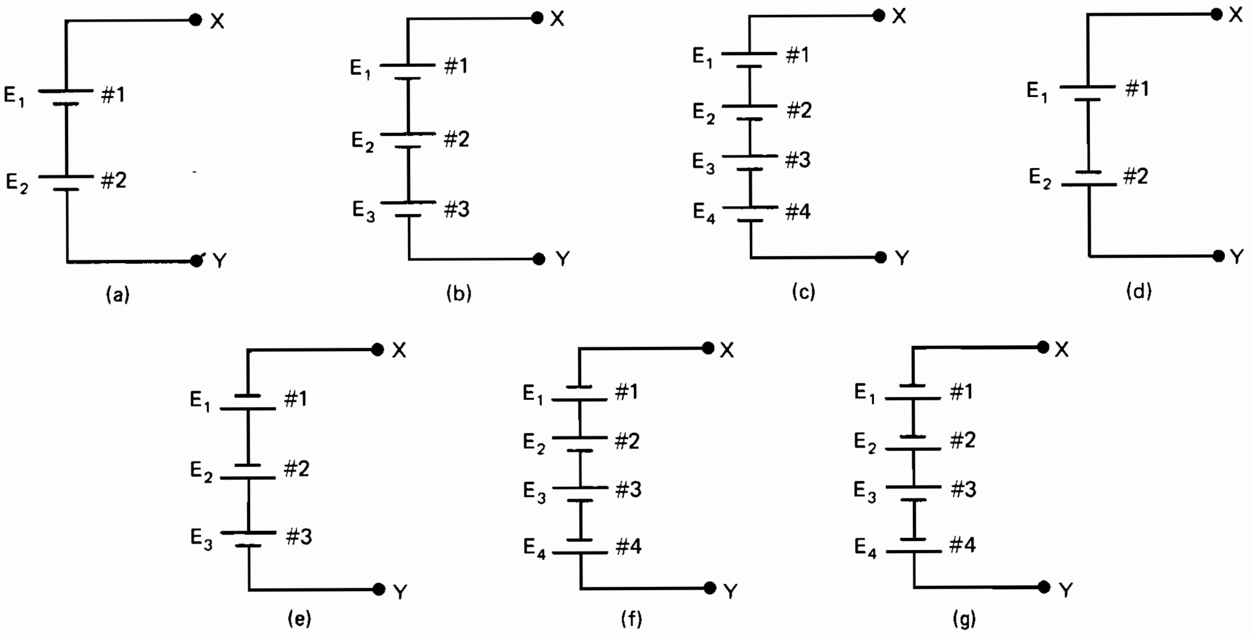


Fig. 2-8. **Series arrangements of cells.**

Table 2-3

Figure 2-8 Formation	Calculated E_T (V)	Measured E_T	
		EVM (V)	VOM (V)
(a)			
(b)			
(c)			
(d)			
(e)			
(f)			
(g)			

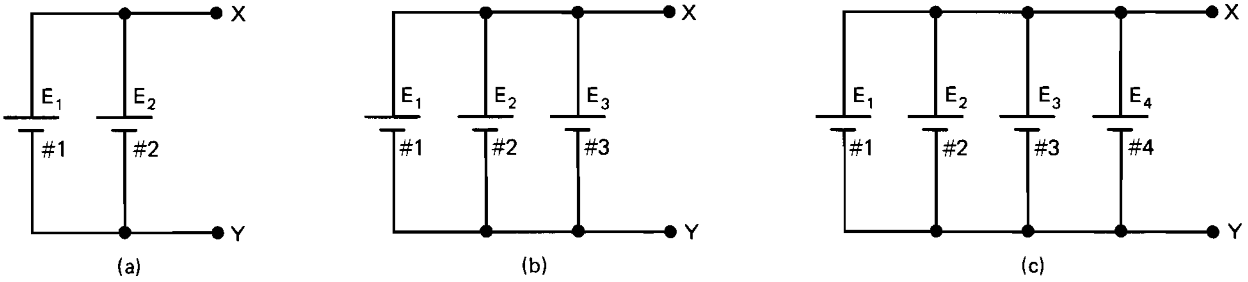


Fig. 2-9. Parallel arrangements of cells.

Table 2-4

Figure 2-9 Formation	Calculated E_T (V)	Measured E_T	
		EVM (V)	VOM (V)
(a)			
(b)			
(c)			

Cells in Parallel

4. Repeat step 3 for the parallel formations of Figs. 2-9(a) through (c). Enter the results in Table 2-4.

Cells in Series-Parallel

5. Repeat step 3 for the series-parallel formations of Figs. 2-10(a) through (d). Enter the results in Table 2-5.

Low-Voltage Regulated DC Power Supply

6. Figure 2-11 shows a modern low-voltage power supply which is commonly used with solid-state circuitry. The dc voltage output can be varied continuously from zero to 30 V with a load current which can range from zero to 400 mA. A fixed current-limiting circuit protects the power supply from all overloads (including a short circuit). This allows series and/or parallel operation of two or more supplies to achieve a greater output voltage and a greater load current capability. The supply can be operated floating; alternatively, either the positive or negative output terminal may be grounded.

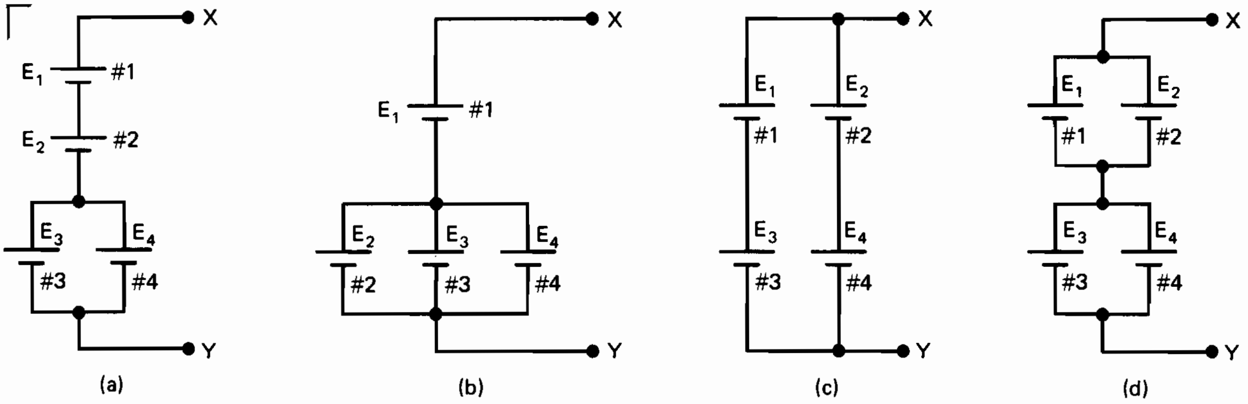


Fig. 2-10. Series-parallel arrangements of cells.

Table 2-5

Figure 2-10 Formation	*Calculated* E_T (V)	*Measured* E_T	
		EVM (V)	*VOM* (V)
(a)			
(b)			
(c)			
(d)			

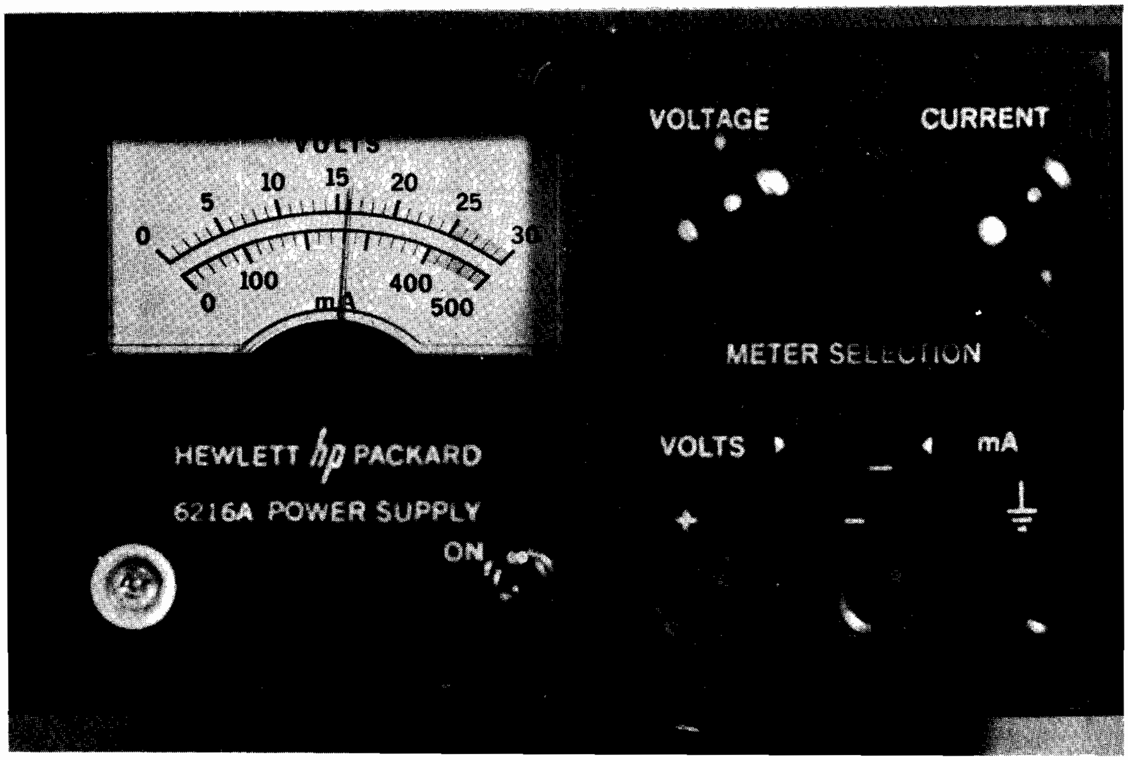


Fig. 2-11. Regulated low voltage DC power supply.

Table 2-6

Power Supply Meter (V)	*EVM* (V)	*VOM* (V)
0		
5		
10		
15		
20		
25		
30		

The procedure for operating the power supply is:

a. Set the AC switch to the upward "ON" position. The indicator light should come on. Both the light and switch are located beneath the meter face.
b. Switch the METER SELECTION control to the VOLTS position.
c. Use the COARSE and FINE VOLTAGE controls to set the required dc output voltage.
d. Connect the load across the output terminals. The load current may be checked by switching the METER SELECTION control to the "mA" position.

To check the instrument's meter readings against the voltage readings taken with the EVM and the VOM, set the voltage control so that the power supply meter reads in turn 0, 5, 10, 15, 20, 25, and 30 V. For each setting, measure the output voltage with the EVM and the VOM. Record all readings in Table 2-6.

QUESTIONS

1. What is the accuracy of your EVM and VOM on dc voltage ranges? Consult the operator's manuals.
2. If the accuracy of a VOM on the dc voltage range 0–10 V is 2% of full scale, what is the permitted voltage error when the meter reads 3 V?
3. In Fig. 2-8(e) the function switch of the VOM is set to the "+ DC" position. To measure V_{XY}, should the black lead or the red lead be connected to terminal X? Explain your answer.
4. If a short circuit were connected across the terminals of a dry cell, what would be the effect on the cell? What resistance limits the flow of current in the circuit?
5. What arrangement of eight 1.5-V cells would provide an output of 12.0 V dc output?
6. What arrangement of eight 1.5-V cells would provide a 1.5-V dc output? What is the purpose of such an arrangement?
7. What arrangements of eight 1.5-V cells would provide a 6.0-V dc output? Draw the schematics of the arrangements.
8. What are the precautions which you must observe when taking dc voltage readings?
9. In step 6, how did the power supply's meter readings compare with those of the EVM and the VOM? Which of the three readings would you regard as the most reliable?
10. What arrangement of the power supplies (as described in step 6) would you use to provide 50 V dc for a total load current of 600 mA?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 3

Direct-Current Measurement

READING ASSIGNMENT

Modern Electronics: A First Course, pages 100–104, 145–148, 415–419

Topics: The Rheostat; The DC Current Meter

OBJECTIVES OF EXPERIMENT

1. To take dc measurements in a variety of circuits containing dry cells
2. To become familiar with the current ranges of a VOM
3. To use a rheostat to control the current through a load

COMPONENTS AND EQUIPMENT REQUIRED

1. Four $1\frac{1}{2}$-V dry cells (Eveready 1S6 or equivalent)
   Three variable regulated dc power supplies, 0-30 V, 0-400 mA
2. Resistors: 4 Ω, 10 W (see step 6); 2 W, 10%, 18 Ω; 1 W, 10%, 56 Ω, 100 Ω; $\frac{1}{2}$ W, 10%, 820 Ω, 6.8 kΩ
   Potentiometer: 15 Ω, 12.5 W
   Lamp: 12 W, 12 V (GE 12S8/93T or equivalent)
3. Meters: EVM; VOM
4. Three single-pole single-throw (SPST) switches

PROCEDURE

Operation of the VOM as a DC Current Meter

The analog VOM of Experiments 1 and 2 is shown in Fig. 3-1. The three current ranges are located at the top left-hand side and top right-hand side of the range switch. In addition, there are two jacks for "- 10 A" and "+ 10 A" (panel's top left and top right); to use these jacks, the range switch is set to "10 mA AMPS." There is also a jack for "+ 50 μAMPS, 250 mV" which requires the range switch to be set to "50 V μAMPS." The total number of dc current ranges is therefore six: 0–50 μA, 0–1 mA, 0–10 mA, 0–100 mA, 0–500 mA, and 0–10 A.

The linear dc current scale (Fig. 3-2) is the same as that used for the voltage measurements of Experiment 2. However, this time the scale is graduated (1) from 0 to 50 for the ranges 0–50 μA and 0–500 mA and (2) from 0 to 10 for the ranges 0–1 mA, 0–10 mA, 0–100 mA, and 0–10 A. Consequently, the scale graduated from 0 to 250 is not used for current measurement. Examples of obtaining the actual current for each range are shown in Figs. 3-3(a) through (f).

Fig. 3-1. Analog VOM.

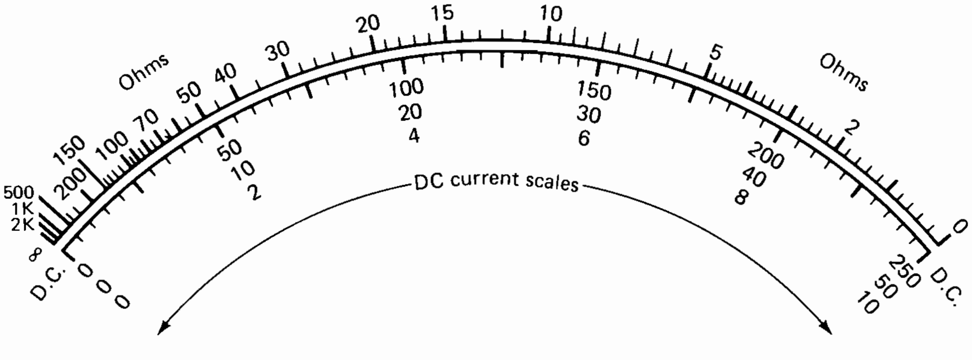


Fig. 3-2. DC current scales of the VOM.

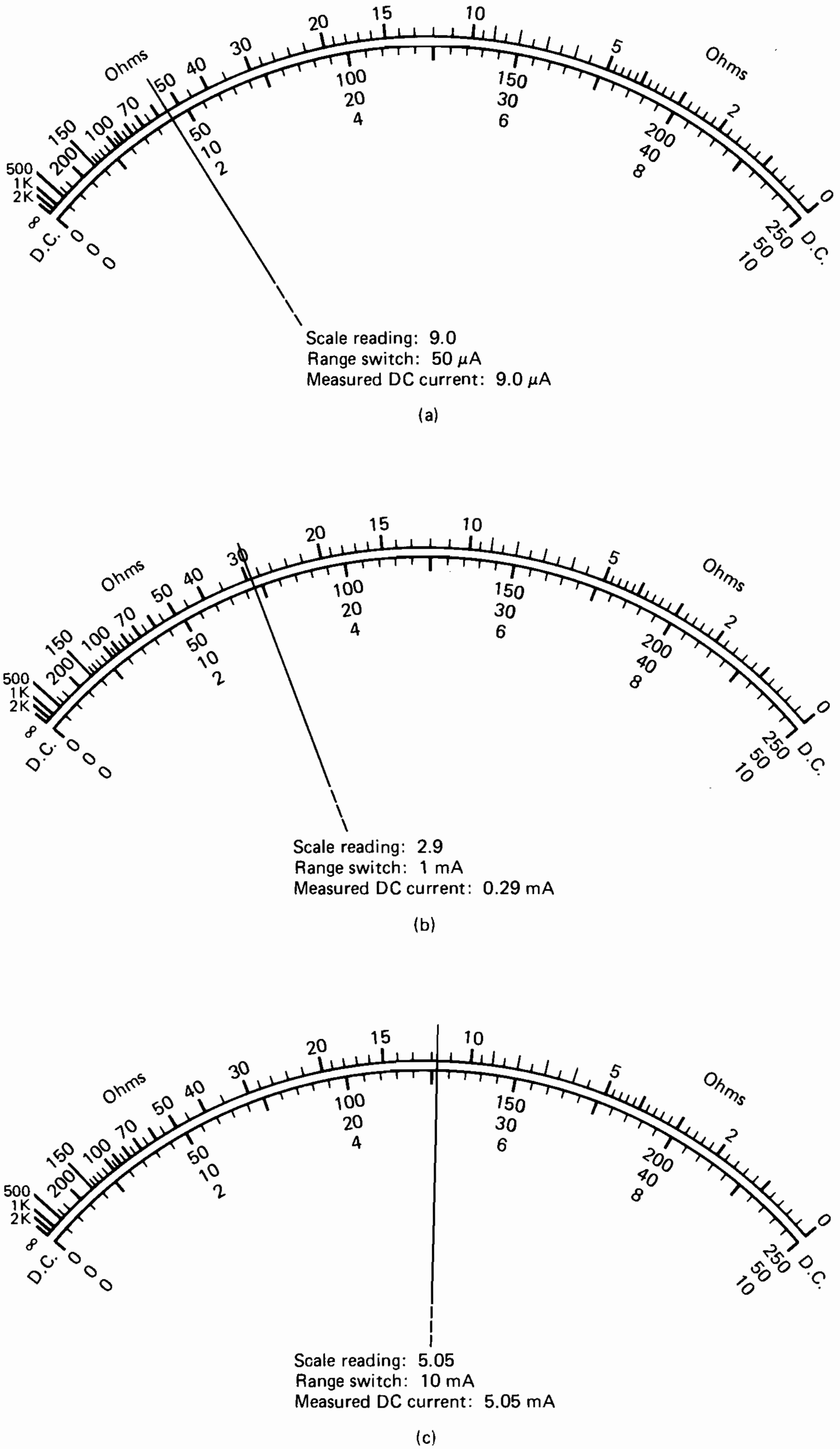
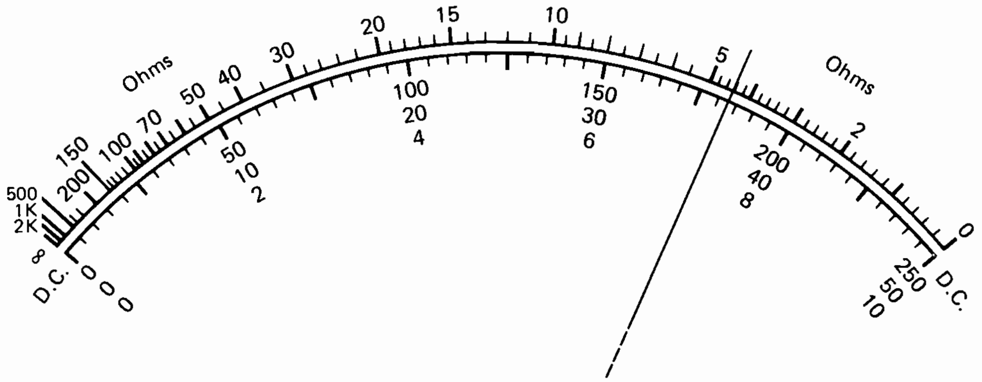
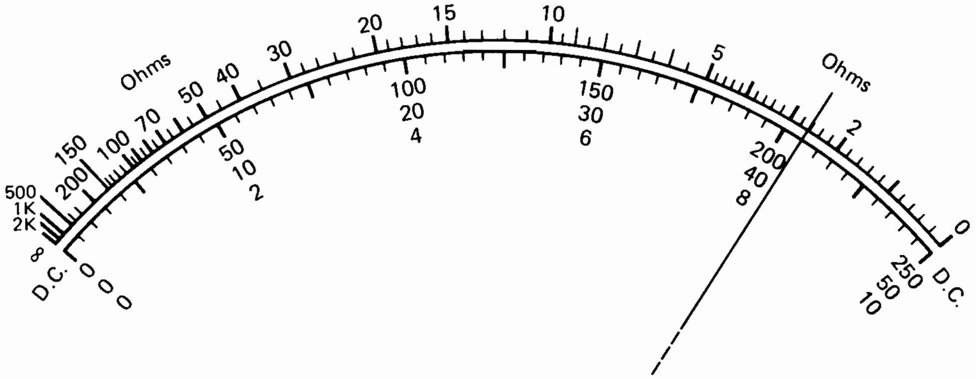
Ohms
∞
2K
1K
500
200
150
100
70
50
40
30
20
15
10
5
2
0
Ohms
D.C.
0
0
0
50
10
2
100
20
4
150
30
6
200
40
8
250
50
10
D.C.
Scale reading: 9.0
Range switch: 50 μA
Measured DC current: 9.0 μA
(a)
Scale reading: 2.9
Range switch: 1 mA
Measured DC current: 0.29 mA
(b)
Scale reading: 5.05
Range switch: 10 mA
Measured DC current: 5.05 mA
(c)

Fig. 3-3



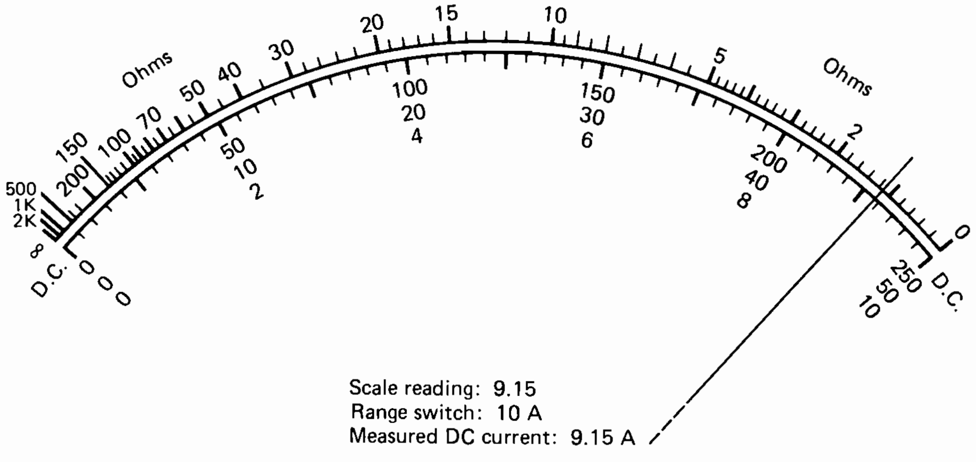
Scale reading: 7.3
Range switch: 100 mA
Measured DC current: 73 mA

(d)



Scale reading: 41.0
Range switch: 500 mA
Measured DC current: 410 mA

(e)



Scale reading: 9.15
Range switch: 10 A
Measured DC current: 9.15 A

(f)

Fig. 3-3 Continued

The following precautions must be observed when taking current measurements.

1. *Never* attempt to take a voltage reading when the range switch is set to one of the current (or resistance) positions. This can damage the instrument.
2. Do not alter the settings of either the function or the range switch while power is applied to the circuit whose currents you are measuring.
3. Connect the test leads to the circuit before applying power. Turn the power off and discharge all capacitors before disconnecting the leads. At this stage you should consult your instructor about the discharging of capacitors.

The procedure for taking a dc current measurement is as follows:

1. Set the function switch to "+ DC." The "- DC" position will not reverse the polarity for the 0-50 μA and 0-10 A ranges, which involve the additional jacks. For these two ranges the polarity can be changed only by reversing the leads.
2. For the 0-1 mA, 0-10 mA, 0-100 mA, and 0-500 mA ranges, plug the black lead into the "COMMON" jack and the red lead into the "+" jack. On the 0-50 μA range, the red lead is plugged into the "+ 50 μAMPS, 250 mV" jack. When using the 0-10 A range, plug the black lead into the "- 10 A" jack and the red lead into the "+ 10 A" jack.
3. To protect the meter, set the range switch to one position higher than the anticipated current. Then switch to that lower range which causes the needle to deflect to the high side of the scale (this is the region of the scale where the reading is most accurate).
4. Open the ground side of that part of the circuit where the dc current is to be measured. Connect the VOM in series (red lead to the positive side, black lead to the negative side) so that the meter is directly in the path of the current to be measured.
5. Apply power to the circuit, read the dc scale, and multiply the reading by the appropriate range factor to obtain the actual current.
6. Remove power from the circuit and then disconnect the test leads.

EXPERIMENTAL PROCEDURE

1. With the EVM measure the value of the 100-Ω resistor R. Use only the *measured* value in your calculations.
2. It is assumed that you have the same four cells which were used in Experiment 2. Using these cells, connect the circuit of Fig. 3-4(a). Assuming that switch S is closed, calculate the values of E_T and I. Break the circuit open at point A and insert the VOM with the polarity shown in Fig. 3-4(b). Close switch S, then use the EVM to measure E_T and the VOM to measure I. Open switch S. Repeat the procedure to measure the current at points B, C, D, and E. Enter all calculated values and measured readings in Table 3-1.

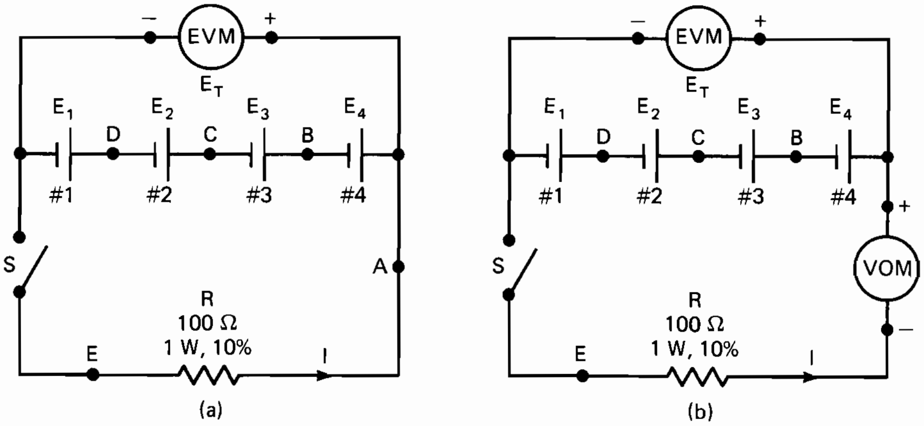


Fig. 3-4. Measurement of current in a series arrangement of cells.

Table 3-1

	Calculated Value	*Measured Reading*
E_T (V)		
Current at point *A* (mA)		
Current at point *B* (mA)		
Current at point *C* (mA)		
Current at point *D* (mA)		
Current at point *E* (mA)		

3. Connect the circuit of Fig. 3-5. Assuming that switch *S* is closed, calculate the values of E_T and the currents at points *A*, *B*, *C*, *D*, *E*, *F*, and *G*. Break the circuit open at point *A* and insert the VOM. Close switch *S*, then use the EVM to measure E_T and the VOM to measure I_T. Open switch *S* and repeat the procedure for points *B*, *C*, *D*, *E*, *F*, and *G*. Enter all calculated values and measured readings in Table 3-2.

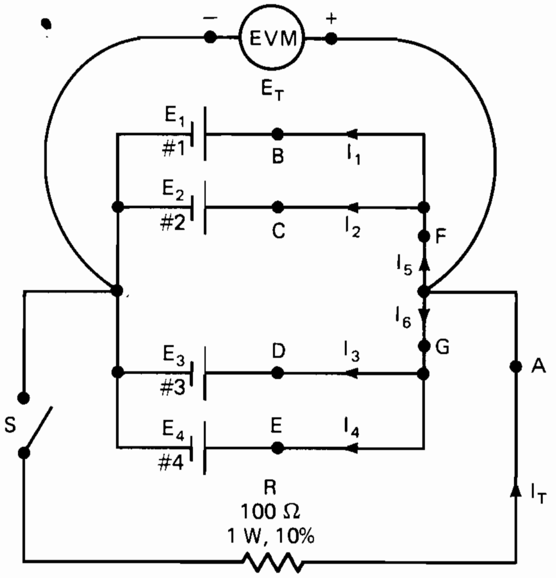


Fig. 3-5. Current measurements in a parallel arrangement of cells.

Table 3-2

	Calculated Value	*Measured Reading*
E_T (V)		
Current at point *A* (mA)		
Current at point *B* (mA)		
Current at point *C* (mA)		
Current at point *D* (mA)		
Current at point *E* (mA)		
Current at point *F* (mA)		
Current at point *G* (mA)		

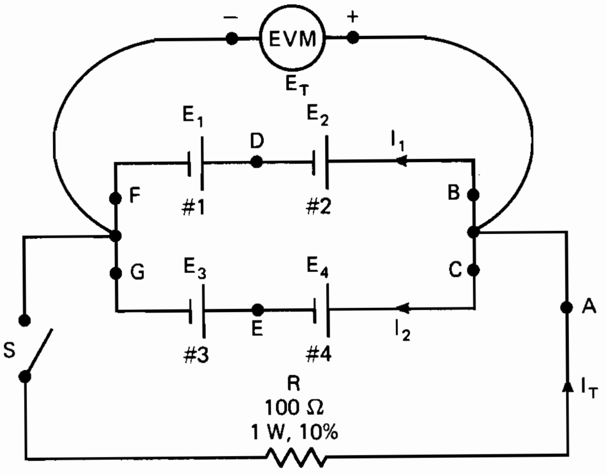


Fig. 3-6. **Current measurements in a series-parallel arrangement of cells.**

Table 3-3

	Calculated Value	*Measured Reading*
E_T (V)		
Current at point A (mA)		
Current at point B (mA)		
Current at point C (mA)		
Current at point D (mA)		
Current at point E (mA)		
Current at point F (mA)		
Current at point G (mA)		

4. Connect the circuit of Fig. 3-6 and repeat step 3. Enter all calculated values and measured readings in Table 3-3.
5. Connect the circuit of Fig. 3-7 and repeat step 3. Enter all calculated values and measured readings in Table 3-4.

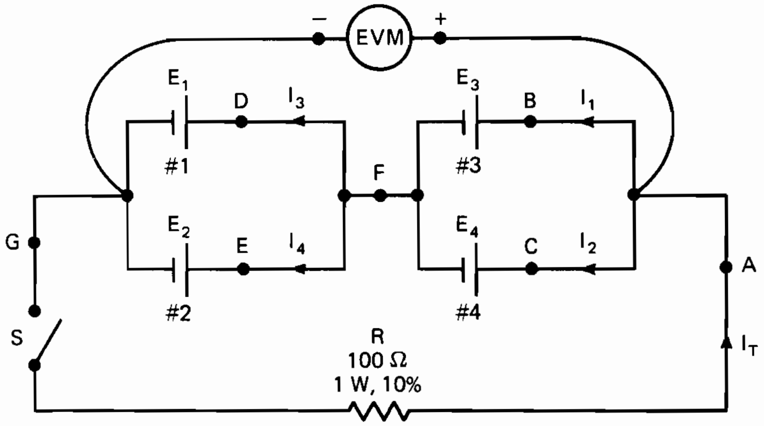


Fig. 3-7. **Current measurements in a series-parallel arrangement of cells.**

Table 3-4

	Calculated Value	*Measured Reading*
E_T (V)		
Current at point A (mA)		
Current at point B (mA)		
Current at point C (mA)		
Current at point D (mA)		
Current at point E (mA)		
Current at point F (mA)		
Current at point G (mA)		

6. Connect the circuit of Fig. 3-8 and use the EVM to set the output of the low-voltage power supply at $E = 5$ V, which is maintained throughout the experiment. Measure the value of the 180-kΩ $\frac{1}{2}$-W 10% resistor with the EVM, and assuming that S is closed, use this measured resistance to calculate the value of the current I. Close switch S and use the VOM on the 0-50 μA range to measure the current. Repeat the procedure for $R = 6.8$ kΩ, $\frac{1}{2}$ W, 10% (0-1 mA range); 820 Ω, $\frac{1}{2}$ W, 10% (0-10 mA range); 56 Ω, 1 W, 10% (0-100 mA range); 18 Ω, 2 W, 10% (0-500 mA range); 4 Ω, 10 W (0-10 A range). If the 4-Ω 10-W resistor is not readily available, its equivalent can be created from a parallel combination of resistors: for example, five 20-Ω 2-W 5% resistors; consult your instructor if necessary. Enter all calculated and measured values in Table 3-5. Open switch S and disconnect the meters.

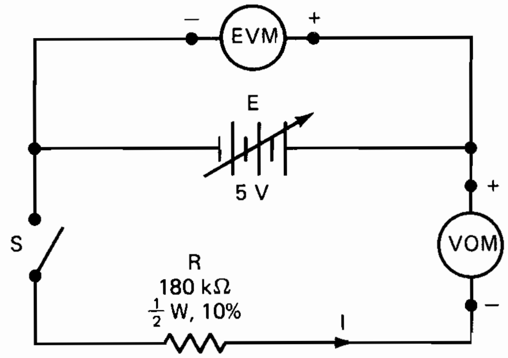


Fig. 3-8. **Use of the various current ranges.**

Table 3-5

$E = 5$ V				
R *(Rated Value)*	R *(Measured Value)*	I *(Calculated Value)*	I *(Measured Value)*	*VOM Range*
180 kΩ, $\frac{1}{2}$ W				0-50 μA
6.8 kΩ, $\frac{1}{2}$ W				0-1 mA
820 Ω, $\frac{1}{2}$ W				0-10 mA
56 Ω, 1 W				0-100 mA
18 Ω, 2 W				0-500 mA
4 Ω, 10 W				0-10 A

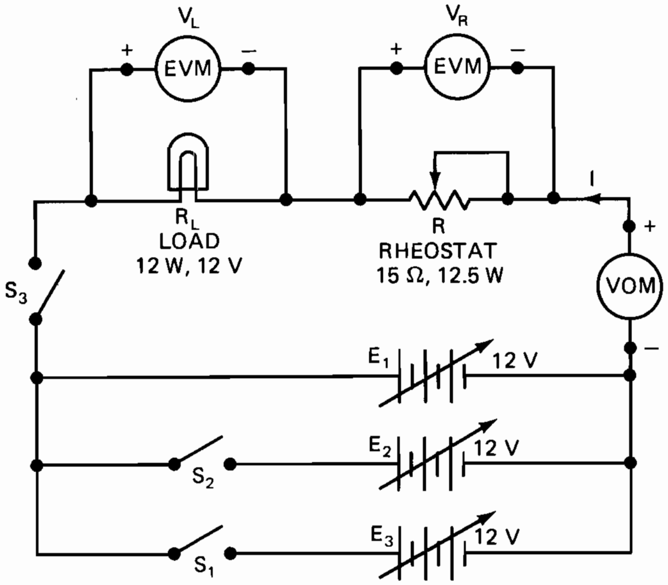


Fig. 3-9. Use of the rheostat to control a load current.

Use of the Rheostat to Control the Load Current

7. Construct the circuit of Fig. 3-9. The 15-Ω potentiometer is set for its maximum resistance. Switch the VOM to the 0–10 A current range. Use the EVM to adjust the output of each low-voltage variable regulated dc power supply to 12 V and maintain this value throughout the experiment. Close switches S_1, S_2, and S_3 in sequence and adjust the rheostat so that the reading of I is 0.6 A. Use the EVM to measure in turn the voltage V_R across the rheostat and the voltage V_L across the load of the lamp. Repeat the procedure for $I = 0.7, 0.8, 0.9$, and 1.0 A (when $I = 1.0$ A, the rheostat resistance should be zero). Enter all measured readings in Table 3-6 and complete the required calculations. Open switch S and disconnect the meters.

Table 3-6

Current I (A)	*Voltage across Rheostat* V_R (V)	*Voltage across Load (Lamp)* V_L (V)	*Resistance of Rheostat* $R = V_R/I$ (Ω)	*Resistance of Lamp* $R_L = V_L/I$ (Ω)
0.6				
0.7				
0.8				
0.9				
1.0		12	0	

QUESTIONS

1. What is the accuracy of your VOM when switched to the dc current ranges? (*Hint:* Consult the operator's manual of the VOM.)
2. The accuracy of a VOM on the 0–100 mA range is ±2% of full scale. What is the permitted error when the VOM reads 40 mA?
3. What precautions must be observed when taking dc current measurements?
4. In Fig. 3-4, what can you say about the current values measured at points A, B, C, D, and E?

5. In Fig. 3-5, what relationship exists between the current measured at point A and the currents at points B, C, D, and E? Express this relationship as a mathematical equation and discuss any unexpected results.
6. In Fig. 3-6, what relationship exists between the current measured at point A and the currents at points F and G? Express this relationship as a mathematical equation and discuss any unexpected results.
7. In Fig. 3-7, what relationship exists between the current measured at point A and the currents at points D and E? Express this relationship as a mathematical equation and discuss any unexpected results.
8. In step 6, the value of E is held constant at 5 V. From the readings in Table 3-5, what is the relationship between the measured values of the resistance and the current?
9. In step 7, does the lamp behave as a linear or a nonlinear resistor? Give reasons for your answer.
10. When $I = 0.6$ A in step 7, what are the powers dissipated in the lamp and the rheostat?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 4

Ohm's Law Measurements

READING ASSIGNMENT

Modern Electronics: A First Course, pages 32–39

Topic: Ohm's Law

OBJECTIVE OF EXPERIMENT

By experiment to verify the Ohm's law relationship for a variety of resistor values

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0–30 V
2. Resistors: 2 W, 5%, 200 Ω; 1 W, 5%, 1 kΩ; $\frac{1}{2}$ W, 5%, 2 kΩ, 20 kΩ, 200 kΩ, 2 MΩ
3. Meters: EVM; VOM
4. Single-pole single-throw (SPST) switch

PROCEDURE

Experimental Verification of Ohm's Law

1. With the EVM as an ohmmeter, measure the values of a number of 5% resistors and find those whose actual values are 200 Ω (2 W), 1 kΩ (1 W), 2 kΩ ($\frac{1}{2}$ W), 20 kΩ ($\frac{1}{2}$ W), 200 kΩ ($\frac{1}{2}$ W), and 2 MΩ ($\frac{1}{2}$ W) (to within the limits of measurement).
2. Construct the circuit of Fig. 4-1 and leave switch *S* open. Make certain that the polarities of the meters are connected as shown. Switch on the power supply and use the EVM to adjust the output voltage to

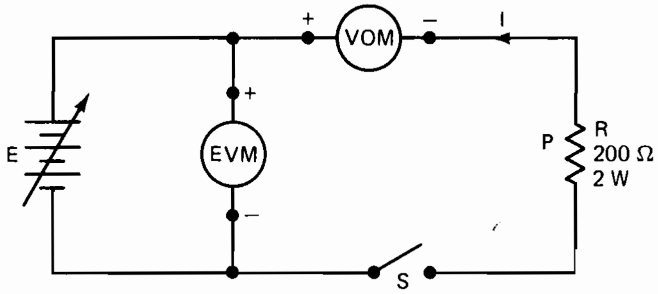


Fig. 4-1. **Verification of Ohm's law.**

E = 2 V. Close switch S and measure the current I with the VOM on the 0–100 mA range. Alter the power supply output to produce, in turn, E = 2 V, 4 V, 6 V, . . . , 24 V and in each case measure the current I. Record all readings in Table 4-1 and complete the table. (When E = 24 V, touch the casing of the resistor and get a feeling for its temperature.)

Table 4-1

R = 200 Ω, 2 W

E (V)	I (mA)	$R = E/I$ (Ω)	$P = EI$ (mW)
0	0	200 Ω (ohmmeter measurement)	0
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			
22			
24			

3. Open switch S and remove the 200-Ω, 2-W resistor. Connect in the 1-kΩ, 1-W resistor and repeat step 2 for E = 2 V, 4 V, 6 V, . . . , 30 V. Enter all the current readings in Table 4-2 and complete the table. (Start with the VOM on the 0–10 mA range and later switch to the 0–100 mA range.)
4. Repeat step 3 for the $\frac{1}{2}$-W 5% 2-kΩ, 20-kΩ, 200-kΩ, and 2-MΩ resistors and complete Tables 4-3 through 4-6. The VOM ranges to use are:

Resistor: $\frac{1}{2}$ W, 5%	*Starting Range VOM*	*Subsequent Range VOM*
2 kΩ	0–10 mA	0–100 mA
20 kΩ	0–1 mA	0–10 mA
200 kΩ	0–50 μA	0–1 mA
2 MΩ	0–50 μA	

Table 4-2

$R = 1000\ \Omega$, 1 W

E (V)	I (mA)	$R = E/I$ (kΩ)	$P = EI$ (mW)
0	0	1 kΩ (ohmmeter measurement)	0
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			
22			
24			
26			
28			
30			

Table 4-3

$R = 2\ \mathrm{k}\Omega$, $\frac{1}{2}$ W

E (V)	I (mA)	$R = E/I$ (kΩ)	$P = EI$ (mW)
0	0	2 kΩ (ohmmeter measurement)	0
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			
22			
24			
26			
28			
30			

Table 4-4

$R = 20\ \text{k}\Omega, \frac{1}{2}\ \text{W}$

E (V)	I (mA)	$R = E/I$ (kΩ)	$P = EI$ (mW)
0	0	20 kΩ (ohmmeter measurement)	0
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			
22			
24			
26			
28			
30			

Table 4-5

$R = 200\ \text{k}\Omega, \frac{1}{2}\ \text{W}$

E (V)	I (mA)	$R = E/I$ (kΩ)	$P = EI$ (mW)
0	0	200 kΩ (ohmmeter measurement)	0
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			
22			
24			
26			
28			
30			

Table 4-6

$R = 2\ \text{M}\Omega, \frac{1}{2}\ \text{W}$

E (V)	I (μA)	$R = E/I$ (MΩ)	$P = EI$ (μW)
0	0	2 MΩ (ohmmeter measurement)	0
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			
22			
24			
26			
28			
30			

5. Using the readings in the tables, plot the graphs of current versus voltage and power dissipated versus voltage for each resistor.

QUESTIONS

1. In each table compare the currents for $E = 10$ V and $E = 20$ V. From these readings, what can you say about the relationship between the current I and the applied voltage E when the resistance R remains constant?
2. In Tables 4-2 and 4-3, compare the currents for $E = 10$ V. What do you deduce about the relationship between the current I and the resistance R when the applied voltage E remains constant?
3. Using the current versus voltage graph derived from Table 4-3, what is the current corresponding to $E = 15$ V? How does this current value compare with the value calculated by Ohm's law?
4. Using the voltage versus power graph from Table 4-2, what is the power dissipated corresponding to $E = 21$ V? How does the power value compare with the value calculated from the equation $P = E^2/R$?
5. What is the shape of the current versus voltage graphs obtained in step 5? What is the meaning of this shape?
6. From the information contained in the tables, what happens to (a) the current and (b) the power dissipated if the voltage is doubled and the resistance remains constant?
7. From the information contained in the tables, what happens to (a) the current and (b) the power dissipated if the voltage is halved and the resistance remains constant?
8. In what part of the experiment was the wattage rating of a resistor exceeded? In step 2, did the 200-Ω resistor feel warm for $E = 24$ V? Explain your answers.

9. For E = 10 V, what is the shape of the graph of current versus resistance using the data in the tables? (*Note:* This shape shows the relationship between two inversely related quantities.)
10. What is the accuracy of the EVM as a voltmeter, the EVM as an ohmmeter, and the VOM as a current meter? (Obtain this information from the equipment manuals.)

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 5

Power Ratings of Resistors

READING ASSIGNMENT

Modern Electronics: A First Course, pages 51–58

Topics: Power Relationships involving E, I, P, and R; Resistor Wattage Ratings

OBJECTIVES OF EXPERIMENT

1. To examine experimentally the maximum voltage that can be applied across a composition resistor without exceeding its wattage rating
2. To examine experimentally the maximum current that can flow through a composition resistor without exceeding its wattage rating

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0–30 V
2. Resistors: $\frac{1}{2}$ W, 5%, 100 Ω, 200 Ω, 390 Ω; 1 W, 5%, 100 Ω; 2 W, 5%, 100 Ω
3. Meters: EVM; VOM
4. Single-pole single-throw (SPST) switch

PROCEDURE

1. By substituting the rated resistance and wattage values in the formula $E = \sqrt{P \times R}$, calculate the maximum voltage that can be applied across the 100-Ω, 1-W, 5% resistor without exceeding its wattage rating. Use the formula $I = \sqrt{P/R}$ to calculate the maximum permissible current. Enter both calculated values in Table 5-1.

Table 5-1

Resistor:	*Calculated Maximum Voltage*	*Calculated Maximum Current*		
100 Ω, 1 W, 5%	(V)	(mA)		
Applied Voltage E (V)	*Current* I (mA)	*Power Dissipated* P (mW)		
		$P = EI$	$P = I^2R$	$P = E^2/R$
0	0	0	0	0
2				
4				
6				
8				
10				

2. Connect the circuit of Fig. 5-1 in which R is the 100-Ω, 1-W, 10% resistor. Use the EVM to set the output of the power supply to $E = 2$ V. Close switch S and use the VOM to measure the current I. Repeat the procedure for $E = 4$, 6, 8, and 10 V. When $E = 10$ V, touch the resistor and get a feeling for its temperature. Record the current readings in Table 5-1 and calculate the power dissipated from the equations $P = E \times I = I^2R = E^2/R$. Open switch S.

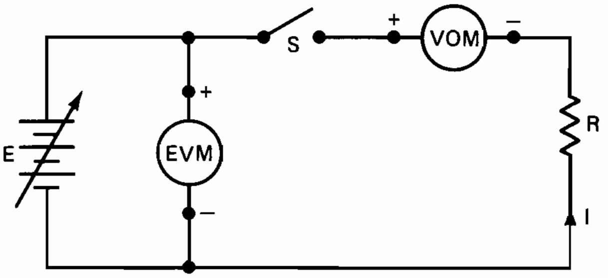


Fig. 5-1. Power dissipation in a resistor.

3. Replace the 100-Ω, 1-W resistor with the 100-Ω, 2-W resistor. Repeat step 2 for $E = 2, 4, 6, 8, 10, 12, 14$, and 15 V. When $E = 15$ V, touch the resistor and get a feeling for its temperature. Record all current readings in Table 5-2. Open switch S and complete Table 5-2. Plot the graphs of P ($= E \times I$) versus E and P versus I.
4. Replace the 100-Ω, 2-W resistor with the 100-Ω, $\frac{1}{2}$-W resistor. Repeat step 2 for $E = 2$, 4, 6, and 8 V. When $E = 8$ V, touch the resistor and get a feeling for its temperature. Record all current readings in Table 5-3. Open switch S and complete Table 5-3.

Table 5-2

Resistor:	*Calculated Maximum Voltage*	*Calculated Maximum Current*		
100 Ω, 2 W, 5%	(V)	(mA)		
Applied Voltage E (V)	*Current* I (mA)	*Power Dissipated* P (mW)		
		$P = EI$	$P = I^2R$	$P = E^2/R$
0	0	0	0	0
2				
4				
6				
8				
10				
12				
14				
15				

5. Replace the 100-Ω, $\frac{1}{2}$-W resistor with the 200-Ω, $\frac{1}{2}$-W resistor. Repeat step 2 for E = 2, 4, 6, 8, and 10 V and complete Table 5-4.
6. Replace the 200-Ω, $\frac{1}{2}$-W resistor with the 390-Ω, $\frac{1}{2}$-W resistor. Repeat step 2 for E = 2, 4, 6, 8, 10, 12, and 14 V and complete Table 5-5.

Table 5-3

Resistor:	*Calculated Maximum Voltage*	*Calculated Maximum Current*		
100 Ω, $\frac{1}{2}$ W, 5%	(V)	(mA)		
Applied Voltage E (V)	*Current* I (mA)	*Power Dissipated* P (mW)		
		$P = EI$	$P = I^2R$	$P = E^2/R$
0	0	0	0	0
2				
4				
6				
8				

Table 5-4

Resistor:	Calculated Maximum Voltage	Calculated Maximum Current		
200 Ω, $\frac{1}{2}$ W, 5%	(V)	(mA)		
Applied Voltage E (V)	Current I (mA)	Power Dissipated P (mW)		
		$P = EI$	$P = I^2R$	$P = E^2/R$
0	0	0	0	0
2				
4				
6				
8				
10				

Table 5-5

Resistor:	Calculated Maximum Voltage	Calculated Maximum Current		
390 Ω, $\frac{1}{2}$ W, 5%	(V)	(mA)		
Applied Voltage E (V)	Current I (mA)	Power Dissipated P (mW)		
		$P = EI$	$P = I^2R$	$P = E^2/R$
0	0	0	0	0
2				
4				
6				
8				
10				
12				
14				

QUESTIONS

1. At what point during the experiment did you exceed the wattage rating of a resistor?
2. Were there any significant differences between the values of the power dissipated as calculated from the formulas $P = E \times I$, $P = I^2R$, and $P = E^2/R$? Discuss the reasons for any differences.
3. By what factor must you multiply the applied voltage in order to halve the power dissipated? (Assume that the resistance is kept constant.) (*Hint:* Study the readings of Table 5-2.)

4. If the applied voltage is doubled and the resistance is kept constant, by what factor is the power multiplied? (*Hint:* Study the readings of Table 5-2.)
5. If the supply voltage is kept constant but the resistance is doubled, by what factor is the power multiplied? (*Hint:* Compare the readings of Tables 5-3 and 5-4.)
6. If the resistance is halved, by what factor must the current be multiplied in order to keep the power dissipated the same? (*Hint:* Compare the readings of Tables 5-4 and 5-5.)
7. If the resistance is kept constant, is there a linear relationship between the power dissipated and (a) the current; (b) the voltage? (*Hint:* Study the graphs of step 3.)
8. Upon what physical factors does the wattage rating of a resistor depend?

Note: Questions 9 and 10 should be regarded as advanced problems.

9. Assuming that the resistance remains constant, what percentage increase in the current corresponds to a 50% increase in the power dissipated?
10. Assuming that the resistance remains constant, what percentage decrease in the applied voltage corresponds to a 50% decrease in the power dissipated?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 6

Resistance of Conductors, Semiconductors, and Insulators

READING ASSIGNMENT

Modern Electronics: A First Course, pages 41–46

Topics: Comparison between Conductors, Semiconductors, and Insulators; Specific Resistance

OBJECTIVES OF EXPERIMENT

1. To verify by experiment the factors that determine the resistance of a cylindrical conductor
2. To examine by experiment the resistance of a semiconductor diode
3. To measure the resistances of a variety of insulators
4. To measure the resistance of the human body

COMPONENTS AND EQUIPMENT REQUIRED

1. Cylindrical conductors: 1-m length of No. 30 copper wire, two 1-m lengths of No. 30 Nichrome wire, 1-m length of No. 33 Nichrome wire
2. Resistors: 1-MΩ, $\frac{1}{2}$-W, 20% composition resistor; 500-Ω wirewound power resistor (*Note:* These values are not critical.)
3. Silicon diode: 1N4002 or equivalent
4. Inductor: 4-H iron-core choke (*Note:* This value is not critical.)
5. Capacitors: 220-pF mica, 0.01-μF paper, and 0.1-μF ceramic (*Note:* These values are not critical.)
6. Assorted insulators: 1-m lengths of string, paper strip, wood (rule), plastic (rule), rubber (hose), and glass
7. Meter: EVM

PROCEDURE

Resistance of Cylindrical Conductors

1. Use the data in Chapter 1 of *Modern Electronics: A First Course* to calculate the resistance of a 1-m length of No. 30 copper wire at room temperature. Enter this result in Table 6-1. With the EVM on the R X 1 scale, measure the wire's resistance and record the reading in Table 6-1. Make certain that any insulation at the ends of the wire is carefully scraped off so that the metal tips of the EVM leads make good contact with the wire.
2. Repeat step 1 for the first 1-m length of No. 30 Nichrome wire and enter both the calculated value and the measured reading in Table 6-1. Reverse the leads of the EVM and confirm that the measured resistance value remains unchanged. Connect the other 1-m length of No. 30 Nichrome wire in series so that the total equivalent length is now 2 m. Calculate the resistance of the 2-m length and measure its resistance with the EVM. Enter the calculated value and the measured reading in Table 6-1.
3. Repeat step 1 for the 1-m length of No. 33 Nichrome wire and enter both the calculated value and the measured reading in Table 6-1.

Table 6-1

Cylindrical Conductor	*Calculated Resistance* (Ω)	*Measured Resistance* (Ω)
1-m length No. 30 copper wire		
1-m length No. 30 Nichrome wire		
2-m length No. 30 Nichrome wire		
1-m length No. 33 Nichrome wire		

Resistances of Different Resistors

4. With the EVM on the R X 100 K range, measure the resistance of the 1-MΩ composition resistor and enter the reading in Table 6-2. Change the range to R X 100 and check the adjustments on the ZERO and OHMS controls. Measure the value of the 500-Ω power resistor and record the reading in Table 6-2. For each of the resistors confirm that switching the leads of the EVM does not change the value of the measured resistance. Draw a straight line 0.25 m long with a No. 2 pencil. Measure the line's resistance and enter the reading in Table 6-2.

Table 6-2

Resistor	*Rated Resistance*	*Measured Resistance*
Composition	1 MΩ	MΩ
Wirewound	500 Ω	Ω
Pencil line		Ω

Resistance of the Silicon Diode

5. With the range switch on R X 1, measure the resistance by switching the ohmmeter leads back and forth across the diode. There should be a low resistance in one direction (corresponding to one polarity) and a high resistance in the opposite direction. Measure the low resistance and enter its value in Table 6-3.

Table 6-3

Range	*Low Resistance*	*High Resistance*
R X 1	Ω	
R X 10	Ω	
R X 100	Ω	
R X 1 MEG		MΩ

Change first to the R X 10 range and then to the R X 100 range and again measure the low resistance; record both readings in Table 6-3. Switch to the R X 1 MEG range and measure the high resistance; enter this reading in Table 6-3.

Resistance of an Inductor

6. With the EVM on the R X 10 range, measure the resistance of the 4-H choke. Switch the ohmmeter leads to confirm that the value of the measured resistance does not change. Enter the resistance reading in Table 6-4.

Resistances of Difference Capacitors

7. With the EVM on the R X 1 MEG range, measure the resistances of the three capacitors. Reverse the ohmmeter leads and observe that the needle may shift rapidly downscale but subsequently move upscale to record the same resistance value. Enter the three readings in Table 6-4.

Resistances of Various Insulators

8. Measure the resistance of each of the insulators with the EVM on the R X 1 MEG range. Again confirm that switching the ohmmeter leads does not change the value of the measured resistances. Enter all the readings in Table 6-4.

Table 6-4

Item	*Measured Resistance*
Choke	
Mica capacitor	
Paper capacitor	
Ceramic capacitor	
String	
Paper	
Wood	
Plastic	
Rubber	
Glass	
Human body (dry)	
Human body (wet)	

Resistance of the Human Body

9. With the EVM on the R X 100 K range, grasp its metal tips firmly with one tip in each hand and then measure the resistance. Wet your hands and repeat the procedure. Enter both readings in Table 6-4.

QUESTIONS

1. From the information revealed in steps 1 and 2, which has the highest specific resistance, Nichrome or copper?
2. For the No. 30 Nichrome wire, how did the resistance of the 2-m length compare with the resistance of the 1-m length? What is the relationship between the resistance of a cylindrical conductor and its length?
3. How did the resistance of the 1-m length of No. 33 Nichrome wire compare with the resistance of the 1-m length of No. 30 Nichrome wire? What is the relationship between the cross-sectional areas of the two wires? Deduce the relationship between the resistance of a cylindrical conductor and its cross-sectional area.
4. When measuring the low resistance of the silicon diode, the reading changed with the resistance range chosen. Why?
5. From the readings recorded in Table 6-2, what can you say about the resistance of a silicon diode? Does a silicon diode obey Ohm's law?
6. When you reversed the ohmmeter leads, did the measured resistance values of the resistors and the choke change in any way?
7. From your ohmmeter readings in Table 6-4, what can you say about the resistances of the mica, paper, and ceramic capacitors?
8. Using the EVM, were you able to observe any differences in the resistance values of the various insulators?
9. Where is the resistance of the human body mainly concentrated?
10. After wetting your hands, was your body resistance increased or decreased? Is pure water a good conductor?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 7

Comparison between Linear and Nonlinear Resistors; Temperature Coefficient of Resistance

READING ASSIGNMENT

Modern Electronics: A First Course, pages 32–39, 47–51

Topics: Linear and Nonlinear Resistors; Temperature Coefficient

OBJECTIVES OF EXPERIMENT

1. To compare experimentally the voltage/current relationships of linear and nonlinear resistors
2. By experiment to obtain an estimate of the temperature coefficient of resistance for tungsten

COMPONENTS AND EQUIPMENT REQUIRED

1. Four variable regulated dc power supplies, 0-30 V (or one 0-300 V variable dc power supply)
2. Resistors: one 15-W, 120-V incandescent lamp with socket; one 960 Ω wirewound resistor with a wattage rating of 15 W or greater (*Note:* When this resistor is not directly available, it may be created from a combination of power resistors; if necessary, you should consult your instructor.)
   Instructor Note: If only a single 0-30 V power supply is available, you can alternatively use a No. 1819 28-V, 0.04-A, 1.12-W incandescent lamp. The corresponding linear resistor is 680 Ω, 20%, 2 W with a measured value of 700 Ω.
3. Meters: EVM; VOM
4. Four single-pole single-throw (SPST) switches

PROCEDURE

Comparison between the Voltage/Current Relationships of Linear and Nonlinear Resistors

1. Use your EVM as an ohmmeter to measure the resistance of the lamp's tungsten filament at room temperature. (*Note:* The value you obtain is only an estimate since the ohmmeter applies a low voltage to the filament and warms it slightly.) Record this reading in Table 7-1.

Table 7-1

15-W Incandescent lamp			
E_T (V)	I (A)	*Power Dissipated* $P = E_T \times I$ (W)	*Filament Resistance* $R = E_T/I$ (Ω)
0	0	0	(room temperature)
5			
10			
15			
20			
25			
30			
35			
40			
45			
50			
55			
60			
65			
70			
75			
80			
85			
90			
95			
100			
105			
110			
115			
120			

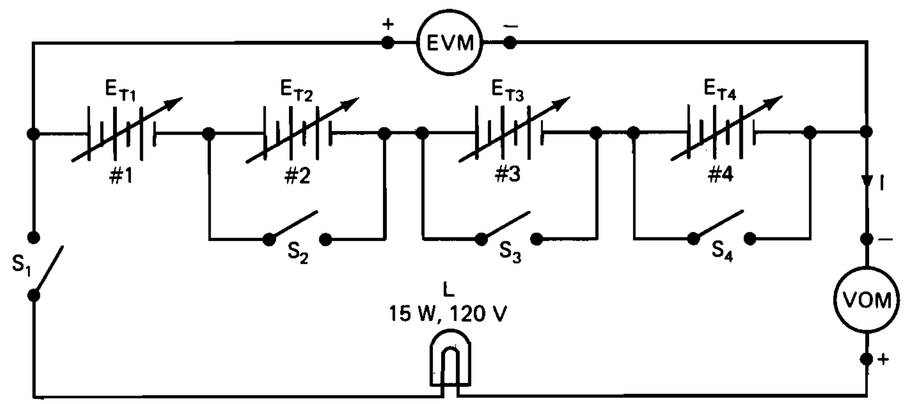


Fig. 7-1. Voltage/current relationship of an incandescent lamp.

2. Connect the circuit of Fig. 7-1 with all power supplies off initially. Switch S_1 should be open but switches S_2, S_3, and S_4 should be closed. Switch on power supply 1 and use the EVM to adjust its output to $E_{T1} = 5$ V. Close S_1 and measure the current I with the VOM. Increase E_{T1} in 5-V steps up to 30 V and measure the current in each case. Record all current readings in Table 7-1.
3. Open switches S_1 and S_2. Maintaining E_{T1} at 30 V, switch on supply 2 and adjust its output until the reading of the EVM is 35 V. Close switch S_1 and measure the current I with the VOM. Increase the reading of the EVM in 5-V steps up to 60 V, and record all current readings in Table 7-1.
4. Repeat step 3 for power supplies 3 and 4 until the EVM finally reads a maximum value of 120 V. Open switch S_1, switch off all power supplies, close switches S_2, S_3, and S_4, and complete Table 7-1.
5. Remove lamp L and replace it by the 960-Ω wirewound resistor (Fig. 7-2). Repeat steps 1 through 4 and complete Table 7-2.

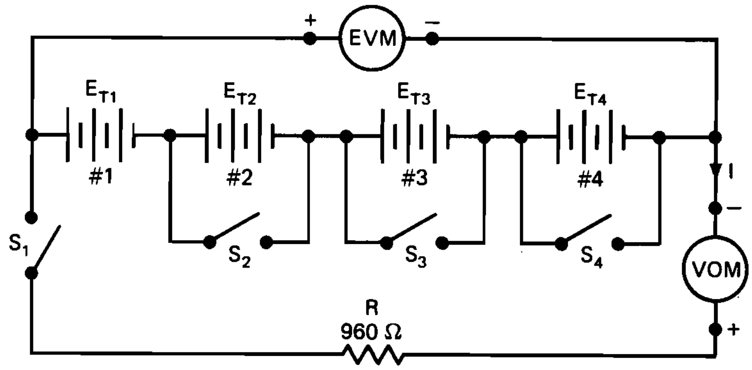


Fig. 7-2. Voltage/current relationship of a wirewound power resistor.

6. Plot the graphs of current versus voltage, resistance versus voltage, and resistance versus power dissipated for both the lamp and the wirewound resistor.

Estimation of Tungsten's Temperature Coefficient of Resistance

7. Assuming that the temperature of the tungsten filament with 120 V applied is approximately 2200°C above room temperature, calculate the average temperature coefficient of resistance, α, over the range of the experiment.

Table 7-2

960-Ω Power Resistor			
E_T (V)	I (A)	*Power Dissipated* $P = E_T \times I$ (W)	*Filament Resistance* $R = E_T/I$ (Ω)
0	0	0	(room temperature)
5			
10			
15			
20			
25			
30			
35			
40			
45			
50			
55			
60			
65			
70			
75			
80			
85			
90			
95			
100			
105			
110			
115			
120			

QUESTIONS

1. Would you describe the incandescent lamp as a linear or a nonlinear power resistor? Give detailed reasons for your answer.
2. Would you describe the 960-Ω wirewound resistor as a linear or a nonlinear component? Give detailed reasons for your answer.

3. What are the differences in appearance between the two current versus voltage graphs? Discuss the reasons for these differences.
4. What are the differences in appearance between the two resistance versus voltage graphs? Discuss the reasons for these differences.
5. What are the differences in appearance between the two resistance versus power graphs? Discuss the reasons for these differences. Which electrical quantity (voltage, current, or power) mainly determines the filament's temperature?
6. How did the resistance of the tungsten filament change as its power dissipation was increased? Does tungsten have a positive or a negative coefficient of resistance?
7. How did the resistance of the wirewound resistor change as its power dissipation was increased? Over the range of the experiment, what can we say about the temperature coefficient of the wire from which the resistor is manufactured?
8. From inspection of the resistance versus power graph for the lamp, do you think that tungsten's temperature coefficient of resistance remained constant over the range of the experiment? Give reasons for your answer.
9. How did the result of step 7 compare with tungsten's α value quoted on page 48 of *Modern Electronics: A First Course*? Discuss the reasons for any significant difference.

Note: Question 10 should be regarded as an advanced problem.

10. In Fig. 7-1, a second identical lamp is connected in series with the lamp shown. If 120 V is applied to the combination, what is the total power dissipated? (*Hint:* The answer cannot be calculated directly and must be found by inspecting Table 7-1.)

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 8

Resistors in Series

READING ASSIGNMENT

Modern Electronics: A First Course, pages 68–83, 92–107

Topics: Resistors in Series; Ground; Potential Measurements; Open and Short Circuits

OBJECTIVES OF EXPERIMENT

1. To investigate the resistance, voltage, current, and power relationships in a series network of resistors
2. To measure the potentials at various points in a series circuit

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0-30 V
2. Resistors: $\frac{1}{2}$ W, 10%, 180 Ω, 330 Ω, 470 Ω, 820 Ω
3. Meters: EVM; VOM
4. Single-pole single-throw (SPST) switch

PROCEDURE

Determination of the Equivalent Resistance

1. Measure the values of the supplied resistors with the EVM and record the *measured* values in Table 8-1.
2. Construct the circuit of Fig. 8-1 and use the measured resistor values to *compute* the total equivalent re-

Table 8-1

Measured R_1 (Ω)	*Measured* R_2 (Ω)	*Measured* R_3 (Ω)	*Measured* R_4 (Ω)	*Computed* $R_T = R_1 + R_2 + R_3 + R_4$ (Ω)	*Measured* R_T (Ω)	*Current* I (mA)	$R_T = E/I$ (Ω)

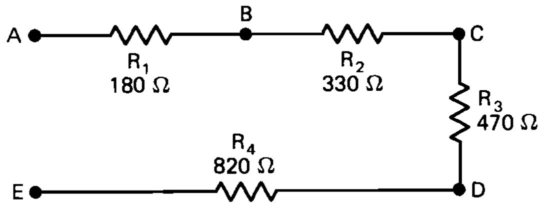


Fig. 8-1. Determination of R_T.

sistance R_T between points A and E. Then use the EVM to measure the value of R_T and record both the computed and measured R_T values in Table 8-1.

3. Turn around the 180-Ω resistor between points A and B and measure the value of R_T. Interchange the 330-Ω and 820-Ω resistors and again measure the value of R_T.
4. Connect the variable dc power supply and the EVM to the series circuit as shown in Fig. 8-2. Switch on the power supply and use the EVM to adjust its output E to 20 V.

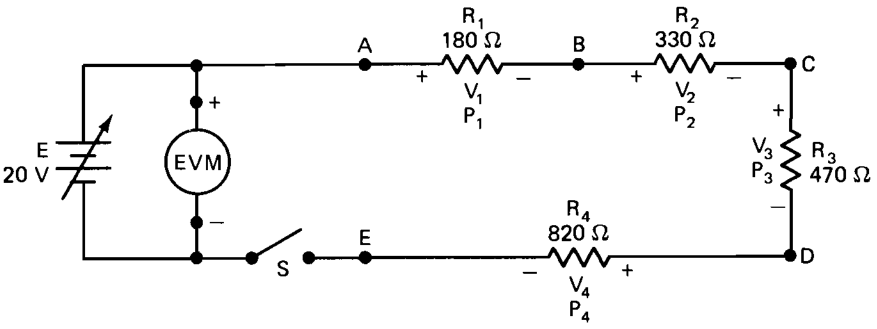


Fig. 8-2. Measurement of voltages in a series circuit.

5. Close switch S and check that the reading of the EVM is still 20 V. Open the circuit at point A and measure the current I with the VOM. In the same way measure the current in turn at points B, C, D, and E. Record the reading of the current I in Table 8-1. Calculate the value of the total equivalent resistance from the equation $R_T = E/I$; enter this R_T value in Table 8-1. Open switch S.

Voltage Measurements with Series-Connected Resistors

6. From the measured values of R_1, R_2, R_3, R_4, and I, compute the values of V_1, V_2, V_3, and V_4 in Fig. 8-2. Enter the computed values in Table 8-2.

Table 8-2

	V_1 (V)	V_2 (V)	V_3 (V)	V_4 (V)	V_{AC} (V)	V_{AD} (V)	V_{BD} (V)	V_{BE} (V)	V_{CE} (V)
Calculated values									
Measured readings									

7. Maintaining the measured value of E at 20 V, close switch S, and use the VOM to measure the values of V_1, V_2, V_3, and V_4. Enter the measured values of these voltages in Table 8-2.
8. From the measured values of the resistors and the current, compute the voltage between points A and C (V_{AC}). Similarly, calculate the voltages V_{AD}, V_{BD}, V_{BE}, and V_{CE} and record the results in Table 8-2.
9. Use the EVM to measure the voltages V_{AC}, V_{AD}, V_{BD}, V_{BE}, and V_{CE} and enter the readings in Table 8-2.
10. In Fig. 8-2, regard point B as grounded by clipping the common probe of the VOM to that point. From the results of steps 7 and 8, compute the potentials at points A, C, D, and E. By using the "+ DC" and "– DC" positions of the VOM's function switch, measure the potentials at points A, C, D, and E. Repeat the procedure by grounding in turn points A, C, D, and E. Enter all computed values and measured readings in Table 8-3. Be sure that you indicate whether the potentials are positive or negative with respect to ground. Open switch S.

Table 8-3

Grounded Point	Potential at A (V)		Potential at B (V)		Potential at C (V)		Potential at D (V)		Potential at E (V)	
	Calc.	*Meas.*	*Calc.*	*Meas.*	*Calc.*	*Meas.*	*Calc.*	*Meas.*	*Calc.*	*Meas.*
A	0	0								
B			0	0						
C					0	0				
D							0	0		
E									0	0

Power Relationships with Series-Connected Resistors

11. From the measured values of V_1, V_2, V_3, and V_4 (step 7) and the current I (step 5) in Fig. 8-2, compute the powers dissipated in the individual resistors. Add up the values of P_1, P_2, P_3, and P_4 to obtain the total power dissipated in the resistors. Enter these computed values in Table 8-4.
12. Using the values of E (20 V) and I, calculate the total power P_T drawn from the source. Record this result in Table 8-4.

Table 8-4

$P_1 = IV_1$ (mW)	$P_2 = IV_2$ (mW)	$P_3 = IV_3$ (mW)	$P_4 = IV_4$ (mW)	$P_T = P_1 + P_2 + P_3 + P_4$ (mW)	$P_T = E \times I$ (mW)

QUESTIONS

1. Throughout the experiment the measured values (*not* the rated values) of the resistors were used. Why was this important?
2. Describe in your own words the methods you used in obtaining the total equivalent resistance.
3. In step 3, did the measured values of R_T change? What did you learn from this step? In Fig. 8-1, what would be the new values of R_T if (a) an open circuit occurred at point C, and (b) a short circuit existed between points B and D?
4. In step 5, how did the current readings at the various points compare? What feature of a series circuit did this step verify?

5. In step 7, which resistor carried the greatest voltage drop and which resistor had the lowest voltage drop? What have you discovered from these results?
6. In step 7, what is the result of adding together the measured values of V_1, V_2, V_3, and V_4? How does the sum of these four voltages compare with the value of E?
7. In step 8, how are the values of V_{AC}, V_{AD}, V_{BD}, V_{BE}, and V_{CE} related to V_1, V_2, V_3, and V_4? Write down expressions for V_{AC}, V_{AD}, V_{BD}, V_{BE}, and V_{CE} in terms of V_1, V_2, V_3, and V_4.
8. In step 10, why are some of the potentials positive whereas others are negative?
9. In step 11, which resistor dissipates the greatest power and which resistor dissipates the least power? Does the power dissipated in any of the resistors exceed its wattage rating? In step 12, what is the relationship between P_T and P_1, P_2, P_3, and P_4? In Fig. 8-2, what is the maximum current that will not cause the power dissipation of any of the resistors to exceed its wattage rating? (Assume that the value of E may be varied.)
10. In Fig. 8-1, what would be the new values of V_1, V_2, V_3, V_4, V_{AC}, V_{AD}, V_{BD}, V_{BE}, and V_{CE} if (a) an open circuit occurred at point C, and (b) a short circuit existed between points B and D?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 9

Voltage-Division Rule; Unloaded Voltage-Divider Circuit

READING ASSIGNMENT

Modern Electronics: A First Course, pages 86–92

Topics: Voltage-Division Rule; The Unloaded Voltage-Divider Circuit Using Fixed Resistors and/or a Potentiometer

OBJECTIVES OF EXPERIMENT

1. To verify by experiment the voltage-division rule for a series network of resistors, and the potentiometer
2. To examine experimentally the unloaded voltage divider circuit

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0–30 V
2. Resistors: $\frac{1}{2}$ W, 10%, 1.8 kΩ, 2.2 kΩ, 3.3 kΩ, 4.7 kΩ; $\frac{1}{2}$ W, 5%, 10 kΩ, 91 kΩ, 910 kΩ
   Potentiometer: 10 kΩ, 2 W
3. Meters: EVM; VOM
4. Single-pole single-throw (SPST) switch

PROCEDURE

Experimental Verification of the Voltage-Division Rule

1. Measure the values of the 10% resistors with the EVM. Use these *measured* values in your calculations.
2. Construct the circuit of Fig. 9-1. Close switch S and use the EVM to set E_T to 25 V. Using the voltage-

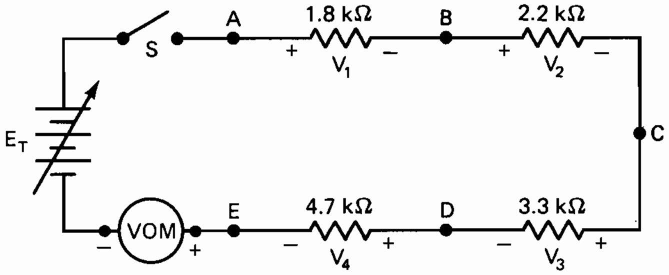


Fig. 9-1. **Experimental verification of the voltage-division rule.**

division rule, calculate the values of V_1, V_2, V_3, and V_4, which are the individual voltage drops across the four resistors. In addition, calculate the values of the current I and the voltages V_{AC}, V_{AD}, V_{BD}, V_{BE}, and V_{CE}. Enter the results of your calculations in Table 9-1.

3. Use the VOM to measure the value of the current I and the EVM to measure the voltages V_1, V_2, V_3, V_4, V_{AC}, V_{AD}, V_{BD}, V_{BE}, and V_{CE}. Enter these readings in Table 9-1.
4. Change the value of E_T so that the VOM reads a current $I = 1$ mA. Calculate the corresponding values of E_T, V_1, V_2, V_3, V_4, V_{AC}, V_{AD}, V_{BD}, V_{BE}, V_{CE}, and enter the results in Table 9-2. Measure these voltages with the EVM and enter the readings in Table 9-2.

Table 9-1

	E_T (V)	V_1 (V)	V_2 (V)	V_3 (V)	V_4 (V)	I (mA)	V_{AC} (V)	V_{AD} (V)	V_{BD} (V)	V_{BE} (V)	V_{CE} (V)
Calculated values	25										
Measured readings	25										

Table 9-2

	E_T (V)	V_1 (V)	V_2 (V)	V_3 (V)	V_4 (V)	I (mA)	V_{AC} (V)	V_{AD} (V)	V_{BD} (V)	V_{BE} (V)	V_{CE} (V)
Calculated values						1					
Measured readings						1					

The Voltage-Division Rule and the Potentiometer

5. Connect the circuit of Fig. 9-2, where X, Y, and Z represent the three terminals of the potentiometer. Wrap a piece of stiff wire around the shaft and leave one end free to act as a pointer. Place the potenti-

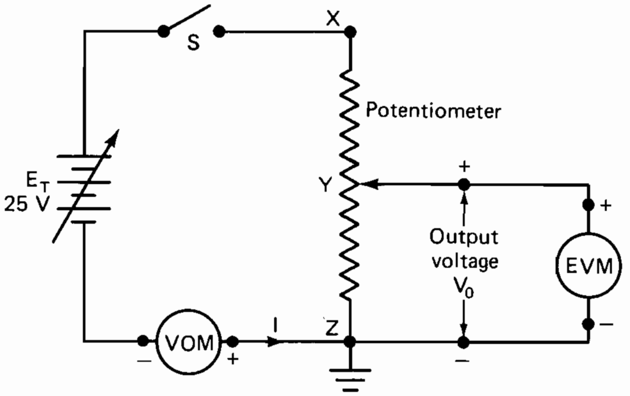


Fig. 9-2. **The potentiometer and the voltage-division rule.**

ometer on a sheet of paper and construct a scale that identifies the extremes of the shaft's rotation. Then determine the positions where the rotation is $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of its full value.

6. Close switch S and use the EVM to set the voltage $E_T = 25$ V. Keep this value constant throughout the experiment. Rotate the potentiometer shaft for minimum output voltage (Y at Z). Close switch S and calculate the current I and the output voltage V_{YZ} at the minimum position, $\frac{1}{4}$ rotation, $\frac{1}{2}$ rotation, $\frac{3}{4}$ rotation, and maximum position. Enter these results in Table 9-3.

Table 9-3

	Calculated Values			*Measured Readings*		
Position of Shaft	E_T (V)	I (mA)	*Output Voltage* V_{YZ} (V)	E_T (V)	I (mA)	*Output Voltage* V_{YZ} (V)
Minimum position (Y at Z)	25			25		
$\frac{1}{4}$ rotation	25			25		
$\frac{1}{2}$ rotation	25			25		
$\frac{3}{4}$ rotation	25			25		
Maximum position (Y at X)	25			25		

7. Use the VOM to measure the current I and the EVM to measure the voltage V_{YZ} for the shaft positions specified in step 6. Record these readings in Table 9-3.

8. Maintaining E_T at 25 V, rotate the shaft until the reading of V_{YZ} is 10 V. Open switch S. Using the EVM as an ohmmeter measure resistances R_{XY}, R_{YZ}, and R_{XZ}. Assuming that $E_T = 25$ V and $V_{YZ} = 10$ V, compute resistances R_{XY} and R_{YZ}. Enter both the measured and computed values in Table 9-4.

Table 9-4

	E_T (V)	V_{YZ} (V)	R_{XY} (kΩ)	R_{YZ} (kΩ)	R_{XZ} (kΩ)
Calculated values	25	10			10
Measured readings	25	10			

The Unloaded Fixed Voltage-Divider Circuit

9. By using the color code and measuring the values of a number of 5%, $\frac{1}{2}$-W resistors, find three resistors whose values are equal to 10 kΩ, 90 kΩ, and 900 kΩ (within the limits of measurement). Construct the circuit of Fig. 9-3. Set the output of the variable power supply to 25 V and maintain this value throughout the experiment.

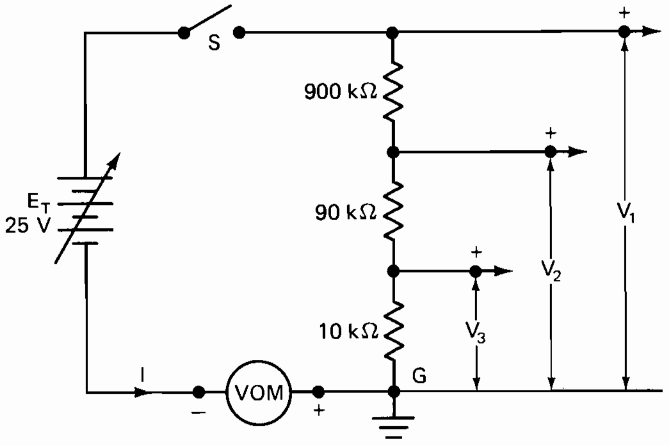


Fig. 9-3. The fixed voltage-divider circuit.

Table 9-5

	E_T (V)	*Current* I (mA)	*Output Voltage* V_1 (V)	*Output Voltage* V_2 (V)	*Output Voltage* V_3 (V)
Calculated values	25				
Measured readings	25				

10. Close switch S and calculate the values of the voltages V_1, V_2, and V_3 (voltage-division rule) and the current I. Measure current I with the VOM and the voltages V_1, V_2, and V_3 with the EVM (clip the common lead to point G). Enter both computed values and measured readings in Table 9-5.

The Unloaded Variable Voltage-Divider Circuit

11. Construct the circuit of Fig. 9-4. Use the EVM to set the value of E_T to 20 V, which should be maintained throughout the experiment. Assuming that switch S is closed, calculate the current I and the maximum and minimum values (by the voltage-division rule) of the output voltage V_o corresponding to the extreme positions of the potentiometer's wiper arm. Enter all the calculated values in Table 9-6.

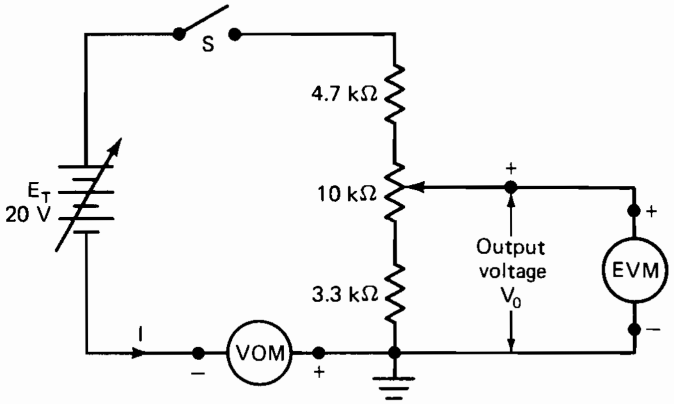


Fig. 9-4. The variable voltage-divider circuit.

Table 9-6

	E_T (V)	I (mA)	V_o *Maximum Value* (V)	V_o *Minimum Value* (V)
Calculated values	20			
Measured readings	20			

12. Close switch S and measure the current I with the VOM; use the EVM to measure the maximum and minimum values of V_o. Record the measured readings in Table 9-6.

QUESTIONS

1. In Fig. 9-1, compute the values of the ratios $R_1 : R_2$ and $V_1 : V_2$. Should these ratios be equal? Discuss your answer.

2. In Fig. 9-1, compute the values of the ratios $R_3 : R_T$ and $V_3 : E_T$. Should these ratios be equal? Discuss your answer.
3. In Fig. 9-1, interchange the 2.2-kΩ and 4.7-kΩ resistors (points A, B, C, D, and E remain in their same positions). Would this action affect the values of the voltage drops across the *individual* resistors? What would be the new values of V_{AC}, V_{AD}, V_{BD}, V_{BE}, and V_{CE}?
4. In Fig. 9-1, what are the values of the powers dissipated in the individual resistors and the total power dissipated?
5. In step 2, what are the relationships between V_{AC}, V_{AD}, V_{BD}, V_{BE}, V_{CE} and V_1, V_2, V_3, V_4?
6. In step 6, what is the value of V_{XY} for each of the five positions of the potentiometer's wiper arm? (Refer to Table 9-3.) Irrespective of the position of the wiper arm, what are the values of $V_{XY} + V_{YZ}$?
7. In step 8, what are the values of the ratios $V_{XY} : V_{YZ}$ and $R_{XY} : R_{YZ}$? Should these ratios be the same? Discuss your answer.
8. In step 10, what are the values of the ratios $V_2 : V_1$ and $V_3 : V_2$? Could Fig. 9-3 be described as a "divide-by-10" circuit in the sense that V_2 is $\frac{1}{10}$ of V_1 and V_3 is $\frac{1}{10}$ of V_2? Why is Fig. 9-3 described as an *unloaded* voltage-divider circuit?
9. In Fig. 9-4, does the value of the current change as the shaft is rotated through its entire travel?

Note: Question 10 should be regarded as an advanced problem.

10. Devise a voltage-divided circuit that has four output voltages with respect to ground and a "divide-by-5" effect ($V_2 = V_1/5$, $V_3 = V_2/5$, etc.). Assuming that the lowest value resistor has a value of 1 kΩ, what are the values of the other three resistors?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 10

Resistors in Parallel; Voltage, Current, and Resistance Measurements; Current-Division Rule

READING ASSIGNMENT

Modern Electronics: A First Course, pages 116–143

Topics: E, I, P, and R Relationships for Resistors in Parallel; Current-Division Rule

OBJECTIVES OF EXPERIMENT

1. To measure the total resistance of a parallel resistor network and to verify experimentally the reciprocal formula
2. To examine by experiment the voltage, current, and power relationships in a parallel resistor network
3. To verify experimentally the current-division rule

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0–30 V
2. Resistors: $\frac{1}{2}$ W, 10%, 2.2 kΩ, two 3.9 kΩ, 4.7 kΩ
3. Meters: one EVM; two VOMs
4. Single-pole double-throw (SPDT) switch

PROCEDURE

1. Use the EVM to measure the values of all the resistors and use only the *measured* values in your calculations.

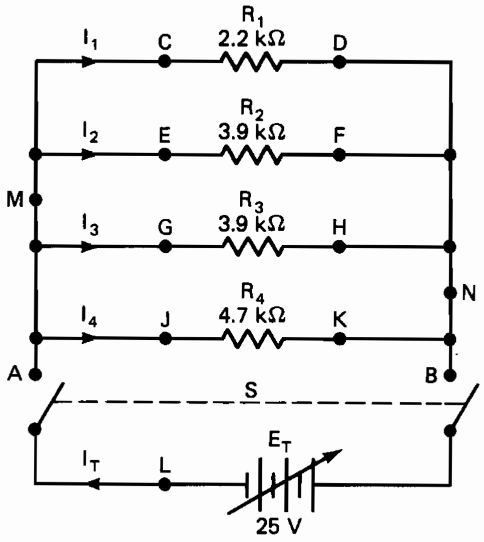


Fig. 10-1. Parallel resistor network.

Total Equivalent Resistance of the Parallel Resistor Network

2. Connect the circuit of Fig. 10-1 and leave switch S open. Use the reciprocal formula to calculate the total resistance between points A and B. Enter the result in Table 10-1.

Table 10-1

R_T Calculated (kΩ)	R_T (EVM) (kΩ)	I_T (mA)	$R_T = E_T/I_T$ (kΩ)	$G_T = I_T/E_T$ (mS)

3. Use the EVM as an ohmmeter to measure the total resistance between points A and B. Record the reading in Table 10-1.
4. With the aid of the EVM, adjust the output of the variable power supply to $E_T = 25$ V. Open the circuit at point L and insert the VOM. Close switch S and measure the total current I_T, which is then recorded in Table 10-1. Compute the value of R_T from the equation $R_T = E_T/I_T$. Use the relationship $G_T = 1/R_T$ to compute the total conductance and enter both results in Table 10-1. Open switch S and remove the VOM from the circuit. Reconnect the circuit at point L.

Voltage and Current Measurements in the Parallel Resistor Network

5. Close switch S and use the EVM to measure the voltage V_{CD} between points C and D. Repeat the procedure for the voltages V_{EF}, V_{GH}, and V_{JK} and record all the readings in Table 10-2.

Table 10-2

E_T (V)	V_{CD} (V)	V_{EF} (V)	V_{GH} (V)	V_{JK} (V)
25				

6. Open switch S and break the circuit at point C by disconnecting the lead from one end of the resistor R_1. Insert the VOM in the break and measure the current I_1. Repeat the procedure at points E, G, and

K and measure the currents I_2, I_3, and I_4. Calculate the values of these branch currents and enter both the calculated and measured values in Table 10-3.

Table 10-3

	I_T (mA)	I_1 (mA)	I_2 (mA)	I_3 (mA)	I_4 (mA)
Calculated					
Measured					

Power Relationships

7. From the results of steps 5 and 6, calculate the individual powers dissipated in the resistors by using the equations $P_1 = V_{CD} \times I_1$, $P_2 = V_{EF} \times I_2$, and so on. Compute the total power $P_T = E_T I_T$ drawn from the source. Enter all results in Table 10-4.

Table 10-4

P_1 (mW)	P_2 (mW)	P_3 (mW)	P_4 (mW)	$P_T = P_1 + P_2 + P_3 + P_4$ (mW)	$P_T = E_T I_T$ (mW)

Current-Division Rule for a Parallel Network of Three Resistors

8. Connect the circuit of Fig. 10-2 and leave switch S open. Measure the total resistance of the network between points A and B and record the reading in Table 10-5. Assuming that the total value of the current I_T is 15 mA, calculate the currents I_1, I_2, and I_3 by using the relationship $I_1 = I_T \times R_T / R_1$, and so on.

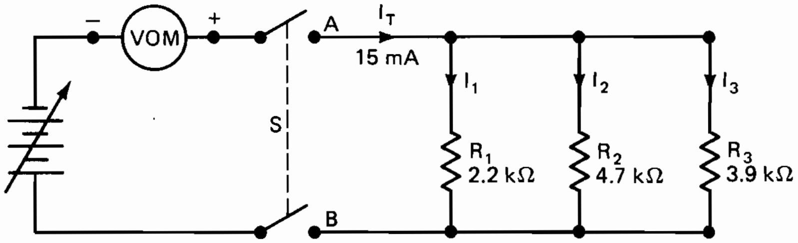


Fig. 10-2. Experimental verification of the current-division rule.

9. Close switch S and adjust the output of the power supply until the VOM reads 15 mA; maintain this value throughout the experiment. Use the second VOM to measure in turn the currents I_1, I_2, and I_3. Record all readings in Table 10-5.

Table 10-5

	R_T (kΩ)	I_T (mA)	I_1 (mA)	I_2 (mA)	I_3 (mA)
Calculated		15			
Measured		15			

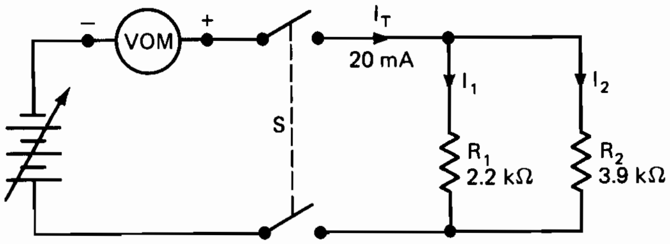


Fig. 10-3. Current-division rule for two resistors.

Current-Division Rule for a Parallel Network of Two Resistors

10. Connect the circuit of Fig. 10-3 and leave switch *S* open. Assuming that the value of the total current is 20 mA, calculate the values of I_1 and I_2 from the relationships

$$I_1 = I_T \times \frac{R_2}{R_1 + R_2} \quad \text{and} \quad I_2 = I_T \times \frac{R_1}{R_1 + R_2}$$

Enter these results in Table 10-6.

Table 10-6

	I_T (mA)	I_1 (mA)	I_2 (mA)
Calculated	20		
Measured	20		

11. Close switch *S* and adjust the output of the power supply until the VOM reads 20 mA. Use the second VOM to measure in turn the currents I_1 and I_2. Record these readings in Table 10-6.

QUESTIONS

1. In steps 2, 3, and 4, how did the three values of R_T compare in Table 10-1? Explain any significant differences.
2. In step 5, what is the relationship between the voltages V_{CD}, V_{EF}, V_{GH}, and V_{JK}?
3. In step 6, what is the relationship between the currents I_2 and I_3? Explain your answer.
4. In step 6, what is the relationship between the current I_T and I_1, I_2, I_3, and I_4?

Note: In questions 5 through 10, it is assumed that switch *S* is closed.

5. In Fig. 10-1, which resistor dissipates the greatest power and which resistor dissipates the least power? What is the maximum value of E_T that will not cause the power dissipation of any of the resistors to exceed its rated value?
6. In Fig. 10-1, what are the calculated values of the currents at points *M* and *N*? Verify your answers experimentally.
7. In Fig. 10-1, an open circuit occurs at point *G*. What are the new calculated values of R_T, I_T, I_1, I_2, I_3, and I_4? Verify your answers experimentally.
8. In Fig. 10-1, an open circuit occurs at point *N*. What are the new calculated values of R_T, I_T, I_1, I_2, I_3, and I_4? Verify your answers experimentally.
9. In Fig. 10-1, assume that points *M* and *N* are joined by a connecting lead (short circuit). What would be the new values of R_T, I_1, I_2, I_3, and I_4?
10. In Fig. 10-1, an additional resistor of value 3300 Ω is connected between points *A* and *B*. What are the new calculated values of R_T, I_T, I_1, I_2, I_3, and I_4?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 11

The Loaded Voltage-Divider Circuit

READING ASSIGNMENT

Modern Electronics: A First Course, pages 180–183

Topic: The Loaded Voltage-Divider Circuit

OBJECTIVES OF EXPERIMENT

1. To determine the resistor values for a loaded voltage divider and to examine the circuit experimentally
2. To show experimentally how a loaded voltage-divider circuit is affected by changes in load current

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0-30 V
2. Resistors and potentiometers: as required by experiment
3. Meters: EVM; VOM
4. Single-pole single-throw (SPST) switch

PROCEDURE

The Loaded Voltage-Divider Circuit

1. Refer to the circuit of Fig. 11-1. Assuming that switch S is closed, calculate the resistances and power dissipations of the loads R_{L1}, R_{L2}, and R_{L3} and the divider resistors R_1, R_2, and R_3; enter these results

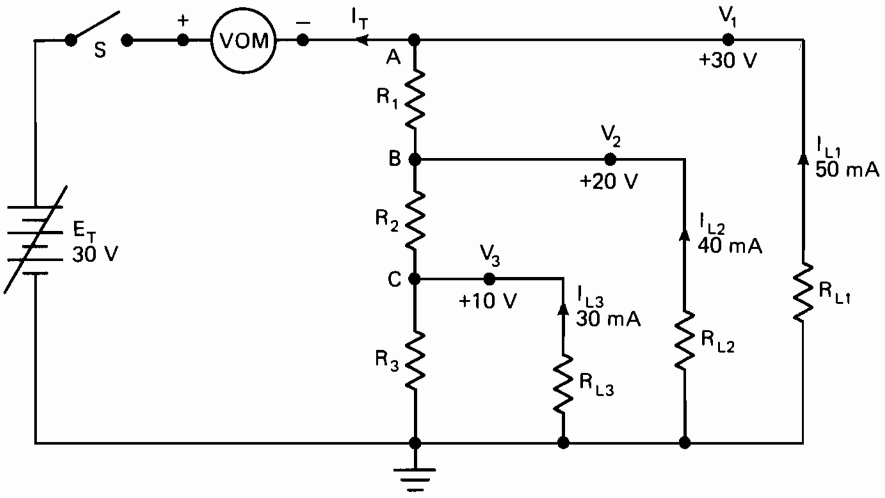


Fig. 11-1. The voltage-divider circuit with fixed load currents.

Table 11-1

	Calculated Values		*Selected Values*	
Resistor	*Resistance* (Ω)	*Power Dissipated* (mW)	*Resistance* (Ω)	*Wattage Rating* (W)
R_{L1}				
R_{L2}				
R_{L3}				
R_1				
R_2				
R_3				

in Table 11-1. (*Note:* You should choose the bleeder current I_B to be 10% of the total load current, which is the sum of the currents I_{L1}, I_{L2}, and I_{L3}.)

2. Choose 5% standard value resistors whose values *and wattage ratings* correspond as closely as possible to the calculated values of R_{L1}, R_{L2}, R_{L3}, R_1, R_2, and R_3. (*Hint:* You should consider using two standard resistors in parallel to represent R_{L3}. The required values of R_{L2} and R_1 may also be achieved by using parallel combinations of resistors.)
3. With the resistors you have chosen, connect the circuit of Fig. 11-1. Use the EVM to adjust the output of the power supply to $E_T = 30$ V and maintain this value throughout the experiment. Close switch S and use the EVM to measure the voltages V_1, V_2, and V_3. With the VOM, measure in turn the currents I_T, I_{L1}, I_{L2}, I_{L3}, and I_B and record both the voltage and current readings in Table 11-2.

Table 11-2

	V_1 (V)	V_2 (V)	V_3 (V)	I_{L1} (mA)	I_{L2} (mA)	I_{L3} (mA)	I_B (mA)	I_T (mA)
Required	+ 30	+ 20	+ 10	50	40	30	$\frac{10}{100} \times (50 + 40 + 30) = 12$	132
Measured								

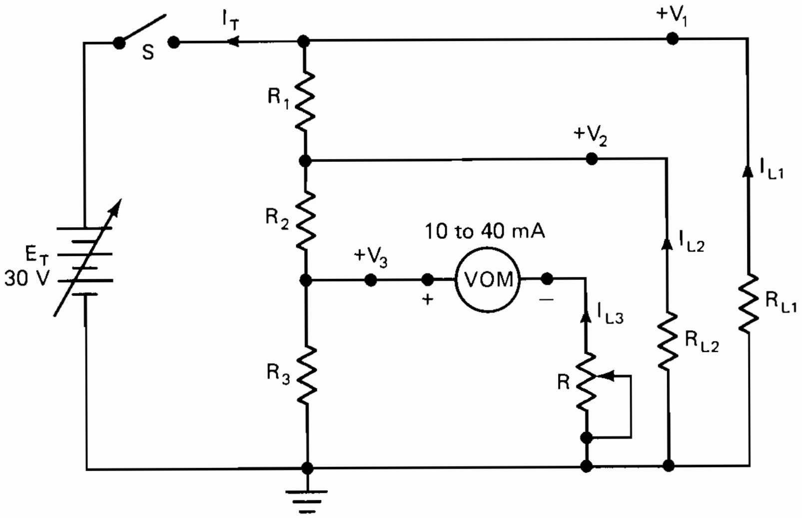


Fig. 11-2. The voltage-divider circuit with a varying load current.

Voltage Divider with Varying Load Current

4. Open switch S and remove R_{L3} so that I_{L3} is zero. Measure the values of V_1, V_2, and V_3 and record the readings in Table 11-3. Replace R_{L3} by a 1-kΩ 2-W potentiometer R, which is connected as a rheostat (Fig. 11-2) and is set at its maximum resistance value.

   Close switch S and adjust the rheostat until the reading of the VOM is $I_{L3} = 10$ mA. Use the EVM to measure the values of V_1, V_2, and V_3. Repeat the procedure for $I_{L3} = 20, 30$, and 40 mA. Record all readings in Table 11-3.

Table 11-3

I_{L3} (mA)	V_1 (V)	V_2 (V)	V_3 (V)
0			
10			
20			
30			
40			

QUESTIONS

1. How did you determine the wattage ratings to use in step 2?
2. How did the required and measured values compare in Table 11-2? Explain any significant differences.
3. In Fig. 11-1, assume that the value of I_{L1} is increased to 60 mA and that E_T is maintained at 30 V. What changes would occur in the values of V_2 and V_3?
4. If the loaded voltage-divider circuit of Fig. 11-1 were to be operated from a 50-V source, what would be the value of the required series dropping resistor and its power dissipation? In this calculation use the *measured* value of I_T.
5. In Fig. 11-1, calculate the values of V_1, V_2, and V_3 if the loads R_{L1}, R_{L2}, and R_{L3} are removed to create an unloaded divider circuit. Verify your answers experimentally.
6. The load R_{L2} open-circuits in Fig. 11-1. What would be the new values of V_2 and V_3? Verify your answers experimentally.
7. If the load R_{L3} short-circuits in Fig. 11-1, what would be the new values of V_2 and V_3?

8. In Fig. 11-1, what would be the resistance measurements between (a) point *A* and ground (b) point *B* and ground and (c) point *C* and ground? Open switch *S* and verify your answers experimentally.
9. In Fig. 11-2, what happened to the voltages V_2 and V_3 as the load current I_{L3} was increased from 0 to 40 mA by adjusting the value of *R*? Explain your answer.
10. In Fig. 11-2, what happened to the bleeder current I_B as the load current I_{L3} was increased? Explain your answer.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 12

Series-Parallel Resistor Network

READING ASSIGNMENT

Modern Electronics: A First Course, pages 237–257

Topic: E, I, P, and R Relationships in Series–Parallel Resistor Networks

OBJECTIVES OF EXPERIMENT

1. To determine experimentally the total resistance of a series-parallel resistor network
2. To examine experimentally the voltage, current, and power relationships that exist in a series-parallel network

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0-30 V
2. Resistors: $\frac{1}{2}$ W, 10%, 1.0 kΩ, 1.5 kΩ, 1.8 kΩ, 2.2 kΩ, 3.3 kΩ, 4.7 kΩ
3. Meters: EVM; VOM
4. Double-pole single-throw (DPST) switch

PROCEDURE

1. Measure the values of all the resistors with the EVM and use only the *measured* values in your calculations.

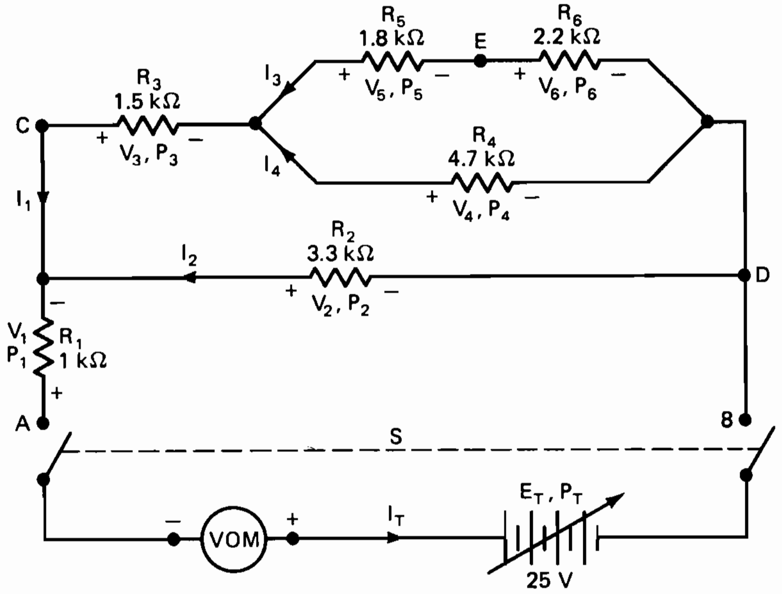


Fig. 12-1. Series-parallel resistor network.

Total Resistance of a Series-Parallel Resistor Network

2. Connect the circuit of Fig. 12-1. Assuming that switch S is open, calculate the value of the total equivalent resistance R_T between points A and B. Enter this result in Table 12-1.
3. With switch S open, use the EVM as an ohmmeter to measure the total resistance R_T between points A and B. Record this reading in Table 12-1.

Table 12-1

R_T *Calculated* (kΩ)	R_T (EVM) (kΩ)	I_T (mA)	$R_T = E_T/I_T$ (kΩ)

4. Use the EVM to adjust the output of the variable power supply to $E_T = 25$ V and maintain this value throughout the experiment. Close switch S and use the VOM to measure the value of I_T which is entered in Table 12-1. Compute the value of R_T from the relationship $R_T = E_T/I_T$ and enter this result in Table 12-1.

Voltage and Current Measurements

5. Assuming that switch S is closed, calculate the values of I_1, I_2, I_3, I_4, V_1, V_2, V_3, V_4, V_5, and V_6. Enter your calculated results in Table 12-2.
6. Close switch S and use the VOM to measure *in turn* the currents I_1, I_2, I_3, and I_4. With the EVM measure the voltages V_1, V_2, V_3, V_4, V_5, and V_6. Record all these readings in Table 12-2.

Table 12-2

	I_1 (mA)	I_2 (mA)	I_3 (mA)	I_4 (mA)	V_1 (V)	V_2 (V)	V_3 (V)	V_4 (V)	V_5 (V)	V_6 (V)
Calculated										
Measured										

Power Relationships

7. From the results of step 6, calculate the individual powers dissipated in the resistors; for each resistor multiply its voltage drop by the current flowing through the resistor and enter the results in Table 12-3. Add together the individual powers to obtain the total power dissipated. Calculate the total power P_T drawn from the source by using the equation $P_T = E_T \times I_T$. Use these results to complete Table 12-3.

Table 12-3

$P_1 = I_T V_1$ (mW)	$P_2 = I_2 V_2$ (mW)	$P_3 = I_1 V_3$ (mW)	$P_4 = I_4 V_4$ (mW)	$P_5 = I_3 V_5$ (mW)	$P_6 = I_3 V_6$ (mW)	$P_T = P_1 + P_2 + P_3 + P_4 + P_5 + P_6$ (mW)	$P_T = E_T I_T$ (mW)

QUESTIONS

1. In Table 12-1, how did the three R_T values compare? Explain any significant differences.
2. Looking at the results of Table 12-2, what single voltage is equal to $V_1 + V_2$? Explain your answer.
3. What single voltage equals in value (a) $V_3 + V_5 + V_6$; (b) $V_1 + V_3 + V_4$?
4. What single current equals in value $I_2 + I_3 + I_4$?
5. What is the *algebraic* sum of the voltages V_2, V_3, V_5, and V_6? Explain your answer.
6. In Fig. 12-1, an open circuit occurs at point *E*. What is the new calculated value of R_T? Verify your answer experimentally.
7. In Fig. 12-1, points *C* and *D* are joined by a connecting wire (short circuit). What is the new value of R_T? Verify your answer experimentally.
8. How did the value of $P_T = E_T \times I_T$ compare with the value of $P_1 + P_2 + P_3 + P_4 + P_5 + P_6$? Did the power dissipation in any one of the resistors exceed its wattage rating?
9. If an additional 1.2-kΩ resistor is connected between points *A* and *B* in Fig. 12-1, what are the new values of the total resistance R_T, the total current I_T, and the total power P_T? Verify your answers experimentally.

Note: Question 10 should be regarded as an advanced problem.

10. In Fig. 12-1, points *C* and *E* are joined by a connecting wire (short circuit). What is the new calculated value of R_T? Verify your answer experimentally.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 13

The Wheatstone Bridge

READING ASSIGNMENT

Modern Electronics: A First Course, pages 177–180

Topic: The Wheatstone Bridge and the Accurate Measurement of Resistance

OBJECTIVE OF EXPERIMENT

To use the principle of the balanced Wheatstone Bridge to measure a wide range of unknown resistances

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0–30 V
2. Resistors: $\frac{1}{2}$ W, 5%, two 10 kΩ, one 1 kΩ; $\frac{1}{2}$ W, 20%, 470Ω, 680Ω, 3.3 kΩ, 4.7 kΩ, 6.8 kΩ, 47 kΩ, 68 kΩ
   Decade resistor box
3. Meters: EVM; VOM: 20,000-Ω/V sensitivity
4. Two single-pole single-throw (SPST) switches

PROCEDURE

Using the Wheatstone Bridge to Measure Resistance

1. Use the EVM to measure the values of a number of 5% tolerance resistors and find two resistors whose values are each 10 kΩ and a third resistor whose value is 1 kΩ (within the limits of measurement).

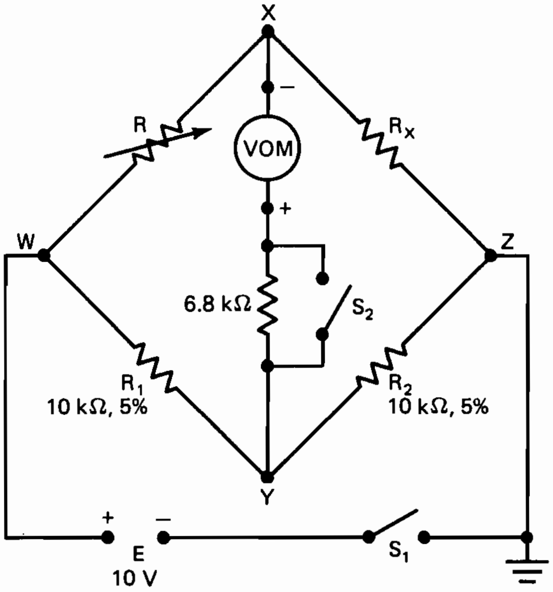


Fig. 13-1. The Wheatstone bridge experiment.

2. Construct the circuit of Fig. 13-1 (R_X is the 20% tolerance 3.3-kΩ resistor) and leave open both switches S_1 and S_2. The purpose of the 6.8-kΩ resistor is to protect initially the VOM, which should be switched to the 0-50 μA range.
3. Use your EVM to set the value of E at 10 V and maintain this value throughout the experiment. Set the decade resistance box R to 10 kΩ; then close switch S_1 but leave switch S_2 open. Since the bridge is unbalanced, the VOM will indicate an upscale deflection.
4. Reduce the resistance of the decade box R in small steps until the reading of the VOM is nearly at the zero mark. Then close S_2 and adjust the value of R until the reading of the VOM is actually zero. The bridge is now balanced, so that

$$R_X = R \times \frac{R_2}{R_1} = R \times \frac{10\ \text{k}\Omega}{10\ \text{k}\Omega} = R$$

   From the reading R of the decade resistance box, enter the value of R_X in Table 13-1. Open switches S_1 and S_2, remove the 3.3-kΩ resistor, and use the EVM to measure its resistance; record this reading in Table 13-1. Repreat the entire procedure by using the 20% tolerance 4.7-kΩ resistor to represent the unknown resistance, R_X.

Table 13-1

Method of Measurement	R_X (3.3 kΩ, 20%)	R_X (4.7 kΩ, 20%)	R_X (47 kΩ, 20%)	R_X (68 kΩ, 20%)	R_X (470 Ω, 20%)	R_X (680 Ω, 20%)
Wheatstone bridge						
EVM						
Calculated permitted upper and lower limits of resistance						

5. With switches S_1 and S_2 open, remove the 10-kΩ resistor (R_1) and replace it by the 5% 1-kΩ resistor. Use the 20% 47-kΩ resistor as the unknown resistance R_X. Repeat steps 3 and 4. When the bridge is balanced,

$$R_X = R \times \frac{R_2}{R_1} = R \times \frac{10\text{ k}\Omega}{1\text{ k}\Omega} = 10 \times R$$

From this equation and the reading R of the resistance decade box, enter the value of R_X in Table 13-1. Open switches S_1 and S_2, remove the 20%, 47-kΩ resistor, and measure its resistance with the EVM; record the reading in Table 13-1. Repeat the entire procedure by using the 20%, 68-kΩ resistor to represent the unknown resistance R_X.

6. With switches S_1 and S_2 open, remove the 5%, 1-kΩ resistor (R_1) and replace it by the 5%, 10-kΩ resistor. Remove the 5%, 1-kΩ resistor (R_2) and replace it by the 5%, 1-kΩ resistor. Use the 20%, 470-Ω resistor as the unknown resistance R_X. Repeat steps 3 and 4. When the bridge is balanced,

$$R_X = R \times \frac{R_2}{R_1} = R \times \frac{1\text{ k}\Omega}{10\text{ k}\Omega} = \frac{R}{10}$$

Using this equation and the reading R of the decade resistance box, enter the value of R_X in Table 13-1. Repeat the entire procedure by using the 20%, 680-Ω resistor as the unknown resistance R_X.

7. Calculate the upper and lower resistance limits for each of the 20% resistors used to represent R_X. Enter the results of your calculations in Table 13-1.

QUESTIONS

1. When the bridge is balanced, what is the relationship between the potentials at points X and Y (Fig. 13-1) with respect to ground?
2. Why was the VOM switched to the 0–50 μA range when balancing the bridge?
3. What resistance values would you use for a Wheatstone bridge that is capable of accurately measuring unknown resistances of less than 1 Ω? Draw the schematic diagram of such a bridge.
4. What resistance values would you use for a Wheatstone bridge that is capable of accurately measuring unknown resistances of more than 100 kΩ. Draw the schematic diagram of such a bridge.
5. What is the major factor in determining the measurement accuracy in the Wheatstone bridge experiment?
6. If the voltage level E were maintained at 12 V rather than 10 V, would this affect the measured values of the unknown resistances?
7. If $R_1 : R_2 = 100$, as opposed to $R_1 : R_2 = 1$, is the error of measurement greater or less?
8. Does the Wheatstone bridge or the EVM provide the more accurate measurement of the unknown resistances?
9. Are any of the measured unknown resistances outside their tolerance limits?
10. Why was it not necessary to reverse the leads of the VOM during the experiment?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 14

Internal Resistance of a Voltage Source; Maximum Power Transfer

READING ASSIGNMENT

Modern Electronics: A First Course, pages 195–214

Topics: Internal Resistance; Matching; Maximum Power Transfer; Circuit Efficiency

OBJECTIVES OF EXPERIMENT

1. To measure the internal resistance of a cell
2. To verify the condition for maximum dc power transfer to a resistive load

COMPONENTS AND EQUIPMENT REQUIRED

1. 6-V (lighting) primary cell (Eveready 510S or equivalent)
   Variable regulated dc power supply, 0–30 V
2. Resistors: 5 Ω, 10 W; 10 Ω, 5 W; 2 kΩ, $\frac{1}{2}$ W, 5%
   Potentiometer: 10 kΩ, 2 W
3. Meters: EVM; VOM
4. One single-pole double-throw (SPDT) switch; one double-pole single-throw (DPST) switch

PROCEDURE

Determination of a Cell's Internal Resistance

1. Construct the circuit of Fig. 14-1 with the VOM connected to read the current through the 5-Ω resistor. When switch S is open, measure the open-circuit voltage with the EVM. This is the cell's EMF, E, which is recorded in Table 14-1.

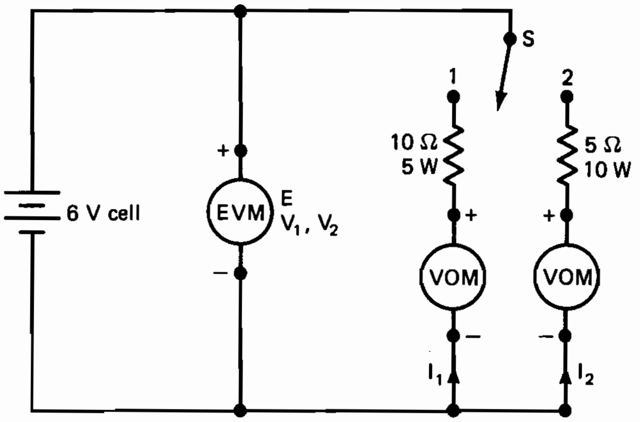


Fig. 14-1. **Determination of a cell's internal resistance.**

Table 14-1

E (V)	V_1 (V)	V_2 (V)	I_1 (mA)	I_2 (mA)	$V_2 - V_1 = \Delta V$ (V)	$I_1 - I_2 = \Delta I$ (mA)	R_{int} (Ω)
							(14-1)
							(14-2)
							(14-3)

2. *Momentarily* close switch S in position 1 and measure the current I_1 and the cell's terminal voltage V_1. Enter these readings in Table 14-1.
3. Transfer the VOM to measure the current through the 10-Ω resistor. *Momentarily* close switch S in position 2 and measure the values of I_2 and V_2, which are then entered in Table 14-1.
4. Using the data of Table 14-1, the cell's internal resistance R_{int} may be calculated in three possible ways:

$$R_{\text{int}} = \frac{E - V_1}{I_1} \tag{14-1}$$

$$R_{\text{int}} = \frac{E - V_2}{I_2} \tag{14-2}$$

$$R_{\text{int}} = \frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_1 - I_2} \tag{14-3}$$

Calculate the three values of R_{int} and enter the results in Table 14-1.

Condition for Maximum Power Transfer

5. Construct the circuit of Fig. 14-2. The 2-kΩ resistor is being used to simulate the internal resistance of a power supply whose output terminals are points X and Y. The potentiometer is connected as a rheostat and represents the load connected between the output terminals. The EVM measured the load voltage V_L, while the VOM records the load current I_L.
6. Set the level of E to be 20 V and maintain it at this value throughout the experiment. With switch S open, use the EVM as an ohmmeter to adjust the value of the rheostat to zero ($R_L = 0$ Ω). Then switch the EVM to a voltage range, close switch S, and measure the values of V_L and I_L. Enter these readings in Table 14-2.
7. Open switch S and use the EVM as an ohmmeter to set the rheostat to 200 Ω (R_L). Then switch the EVM to a voltage range, close switch S, and again measure the values of V_L and I_L, which are recorded in Table 14-2.

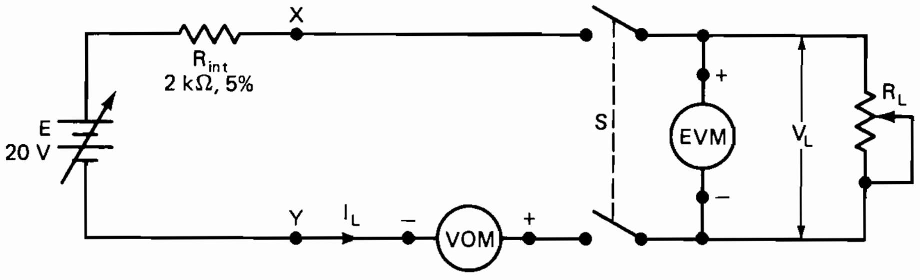


Fig. 14-2. **Verification of the maximum power transfer theorem.**

8. Repeat the procedure of step 7 for every value of R_L shown in Table 14-2. To obtain the readings for $R_L = \infty$ Ω (open circuit), the rheostat is entirely removed.
9. Using the equations $P_L = I_L \times V_L$, $P_T = I_L \times E$ (20 V), and circuit efficiency = $(P_L/P_T) \times 100\%$, calculate the load power, total power, and circuit efficiency for each value of the load resistance and enter the results in Table 14-2.
10. Plot and draw the following graphs:
    a. V_L, P_L, P_T, and circuit efficiency versus R_L
    b. V_L, P_L, P_T, and circuit efficiency versus I_L

Table 14-2

Load Resistance R_L (Ω)	*Load Voltage* V_L (V)	*Load Current* I_L (mA)	*Load Power* $P_L = V_L \times I_L$ (mW)	*Total Power* $P_T = E\,(20\ \text{V}) \times I_L$ (mW)	*Circuit Efficiency* $\frac{P_L}{P_T} \times 100\%$
Zero (short-circuit)					
200					
400					
600					
800					
1,000					
1,200					
1,400					
1,500					
1,600					
1,700					
1,800					
1,900					
2,000					
2,200					
2,400					
2,600					
2,800					
3,000					
3,500					
4,000					
6,000					
8,000					
10,000					
Infinite (∞) ohms (open-circuit)					

QUESTIONS

1. In step 1, what did you expect the measured value of E to be? Discuss your reasons.
2. Why was it necessary to close the switch *momentarily* in steps 2 and 3?
3. In step 4, did you expect the three values of R_{int} to be the same? Discuss the reasons for any differences in the calculated values.
4. Why is it important to maintain E at 20 V throughout the maximum power transfer experiment (steps 5 through 8).
5. For which value of R_L was the load power a maximum? Was this result in accordance with expectations?

In questions 6 through 10, refer to the graphs of step 10.

6. When the load power reached its maximum value, what was the value of the circuit efficiency?
7. What value of load resistance is necessary in order to achieve (a) a high circuit efficiency; (b) a high value of load voltage?
8. How did the total power P_T vary with the load current I_L?
9. Under the condition for maximum power transfer, how was the value of V_L related to the value of E? What was then the relationship between the load current I_L and the short-circuit current ($R_L = 0\ \Omega$)?
10. How does the load voltage V_L change as (a) the load current I_L is increased; (b) the load resistance R_L is increased?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 15

Kirchhoff's Voltage and Current Laws; The Superposition Theorem

READING ASSIGNMENT

Modern Electronics: A First Course, pages 231-236, 244-249

Topics: Kirchhoff's Law; The Superposition Thereom

OBJECTIVES OF EXPERIMENT

1. To verify experimentally Kirchhoff's voltage and current laws in a circuit containing two voltage sources
2. To verify experimentally the superposition theorem in the same circuit as used in objective 1

COMPONENTS AND EQUIPMENT REQUIRED

1. Two variable regulated dc power supplies, 0-30 V
2. Resistors: $\frac{1}{2}$ W, 10%, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, 8.2 kΩ, two 10 kΩ
3. Meters: EVM; VOM
4. Double-pole single-throw (DPST) switch

PROCEDURE

1. Measure the values of all the 10% resistors with the EVM and use only the *measured* values in your calculations.

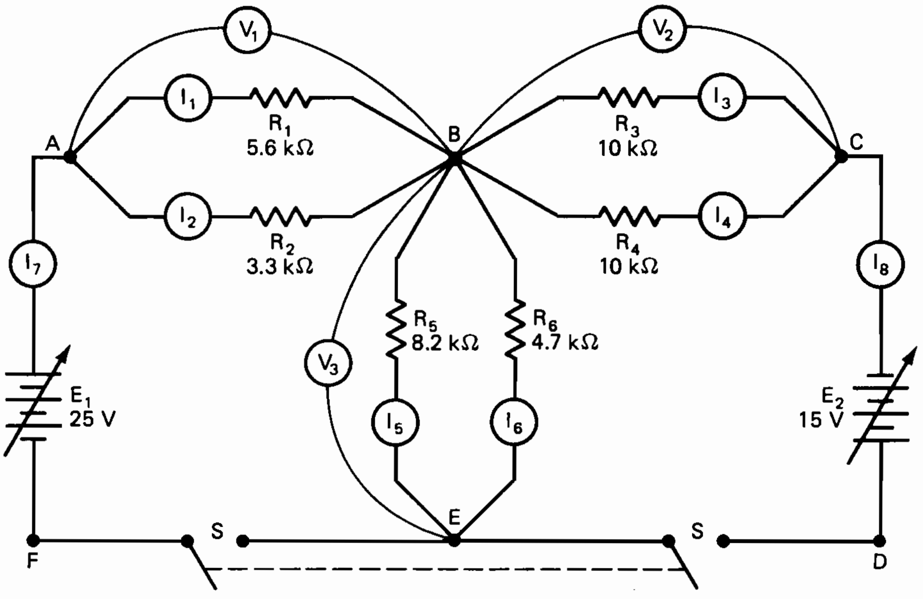


Fig. 15-1. Circuit for analysis by Kirchhoff's Laws and the Superposition Theorem.

Experimental Verification of Kirchhoff's Voltage and Current Laws

2. Connect the circuit of Fig. 15-1. Assuming that switch S is closed, use Kirchhoff's voltage and current laws to calculate the values of $I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8$, V_1, V_2, and V_3. Carefully determine the directions of the currents (electron flow) and the polarities of the voltages. Enter your calculated results in Table 15-1.

Table 15-1

	I_1 (mA)	I_2 (mA)	I_3 (mA)	I_4 (mA)	I_5 (mA)	I_6 (mA)	I_7 (mA)	I_8 (mA)	V_1 (V)	V_2 (V)	V_3 (V)
Calculated											
Measured											

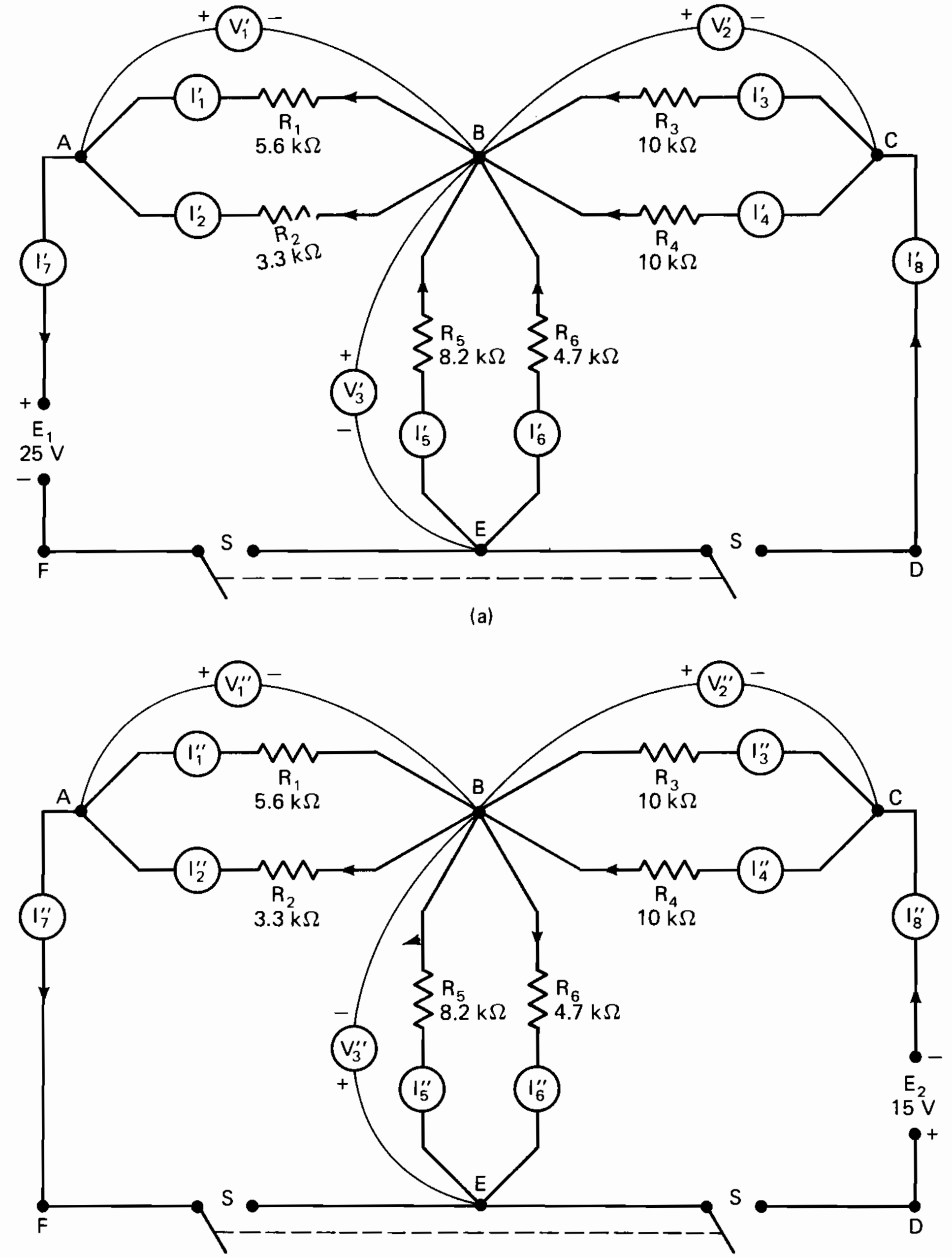
3. Use the EVM to set $E_1 = 25$ V and $E_2 = 15$ V and maintain these values throughout the experiment. Close switch S. By inserting the VOM into the circuit at the various positions, measure *in turn* the currents $I_1, I_2, I_3, I_4, I_5, I_6, I_7$, and I_8. With the EVM measure the voltages V_1, V_2, and V_3. Record all measured readings in Table 15-1 and, by using the *measured* values only, complete Table 15-2.

Table 15-2

$I_1 + I_2$ (mA)	$I_3 + I_4 + I_5 + I_6$ (mA)	$I_3 + I_4$ (mA)	$V_1 + V_3$ (V)	$V_2 - V_3$ (V)

Experimental Verification of the Superposition Theorem

4. Open switch S, switch off the 15-V source, and join a connecting lead (short circuit) between its terminals. The resulting circuit is shown in Fig. 15-2(a). Assuming that switch S is closed, calculate the values of I'_1, $I'_2, I'_3, I'_4, I'_5, I'_6, I'_7, I'_8$, V'_1, V'_2, and V'_3 and enter these results in Table 15-3.



(a)

(b)

Fig. 15-2. Equivalent circuits for the Superposition Theorem.

5. Close switch S and use the EVM to measure the values of V_1', V_2', and V_3'. By inserting the VOM into the circuit at the various positions, measure in turn the currents I_1', I_2', I_3', I_4', I_5', I_6', I_7', and I_8'. Record all the measured readings in Table 15-3. Observe carefully the directions of the currents and the polarities of the voltages in Fig. 15-2(a).
6. Open switch S and remove the connecting lead from the 15-V source. Switch on the 15-V source and use the EVM to check its output voltage. Switch off the 25-V source and join a connecting lead (short circuit) across the terminals. The circuit is now as shown in Fig. 15-2(b). Assuming that switch S is closed, calculate the values of I_1'', I_2'', I_3'', I_4'', I_5'', I_6'', I_7'', I_8'', V_1'', V_2'', and V_3'' and enter these results in Table 15-3. Observe carefully the directions of the currents and the polarities of the voltages in Fig. 15-2(b).
7. Close switch S and use the EVM to measure the values of V_1'', V_2'', and V_3''. By inserting the VOM into the circuit at the various positions, measure in turn the currents I_1'', I_2'', I_3'', I_4'', I_5'', I_6'', I_7'', and I_8''. Record all the measured readings in Table 15-3.

Table 15-3

15-V Source Shorted	I_1' (mA)	I_2' (mA)	I_3' (mA)	I_4' (mA)	I_5' (mA)	I_6' (mA)	I_7' (mA)	I_8' (mA)	V_1' (V)	V_2' (V)	V_3' (V)
Calculated											
Measured											
25-V Source Shorted	I_1'' (mA)	I_2'' (mA)	I_3'' (mA)	I_4'' (mA)	I_5'' (mA)	I_6'' (mA)	I_7'' (mA)	I_8'' (mA)	V_1'' (V)	V_2'' (V)	V_3'' (V)
Calculated											
Measured											
Result of Superposition	I_1 (mA)	I_2 (mA)	I_3 (mA)	I_4 (mA)	I_5 (mA)	I_6 (mA)	I_7 (mA)	I_8 (mA)	V_1 (V)	V_2 (V)	V_3 (V)
Calculated											
Measured											

8. Superimpose the results of the two circuits [Figs. 15-2(a) and (b)] by computing the ***algebraic*** sums of the corresponding currents and the corresponding voltages (e.g., $I_3 = I_3' + I_3''$ but $V_3 = V_3' - V_3''$). Enter the results in Table 15-3.

QUESTIONS

Note: Questions 1 through 4 relate to the data shown in Tables 15-1 and 15-2.

1. What are the relationships between the currents (a) I_1, I_2, and I_7 (point *A*); (b) I_3, I_4, and I_8 (point *C*); (c) I_5, I_6, I_7, and I_8 (point *E*)? Show these relationships with the aid of equations. How closely do the measured values satisfy these relationships?
2. What is the relationship between the currents I_1, I_2, I_3, I_4, I_5, and I_6 (point *B*)? Use an equation to show the relationship. How closely do the measure values satisfy this relationship?
3. What are the Kirchhoff's voltage law relationships for loops *ABEFA*, *BCDEB*, and *ABCDEFA*? Use equations to show the relationships. How closely do the measured values satisfy these relationships?
4. To what voltages are (a) $V_1 + V_3$ and (b) $V_2 - V_3$ equal? Explain your answers carefully.
5. If the polarity of the 15-V source is reversed, what are the new calculated values of I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8, V_1, V_2, and V_3? (Use Kirchhoff's voltage and current laws in your solution.)
6. Did the use of Kirchhoff's laws or the superposition theorem provide the simpler method in the circuit analysis (Fig. 15-1)? Give your reasons.
7. How did the superimposed values of Table 15-3 compare with the measured values of Table 15-1? Look carefully at any significant differences for possible errors.

Note: Questions 8, 9, and 10 should be regarded as advanced problems.

8. How would you use Thévenin's theorem (*Modern Electronics: A First Course,* pages 249–257) to obtain the value of the voltage V_{BE} in Fig. 15-1? Carry out the analysis and compare your answer with the values of V_3 in Tables 15-1 and 15-3.
9. How would you use (a) nodal analysis and (b) Millman's theorem (*Modern Electronics: A First Course,* pages 240–244) to obtain the value of the voltage V_{BE} in Fig. 15-1? Carry out the analysis and compare your answers with the values of V_3 in Tables 15-1 and 15-3.
10. How would you use Norton's theorem (*Modern Electronics: A First Course,* pages 258–263) to obtain the voltage V_{BE} in Fig. 15-1? Carry out the analysis and compare your answers with the values of V_3 in Tables 15-1 and 15-3.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 16

Thévenin's Theorem

READING ASSIGNMENT

Modern Electronics: A First Course, pages 249–257

Topic: Application of Thévenin's Theorem to Network Analysis

OBJECTIVES OF EXPERIMENT

1. To Thévenize a series-parallel network
2. To Thévenize an unbalanced bridge network

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0–30 V
2. Resistors $\frac{1}{2}$ W, 10%, 1.2 kΩ, 1.8 kΩ, 2.2 kΩ, 2.7 kΩ, 3.3 kΩ, 3.9 kΩ, 4.7 kΩ, 8.2 kΩ, 12 kΩ
   Potentiometer: 10 kΩ, 2 W
3. Meters: EVM; VOM
4. Single-pole, single-throw (SPST) switch
5. Decade resistance box (optional)

PROCEDURE

1. Measure the values of all the resistors with the EVM and use only the *measured* values in your calculations

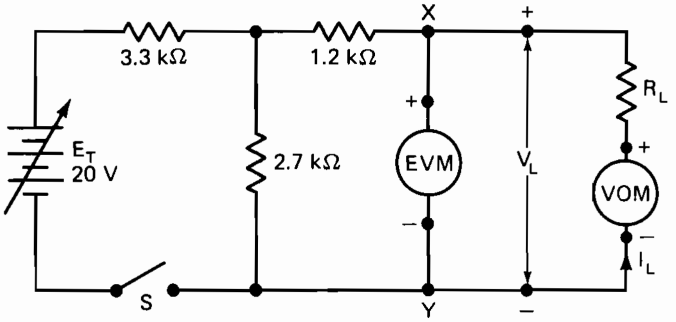


Fig. 16-1. Thévenizing a series-parallel circuit.

Thévenizing a Series-Parallel Circuit

2. Construct the circuit of Fig. 16-1. If the load R_L is equal to 2.2 kΩ, use Ohm's law and/or the voltage-division rule to calculate the values of the load voltage V_L and the load current I_L. If the value of R_L is changed to 3.9 kΩ, calculate the new values of V_L and I_L. Enter your results in Table 16-1.

Table 16-1

Load Resistance R_L (kΩ)	*Calculated Load Voltage* V_L (V)	*Calculated Load Current* I_L (mA)	*Measured* V_L (V)	*Measured* I_L (mA)
2.2				
3.9				

3. Use the EVM to set E_T = 20 V and maintain this value throughout the experiment. Connect the 2.2-kΩ load between points X and Y, and close switch S. Use the EVM to measure the value of V_L and the VOM to measure the value of I_L. Repeat the procedure for R_L = 3.9 kΩ and record all the readings in Table 16-1.
4. Assuming that R_L is disconnected in Fig. 16-1, calculate the value of the Thévenin voltage E_{TH}, which is the open-circuit voltage between points X and Y. By regarding the variable power supply as shorted out, calculate the value of the Thévenin resistance R_{TH} between X and Y. Using the Thévenin equivalent circuit (Fig. 16-2), compute the values of V_L and I_L for the 2.2-kΩ and 3.9-kΩ load resistances. Enter all these results in Table 16-2.
5. Open switch S and remove R_L from the circuit of Fig. 16-1. Close switch S and use your EVM to measure E_{TH} between points X and Y. Then switch off the power supply and join a connecting lead (short circuit) across the power supply's terminals. Close switch S and use your EVM to measure the Thévenin resistance R_{TH} between points X and Y. Record the readings of E_{TH} and R_{TH} in Table 16-2.

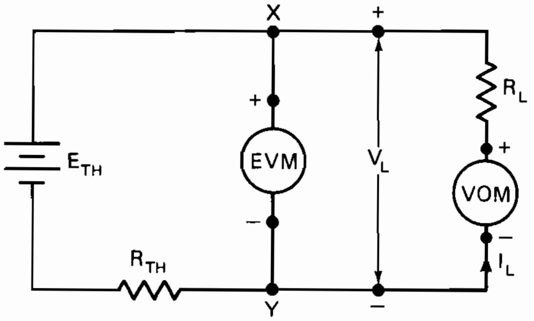


Fig. 16-2. The equivalent Thévenin circuit.

Table 16-2

Load Resistance R_L (kΩ)	*Calculated* E_{TH} (V)	*Measured* E_{TH} (V)	*Calculated* R_{TH} (kΩ)	*Measured* R_{TH} (kΩ)	*Matched Load* R_{TH} (kΩ)	*Measured* V_L (V)	*Measured* I_L (mA)
2.2							
3.9							

6. An alternative method of finding R_{TH} is to use a matched load. Operate the 10-kΩ potentiometer as a rheostat which is connected between points X and Y (R_L is removed). Connect the EVM between X and Y and adjust the rheostat until the reading of the EVM is half of the measured E_{TH} voltage. Remove the rheostat and measure its resistance, which is equal in value to R_{TH}. Enter this result in Table 16-2.
7. Construct the Thévenin equivalent circuit (Fig. 16-2) with $R_L = 2.2$ kΩ connected between points X and Y. Use the EVM to set the output of the variable power supply so that it equals the ***measured*** value of E_{TH}. Set the ***measured*** value of R_{TH} on a decade resistance box or the potentiometer. Measure the values of V_L and I_L. Remove the 2.2-kΩ load resistance and repeat the procedure for $R_L = 3.9$ kΩ. Enter the readings of V_L and I_L in Table 16-2.

Thévenizing an Unbalanced Bridge Circuit

8. Construct the circuit of Fig. 16-3. The 1.8-kΩ resistor is regarded as the load that is connected between points X and Y. ***Calculate*** the values of E_{TH} and R_{TH} between X and Y and then use the Thévenin equivalent circuit, with R_L replaced, to compute the values of V_L and I_L; enter these results in Table 16-3.

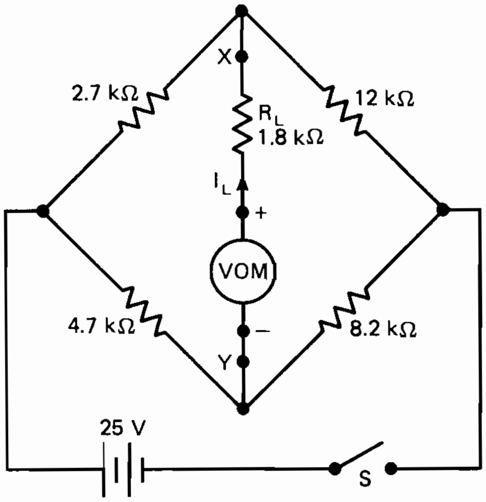


Fig. 16-3. The unbalanced bridge circuit.

9. Close switch S and use the EVM to adjust the variable power supply to 25 V; maintain this value throughout the experiment. Then measure the value of V_L with the EVM and the value of I_L with the VOM. Record these readings in Table 16-3. Open switch S.
10. Remove R_L from the circuit, close switch S, and then use the EVM to measure E_{TH} between points X and Y. Switch off the power supply and join a connecting lead (short circuit) between its terminals. Use the EVM as an ohmmeter to measure the value of R_{TH}. Record the readings of E_{TH} and R_{TH} in Table 16-3.
11. Construct the Thévenin equivalent circuit of the unbalanced bridge (Fig. 16-2). Use the EVM to set the output of the variable power supply so that it equals the measured value of E_{TH}. Set the measured

Table 16-3

Load Resistance R_L (kΩ)	*Calculated* E_{TH} (V)	*Calculated* R_{TH} (kΩ)	*Measured* V_L *Bridge Circuit* (V)	*Measured* I_L *Bridge Circuit* (mA)	*Measured* E_{TH} (V)	*Measured* R_{TH} (kΩ)	*Measured* V_L *Thévenin Circuit* (V)	*Measured* I_L *Thévenin Circuit* mA)
1.8								

value of the R_{TH} on the decade resistance box or the potentiometer and measure the values of V_L and I_L. Record these readings in Table 16-3.

QUESTIONS

1. Compare the analyses of the series-parallel circuit by Thévenin's theorem and by Ohm's law and/or the voltage-division rule. Which method is simpler?
2. How did the values of V_L and I_L measured in the original series-parallel circuit compare with the values obtained from the equivalent Thévenin circuit? Discuss any differences.
3. In the measurement of R_{TH}, the power supply was switched off and a short circuit was connected between its terminals. What factor was ignored in this application of Thévenin's theorem? Was the approximation justified?
4. How was the value of R_{TH} determined by the matched load method? Describe the principle behind this method.
5. Compare the analyses of the unbalanced bridge circuit by Thévenin's theorem and by the use of mesh currents. Which method is simpler?
6. How did the values of V_L and I_L measured in the original bridge network compare with the values obtained from the equivalent Thévenin circuit? Discuss any differences.
7. Have the experiments that you have conducted "proven" or "verified" Thévenin's theorem? Explain your answer.
8. Under what circumstances is it advantageous to use Thévenin's theorem in the analysis of a dc circuit?

Note: Questions 9 and 10 should be regarded as advanced problems.

9. In Fig. 16-3, regard the 2.7-kΩ resistor as the load. What are the calculated values of E_{TH} and R_{TH}? What is the calculated voltage drop across the 2.7-kΩ resistor?
10. From the results of Question 9 and step 8, what are the voltage drops across the 4.7-kΩ, 8.2-kΩ, and 12-kΩ resistors?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 17

Norton's Theorem

READING ASSIGNMENT

Modern Electronics: A First Course, pages 258–263

Topic: Application of Norton's Theorem to Network Analysis

OBJECTIVES OF EXPERIMENT

1. To Nortonize a series-parallel circuit
2. To Nortonize an unbalanced bridge circuit

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0-30V
2. Resistors $\frac{1}{2}$ W, 10%, 1.2 kΩ, 1.5 kΩ, 1.8 kΩ, 2.2 kΩ, 2.7 kΩ, 3.3 kΩ, 3.9 kΩ, 8.2 kΩ, 12 kΩ, 18 kΩ
3. Meters: EVM; VOM
4. Single-pole single-throw (SPST) switch

PROCEDURE

1. Measure the values of all the resistors with the EVM and use only the *measured* values in your calculations.

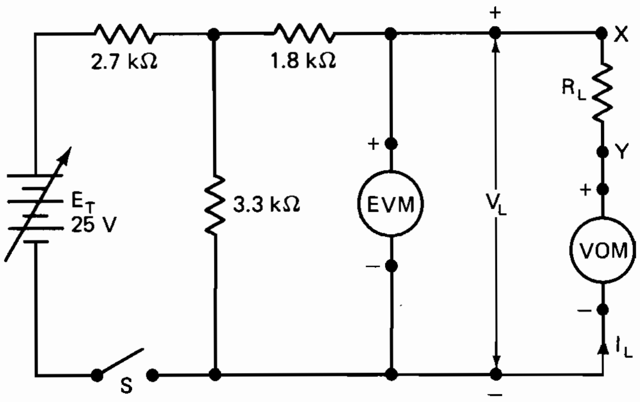


Fig. 17-1. Nortonizing a series-parallel circuit.

Nortonizing a Series-Parallel Circuit

2. Construct the circuit of Fig. 17-1. If the load R_L is equal to 1.2 kΩ, use Ohm's Law principles and the current-division rule to calculate the values of the load current I_L and the load voltage V_L. If the value of R_L is changed to 2.2 kΩ, calculate the new values of I_L and V_L. Enter your results in Table 17-1.

Table 17-1

Load Resistance R_L (kΩ)	*Calculated Load Current* I_L (mA)	*Calculated Load Voltage* V_L (V)	*Measured* I_L (mA)	*Measured* V_L (V)
1.2				
2.2				

3. Use the EVM to set $E_T = 25$ V and maintain this value throughout the experiment. Connect the 1.2-kΩ load between points X and Y and then close switch S. Use the VOM to measure the value of I_L and the EVM to measure the value of V_L. Repeat the procedure for $R_L = 2.2$ kΩ and record all the readings in Table 17-1.
4. Assume that R_L is replaced by a short circuit. Calculate the value of the short-circuit Norton current I_N between points X and Y. After taking away the short circuit which replaced R_L, and then shorting out the variable power supply, calculate the value of the Norton resistance R_N between X and Y. By using the Norton equivalent circuit of Fig. 17-2, compute the values of I_L and V_L for the 1.2-kΩ and 2.2-kΩ load resistances. Enter all your computed values in Table 17-2.
5. Open switch S and remove R_L from the circuit of Fig. 17-1. Join a connecting lead (short circuit) between points X and Y and then close switch S. Use the VOM to measure the Norton current I_N. Open switch S and remove the short circuit between X and Y. Switch off the power supply and join a con-

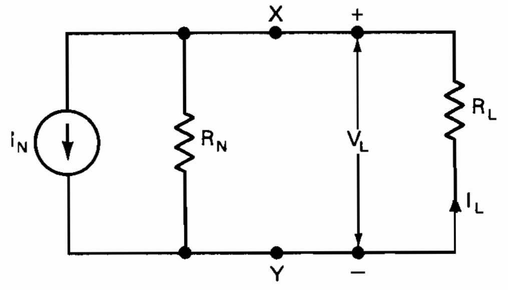


Fig. 17-2. The equivalent Norton circuit.

Table 17-2

Load Resistance R_L (kΩ)	*Calculated* I_N (mA)	*Measured* I_N (mA)	*Calculated* R_N (kΩ)	*Measured* R_N (kΩ)	*Measured* I_L (mA)	*Measured* V_L (V)
1.2						
2.2						

necting lead across its terminals. Close switch S and use the EVM to measure the Norton resistance R_N between points X and Y. Record the readings of I_N and R_N in Table 17-2.

6. Construct the Norton equivalent circuit (Fig. 17-3) with R_L = 1.2 kΩ connected between points X and Y. Operate the potentiometer as a rheostat and use the EVM as an ohmmeter to set the rheostat's resistance to equal the *measured* value of R_N. Switch on the power supply and adjust its output until the reading of the VOM is equal to the *measured* value of I_N. Move the position of the VOM to measure I_L and use the EVM to measure V_L. Repeat the procedure for R_L = 2.2 kΩ and enter the two sets of I_L, V_L readings in Table 17-2.

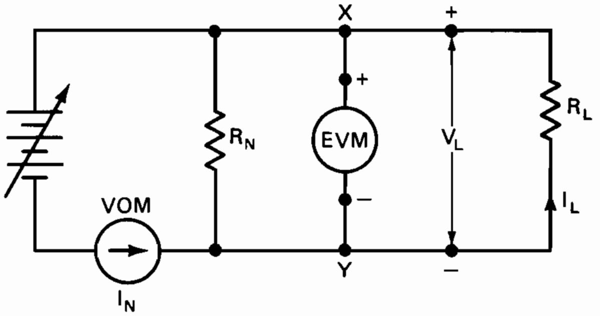


Fig. 17-3. The constructed equivalent Norton circuit.

Nortonizing an Unbalanced Bridge Circuit

7. Construct the circuit of Fig. 17-4. The 1.5-kΩ resistor is regarded as the load that is connected between points X and Y. Calculate the values of I_N and R_N for the equivalent Norton circuit (Fig. 17-3). From the equivalent circuit, compute the values of I_L and V_L. Enter all your calculated results in Table 17-3.

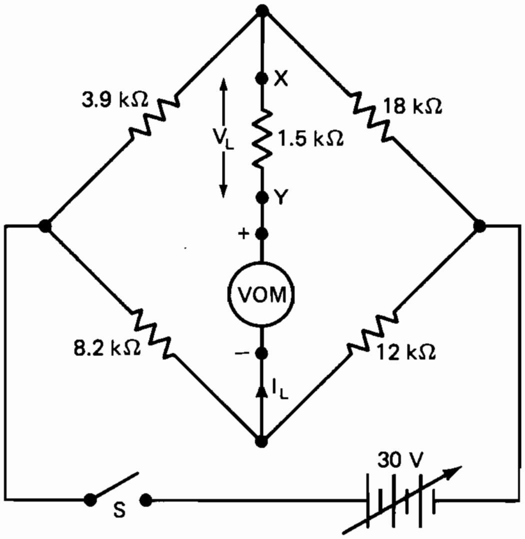


Fig. 17-4. The unbalanced bridge circuit.

Table 17-3

Load Resistance R_L (kΩ)	*Calculated* I_N (mA)	*Calculated* R_N (kΩ)	*Measured* I_L *Bridge Circuit* (mA)	*Measured* V_L *Bridge Circuit* (V)	*Measured* I_N (mA)	*Measured* R_N (kΩ)	*Measured* I_L *Norton Circuit* (mA)	*Measured* V_L *Norton Circuit* (V)
1.5								

8. Close switch S and use the EVM to adjust the output of the variable power supply to 30 V; maintain this value throughout the experiment. Then measure the value of I_L with the VOM and the value of V_L with the EVM. Record these readings in Table 17-3.
9. Open switch S, remove R_L from the circuit, and join a connecting lead (short circuit) between points X and Y. Close switch S and measure the Norton current I_N. Open switch S and remove the connecting lead between X and Y. Switch off the power supply and join the connecting lead across its terminals. Close switch S and use the EVM as an ohmmeter to measure R_N. Record the readings of I_N and R_N in Table 17-3.
10. Construct the Norton equivalent circuit (Fig. 17-3) of the unbalanced bridge. Operate the potentiometer as a rheostat which is set to the *measured* value of R_N. Adjust the output of the power supply so that the VOM reading equals the *measured* value of I_N. Measure the values of I_L and V_L and record these readings in Table 17-3.

QUESTIONS

1. Compare the analysis of the series–parallel circuit by Norton's theorem with the analysis by Ohm's law and the current-division rule. Which method is simpler?
2. How did the values of I_L and V_L measured in the original series–parallel circuit compare with the values obtained from the equivalent Norton circuit? Discuss any differences.
3. In the measurement of R_N, the power supply was switched off and a short circuit was joined between its terminals. What factor was ignored in this application of Norton's theorem? Was the approximation justified?
4. Compare the analysis of the unbalanced bridge circuit by Norton's theorem with the analysis by the use of mesh currents. Which method is simpler?
5. How did the values of I_L and V_L measured in the original bridge network compare with the values obtained from the equivalent Norton circuit? Discuss any differences.
6. Have the experiments that you have conducted "proven" or "verified" Norton's theorem? Explain your answer.
7. Under what circumstances is it advantageous to use Norton's theorem in the analysis of a dc circuit?
8. Compare the analysis of the unbalanced bridge circuit by Norton's theorem and by Thévenin's theorem (Experiment 16). Did one method have any particular advantage over the other?

Note: Questions 9 and 10 should be regarded as advanced problems.

9. In Fig. 17-4, regard the 3.9-kΩ resistor as the load. What are the calculated values of I_N and R_N? What is the calculated current flowing through the 3.9-kΩ resistor?
10. From the results of Question 9 and step 7, what are the calculated currents flowing through the 8.2-kΩ, 12-kΩ, and 18-kΩ resistors? What is the total current drawn from the power supply?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 18

Testing Capacitors

READING ASSIGNMENT

Modern Electronics: A First Course, pages 398–402

Topic: Measurements and Tests with Various Types of Capacitor

OBJECTIVES OF EXPERIMENT

1. To measure with a capacitor checker the capacitance of ceramic, mica, air, oil, paper, and electrolytic capacitors
2. To measure with a capacitor checker the insulation resistance of ceramic, mica, air, oil, and paper capacitors
3. To measure with a capacitor checker the leakage current of an electrolytic capacitor and its power factor
4. To test with an EVM for open, shorted, or leaky capacitors

COMPONENTS AND EQUIPMENT REQUIRED

1. High-voltage regulated dc power supply, 0-300 V
2. Capacitors 200 pF (mica), 250 pF maximum (variable air), 0.01 μF (ceramic), 0.47 μF (paper), 1 μF (oil), and 20 μF (electrolytic) (*Note:* If these values are not readily available, comparable values may be used.)
3. Meters: EVM; VOM
4. Capacitor checker

PROCEDURE

Operating the Capacitor Checker

1. There are a variety of capacitor checkers on the market. In its simplest form a capacitor checker will measure the value of the capacitance and can also indicate whether the capacitor is open- or short-circuited. A more sophisticated version is shown in Fig. 18-1. This type of checker will not only indicate the capacitance value but will also measure the insulation resistances (associated with the dielectrics) of the mica, air, ceramic, paper, and oil-filled capacitors. In addition, the leakage current at the rated voltage and the power factor can be determined for all types of electrolytic capacitors. It is therefore essential that you become familiar with your checker's operating manual so that you know the measurement procedures and the instrument's capabilities.

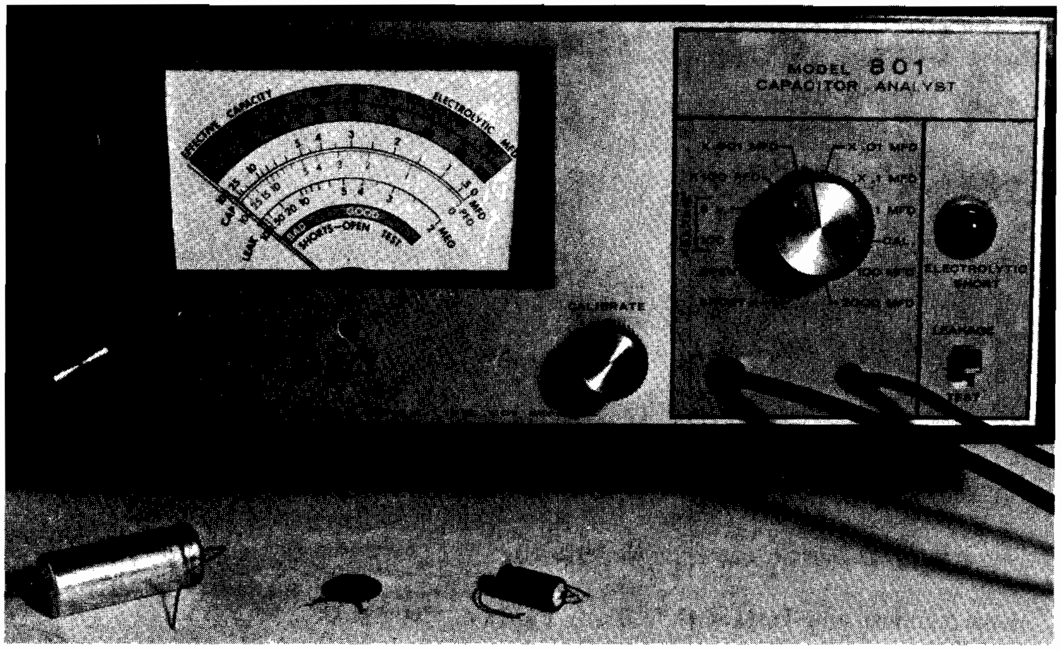


Fig. 18-1. The capacitor checker.

2. From the information available on each capacitor, enter in Table 18-1 the values of the rated capacitance *CR*, the voltage rating, and the tolerance percentage. Use your checker to measure the capacitance values C_M, and enter the readings in Table 18-1. Express the difference between C_M and C_R as a percentage of

Table 18-1

Type of Capacitor	*Rated Capacitance* C_R	*Voltage Rating* (V)	*Tolerance Percentage*	*Measured Capacitance* C_M	$\frac{C_M - C_R}{C_R} \times 100\%$	*Insulation Resistance* (MΩ)	*Leakage Current* (μA)	*Power Factor*
Mica								
Air (variable)	Min Max			Min Max				
Ceramic								
Paper								
Oil								
Electrolytic								

C_R by calculating the value of

$$\frac{C_M - C_R}{C_R} \times 100\%$$

for each capacitor. Enter your answers in Table 18-1 and compare them with the rated tolerance percentages.

3. If your checker has the capability, measure the insulation resistances of the mica, air, ceramic, and oil capacitors; such resistances are typically of the order of GΩ. Enter the readings in Table 18-1.
4. If your checker has the capability, measure the leakage current and the power factor of the electrolytic capacitor. Enter the readings in Table 18-1.

Note: When testing a capacitor in circuit, disconnect the capacitor from the ground side before using the checker.

Testing Capacitors with the EVM

5. Using the EVM as an ohmmeter, connect the leads across the paper capacitor. Notice the "capacitor effect" during the charging action as the needle moves slowly upscale to record the insulation resistance. Now reverse the leads across the capacitor; observe that the needle moves swiftly downscale and then moves relatively slowly upscale to settle at the same reading of the insulation resistance. When the ohmmeter reads zero, the capacitor is short-circuited. If the insulation resistance is low, the capacitor is excessively leaky.
6. Repeat step 5 for the mica, air, ceramic, and oil capacitors. Record the insulation resistance values in Table 18-2. Note that the insulation resistance may be so high that even if the EVM reads "∞" on the "R X 1 MEG" range, the capacitor is not necessarily open-circuited.
7. Connect the probe of the EVM to the positive terminal of the electrolytic capacitor and the common lead to the negative terminal. Measure the capacitor's leakage resistance and record the reading in Table 18-2.

Table 18-2

Type of Capacitor	*EVM Measurement Insulation Resistance* (MΩ)
Mica	
Air (variable)	
Ceramic	
Oil	
	Leakage Resistance
Electrolytic	

8. Connect the circuit of Fig. 18-2, in which C is the mica capacitor. Adjust the output of the power supply so that E is equal to the capacitor's voltage rating (set E at its highest reading if the voltage rating exceeds 300 V). Close switch S and record the voltage reading V of the EVM in Table 18-3. Since the applied

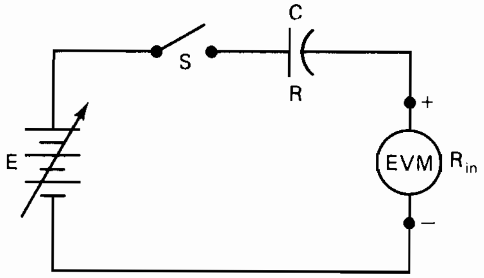


Fig. 18-2. Using the EVM to measure a capacitor's insulation resistance.

Table 18-3

Type of Capacitor	*EVM Voltage Reading* (V)	R $\left(= R_{\text{in}} \times \frac{E - V}{V}\right)$ *EVM* (MΩ)	*VOM Voltage Reading* (V)	R $\left(= R_{\text{in}} \times \frac{E - V}{V}\right)$ *VOM* (MΩ)
		Insulation Resistance		Insulation Resistance
Mica Air (variable) Ceramic Paper Oil				
		Leakage Resistance		Leakage Resistance
Electrolytic				

voltage E is divided between the capacitor's insulation resistance R and the EVM's resistance R_{in}, on dc voltage ranges,

$$R = R_{\text{in}} \times \frac{E - V}{V}$$

From this equation calculate the value of the insulation resistance R, and enter the result in Table 18-3. Repeat the procedure with the VOM replacing the EVM. (Remember, the resistance R_{in} of the VOM is not constant but depends on the voltage range selected.)

9. Repeat step 8 for the air, ceramic, paper, oil, and electrolytic capacitors and complete Table 18-3.

QUESTIONS

1. From the results of Table 18-1, were any of the measured capacitance values beyond the specified tolerances?
2. From the results of Tables 18-2 and 18-3, were any of the capacitors excessively "leaky"? Give reasons for your answer.
3. Did step 5 or step 8 describe the more accurate method of measuring a capacitor's insulation resistance?
4. When a capacitor is in circuit, why must the capacitor be disconnected from the ground side before using the checker?
5. In step 5, why did the needle move swiftly downscale when the leads were reversed?
6. If, in step 7, you reversed the ohmmeter across the electrolytic capacitor, would the measured resistance increase, decrease, or remain the same? Verify your answer experimentally.
7. In step 8, was the EVM or the VOM more effective in measuring the capacitor's insulation resistance?
8. From Table 18-1, what was the ratio of maximum capacitance to minimum capacitance for the air capacitor?
9. In step 8, what would the EVM read if the capacitor were (a) short circuited; (b) open circuited?
10. In electronic circuitry which of the three basic passive components (resistor, inductor, capacitor) is the least reliable?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 19

CR Time Constant

READING ASSIGNMENT

Modern Electronics: A First Course, pages 388–398

Topics: Charge and Discharge of a Capacitor through a Resistor; Transient and Steady-State Conditions

OBJECTIVES OF EXPERIMENT

1. To examine by experiment the charge and discharge of a capacitor through a resistor
2. To determine experimentally the time constant of a resistor and a capacitor in series

COMPONENTS AND EQUIPMENT REQUIRED

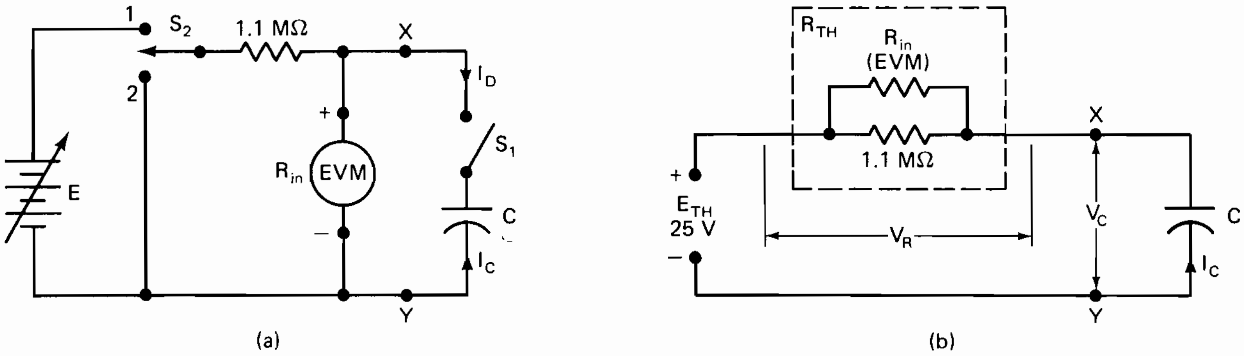
1. Variable regulated dc power supply, 0-30 V
2. Capacitor 10 μF (oil or paper), 50 WVDC or equivalent (*Note:* Do *not* use an electrolytic capacitor. If the single capacitor is not available, the required capacitance can be produced from a parallel combination of lower-value capacitors. Consult your instructor, if necessary.)
3. Resistor: $\frac{1}{2}$ W, 5%, 1.1 MΩ
4. Meter: EVM
5. One single-pole single-throw (SPST) switch; one single-pole double-throw (SPDT) switch; stopwatch

PROCEDURE

1. Consult your EVM manual and find the meter's input resistance R_{in} on dc ranges. Using the EVM as an ohmmeter, measure a number of 5% resistors until you find one whose value is 1.1 MΩ (within the limits of measurement).

Time Constant of Capacitor's Charge

2. Construct the circuit of Fig. 19-1(a) and leave the switches open as shown. Close switch S_2 in position 1 and adjust the output E of the power supply until the reading of the EVM is 25 V. If the capacitor is regarded as the load between points X and Y, the Thévenin equivalent circuit is as shown in Fig. 19-1(b). (Some EVMs have an input resistance R_{in} equal to 11 MΩ on dc ranges; R_{TH} then equals $1.1\ \text{M}\Omega \parallel 11\ \text{M}\Omega = 1\ \text{M}\Omega$, which is a convenient value.) Calculate the time constant of the Thévenin circuit and enter the result in Table 19-1.



(a) (b)

Fig. 19-1. **Charge and discharge of a capacitor through a resistor.**

3. Close switch S_1 (the reading of the EVM falls to zero) and start the stopwatch at the same time. With the EVM measure the voltage across the capacitor after time intervals of 5, 10, 15, 20, . . . , 60 s and record the results in the "First Set" column of Table 19-1. The capacitor should now be charged to 25V. Open S_1 and discharge the capacitor by temporarily touching a connecting lead across its terminals. Close S_1 and obtain a second set of readings. Repeat the procedure for a third set of readings and then average out the three sets. Calculate the values of $V_R = 25\ \text{V} - V_C$ and $I_C = V_R / R_{\text{TH}}$ to complete Table 19-1. Plot graphs of V_C, V_R, and I_C versus time.

Table 19-1

Charge Time Constant (s)					*Calculated*	*Measured*
	V_C (V)				V_R (V)	I_C (μA)
Time (s)	*First Set*	*Second Set*	*Third Set*	*Average*		
0	0	0	0	0	25	
5						
10						
15						
20						
25						
30						
35						
40						
45						
50						
55						
60						

4. From the graph of V_C versus time, derive the time at which $V_C = 0.632 \times 25 = 15.8$ V. This interval is equal to the charge time constant and is recorded in Table 19-1.

Time Constant of the Capacitor's Discharge

5. Use the procedure of step 3 to charge the capacitor to $V_C = 25$ V. Move switch S_2 to position 2 and start the stopwatch. The capacitor is now discharging through the parallel combination of the EVM's R_{in} and the 1.1-MΩ resistor. The time constant of the discharge should therefore be the same as the time constant of the charge. With the EVM, measure the voltage across the capacitor after time intervals of 5, 10, 15, 20, . . . , 60 s and record the results in the "First Set" column of Table 19-2. Repeat the procedure twice more to obtain second and third sets of readings and average out the three sets. Complete Table 19-2 by calculating

$$I_D = \frac{V_R}{R} = \frac{-V_C}{R}$$

where $R = R_{\text{in}} \parallel 1.1$ MΩ. Plot the graphs of V_C, V_R, and I_D versus time.

Table 19-2

Discharge Time Constant(s)					*Calculated*	*Measured*
	V_C (V)				V_R (V)	I_D (μA)
Time(s)	*First Set*	*Second Set*	*Third Set*	*Average*		
0	25	25	25	25	25	
5						
10						
15						
20						
25						
30						
35						
40						
45						
50						
55						
60						

6. From the graph of V_C versus time, derive the time at which $V_C = 0.368 \times 25 = 9.2$ V. This value is equal to the discharge time constant and is recorded in Table 19-2.

QUESTIONS

1. How did the calculated and measured values of the charge time constant compare? Discuss the reasons for any significant difference.
2. When the capacitor was fully charged, what was the total charge stored? What were the amounts of the total electrical flux and the energy stored in the electric field?
3. In what period of time did the capacitor acquire its total charge (to within 1%)? How many time constants were represented by this period of time?

4. What were the possible sources of error in the measurement of the charge time constant?
5. From the graph of V_C versus time during the charging of the capacitor, what were the time intervals corresponding to $V_C = 21.6$, 23.8, and 24.5 V? How do your answers compare with the values of two, three, and four time constants?
6. What was the purpose in obtaining three sets of readings in each of Tables 19-1 and 19-2 and then averaging out?
7. How did the calculated and measured values of the discharge time constant compare? Discuss the reasons for any significant difference.
8. From the graph of V_C versus time during the capacitor's discharge, what were the time intervals corresponding to $V_C = 3.4$, 1.2, and 0.5 V? How do your answers compare with the values of two, three, and four time constants?
9. In step 5, assume that the capacitor is charged to $V_C = 25$ V. If switch S_2 is now opened, what would be the new time constant of the capacitor's discharge? Verify your answer experimentally.
10. Why would an electrolytic capacitor *not* be suitable for this experiment?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 20

The Loading Effect of a Voltmeter

READING ASSIGNMENT

Modern Electronics: A First Course, pages 421–423

Topic: The Loading Effect of Different Voltmeters on an Electrical Circuit

OBJECTIVE OF EXPERIMENT

To examine by experiment the loading effect of various voltmeters on an electrical circuit

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0-30 V
2. Resistors: $\frac{1}{2}$ W, 5%, two 200 kΩ, two 200 Ω resistors
3. Meters: EVM; two VOMs: one 20,000 Ω/V) and one 1000 Ω/V
4. Single-pole single-throw (SPST) switch

PROCEDURE

Loading Effect of the EVM

1. Use the EVM to measure the values of a number of 5% tolerance resistors and find two resistors whose values are each 200 kΩ and two other resistors whose values are each 200 Ω (within the limits of measurement).
2. Connect the circuit of Fig. 20-1. Assuming that switch *S* is closed, calculate the potential at point *X* and the value of the current I. Enter your results in Table 20-1.

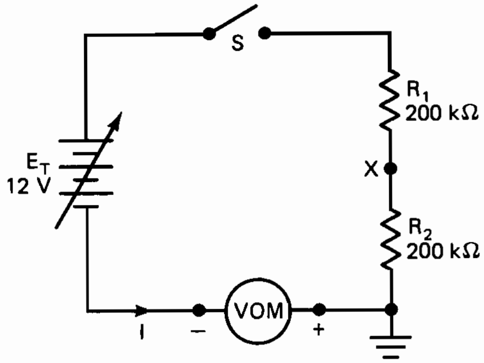


Fig. 20-1. The loading effect of a voltmeter in a high resistance circuit.

3. Use the EVM to adjust the output of the variable power supply to E_T = 12 V and maintain this value throughout this experiment. Close switch *S* and with the range switch set to 0–15 V, connect the EVM between point X and ground. Measure the potential at *X*. With the 20,000-Ω/V VOM switched to the 0–50 μA range, measure the value of *I*. Record both readings in Table 20-1. Look through the EVM operator's manual to discover the voltmeter's input resistance on the dc ranges. By knowing this loading effect, calculate the potential at point *X* with the EVM present. Enter this value in Table 20-1. Open switch *S* and remove the EVM.

Loading Effect of the 20,000-Ω/V VOM

4. Switch the second 20,000-Ω/V VOM to the 0–10 V range and connect this meter between *X* and ground. Close switch *S* and measure the values of the current *I* and the potential at point *X*. Record these readings in Table 20-1. Taking into account the loading effect of the VOM on the 0–10 V range, calculate the potential at point *X* with the voltmeter present. Enter this result in Table 20-1.
5. Switch the VOM to the 0–50 V range and record the new values of the current *I* and the potential at point *X*. Enter these readings in Table 20-1. Taking into account the different loading effect of the VOM on the 0–50 V range, calculate the potential at point *X* and the current *I*; enter these results in Table 20-1. Open switch *S* and remove the 20,000-Ω/V VOM from across R_2.

Loading Effect of the 1000-Ω/V VOM

6. Switch the 1000-Ω/V VOM to the 0–10 V range and connect this meter between *X* and ground. Close switch *S* and record the potential at point *X* and the value of the current *I*; enter these measured values in Table 20-1. Taking into account the loading effect of the 1000-Ω/V meter on the 0–10 V range, calculate the values of the current I and the potential at point *X* with the voltmeter present. Enter these calculated results in Table 20-1.
7. Connect the circuit of Fig. 20-2. Repeat steps 2 through 6 for the new circuit and record all the results in Table 20-2.

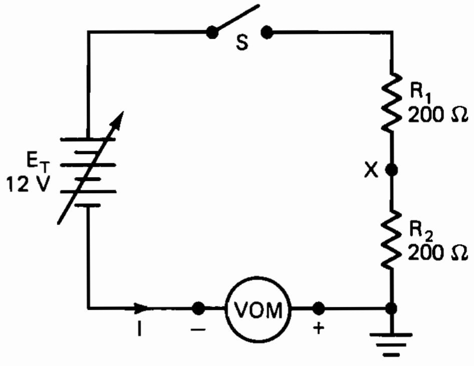


Fig. 20-2. The loading effect of a voltmeter in a low resistance circuit.

Table 20-1

$E_T = 12$ V $R_1 = R_2 = 200$ kΩ	*Calculated Values with No Voltmeter Present*	EVM (0-15 V *Range*)		20,000-Ω/V VOM (0-10 V *Range*)		20,000-Ω/V VOM (0-50 V *Range*)		1000-Ω/V VOM (0-10 V *Range*)	
		Calc.	*Meas.*	*Calc.*	*Meas.*	*Calc.*	*Meas.*	*Calc.*	*Meas.*
Potential at point *X* (V)									
Current *I* (mA)									

Table 20-2

$E_T = 12$ V $R_1 = R_2 = 200$ Ω	*Calculated Values with No Voltmeter Present*	EVM (0-15 V *Range*)		20,000-Ω/V VOM (0-10 V *Range*)		20,000-Ω/V VOM (0-50 V *Range*)		1000-Ω/V VOM (0-10 *V Range*)	
		Calc.	*Meas.*	*Calc.*	*Meas.*	*Calc.*	*Meas.*	*Calc.*	*Meas.*
Potential at point *X* (V)									
Current *I* (mA)									

QUESTIONS

1. Looking through your results, was the voltmeter loading effect greater in the high-resistance circuit or the low-resistance circuit? Explain your answer.
2. In the experiment, which voltmeter had the greatest loading effect and which had the least loading effect? Why?
3. Assume that E_T is changed to 120 V by using a high-voltage supply in Fig. 20-1. If the VOMs are then switched to the appropriate higher voltage ranges, is their loading effect greater or less than in the original low-voltage circuit?
4. In step 4, assume that the 20,000-Ω/V VOM on the 0–10 V range is disconnected from R_2 and is instead connected across R_1 (Fig. 20-3). What is the calculated value of the potential at point X? Check your answer experimentally.

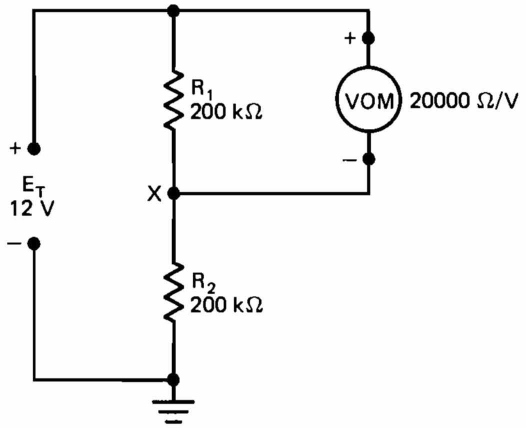


Fig. 20-3. Circuit for Question 4.

5. In step 4, the two 20,000-Ω/V VOMs are connected across R_1, R_2 (Fig. 20-4). What is the calculated value of the potential at point X? Check out your answer experimentally.
6. In Question 5, the VOM across R_2 is switched to the 0–50 V range. What is the new calculated value of the potential at point X? Check your answer experimentally.
7. In step 6, the 1000-Ω/V VOM is switched to the next highest voltage range. What is the new calculated value of the potential at point X? Check your answer experimentally.
8. In step 6, the 1000-Ω/V VOM is switched to the next lowest voltage range. What is the new calculated value of the potential at point X? Check your answer experimentally.

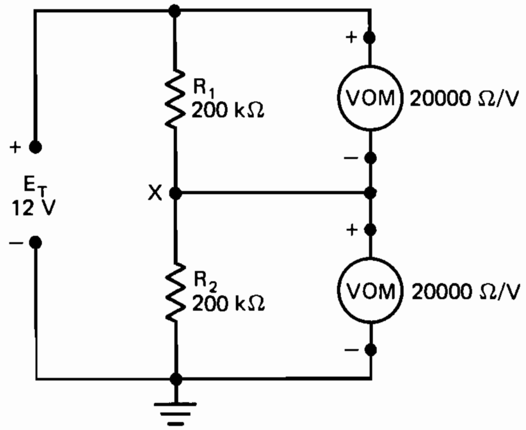


Fig. 20-4. Circuit for Question 5.

9. From the results of steps 4 and 5, the potential at X with no voltmeter present may be calculated from the equation

$$\text{potential at } X = \frac{(50\text{ V} - 10\text{ V})V_1 V_2}{50\text{ V} \times V_2 - 10\text{ V} \times V_1}$$

where V_1 is the voltmeter reading on the 0–50 V range and V_2 is the reading on the 0–10 V range. Using this equation, what is the calculated value of the potential at point X with no voltmeter present? Compare the answer with your calculation in step 2.

10. What are the circuit conditions in which it is suitable to use a 1000-Ω/V VOM as a voltmeter?

CONCLUSION

Describe in your own words what you have learned from this experiment.

1

Introduction to AC Measurements

Many of the procedures for measuring alternating voltages and currents are the same as those which you learned for dc measurements. However, there are some differences. The purpose of this section is to briefly describe the meters and other equipment used in performing ac experiments. The description will provide general background information only. It may be necessary to refer to the manual for the equipment being used for more specific information. The instructor may also demonstrate the use of this equipment. In doing so, he or she will point out the location of the controls, the ranges of voltages and currents available, accuracies to be expected, and fundamental limitations.

The student should be informed of one basic difference between ac and dc measurements. This difference is the consideration of frequency. In the introductory electronics laboratory the experiments are designed to avoid problems regarding the frequency of the quantity to be measured. On the job later, the frequency often determines which of several types of instruments is best suited to the job.

The equipment discussed here includes meters, the oscilloscope, and function generators. Briefly, a function generator will provide one of several waveforms and is used as an ac voltage source. Meters permit the measurement of voltage and current in a circuit. Voltmeters and ammeters are connected in ac circuits in exactly the same way they are connected in dc circuits. The oscilloscope is used to observe the alternating voltage waveform and to measure time intervals and the peak value or peak-to-peak (p–p) value. A modern cathode ray oscilloscope (CRO) provides additional flexibility in making measurements and is widely used in the electronics industry. For both reasons, the use of the CRO is stressed in the experiments to follow.

Before proceeding with descriptions of this equipment, it should be recognized that technical progress is rapidly changing the quality of test equipment available to the electronics engineer and technician. This is the basic reason why the present description of test equipment is fairly general in nature. The industry standard for quality test equipment today may be obsolete in only a few years.

ELECTROMECHANICAL METERS

Electromechanical meters closely resemble dc meters. Readings are taken from calibrated scales in accordance with a needle (or pointer) position. There is a range selector switch which determines the scale to be used. The reading is almost always obtained by interpolating between marked points on the scale. Since there may be a possible disagreement as to the last digit, the highest authority present will determine the reading to be recorded.

The D'Arsonval meter movement, commonly used for dc meters, will not respond to ac, except for very low frequencies. Other types of meter movements are available for ac measurements. Some of their names, which your instructor may not require you to know, are: the moving iron-vane, the electrodynamometer, and the electrostatic movements. Each has relative advantages in cost, frequency range, voltage range, and so on. These considerations will be very important to you on the job. However, they will be postponed for now. Your immediate goal will be to learn how to use the meters for basic measurements. We may refer to these meters as *analog* meters. The position of the pointer indicates the quantity being measured.

ANALOG ELECTRONIC METERS

The dc meter movement (D'Arsonval) together with a rectifying diode (diodes) can be used to measure ac voltages and currents. A new scale will be necessary since the average dc level will be indicated for a dc meter, with rectifier, on the dc scale. The ac scale will most likely be calibrated to indicate the effective (rms) value.

Another type of ac meter uses a thermocouple and heating element. The applied ac voltage or current causes the heating element temperature to rise. The output of the thermocouple changes with temperature so that the dc meter element connected to the thermocouple responds with a deflection to indicate the effective ac quantity. A little thought should lead to the conclusion that this form of instrument can be used for dc as well as ac. Moreover, it will always give the effective value for sine waves and waves of other shapes as well. The instrument described previously does not have this built-in flexibility. When a rectifier is used with a dc meter movement, the scale of effective values applies only for one wave shape, nearly always a sine wave.

Improved performance is possible for an analog meter if the meter movement is driven by an amplifier. Such an instrument can have high input impedance to reduce circuit loading during the measurement of voltage. Formerly, electronic vacuum tubes were used for the amplifier and these instruments were called vacuum-tube voltmeters (VTVMs). Although obsolescent, many of these instruments are still in use and the term "VTVM" is still in use. When transistors were designed into test equipment, the VTVM became the TVM (transistor voltmeter). In the present series of experiments we will use EVM, for "electronic voltmeter," to refer to an instrument employing amplification and measuring voltage, current (dc or ac), and resistance. Moreover, EVM will apply to an analog meter (scale with pointer) or the numerical readout which is found on digital meters. (Please read on for a description.)

DIGITAL VOLTMETERS

Digital voltmeters of increasing sensitivity and accuracy are now replacing older instruments of the types described above. The digital multimeter (DMM) usually measures both dc and ac voltages and currents. It also measures resistance. Both bench models and portable pocket-size versions are available at prices considerably lower than the older analog instruments of comparable or lesser capabilities. The most obvious advantage of the DMM is the numerical indication of the quantity being measured. A second advantage is protection against damage caused by selection of the wrong range or function (current instead of voltage, for example). The student should always keep in mind that whereas the DMM guards against carelessness, the older instruments are endangered by careless practices.

A typical bench DMM is shown in Fig. 1. One set of pushbutton switches allows the function to be selected. The operator chooses voltage, current. or resistance measurement and ac or dc as

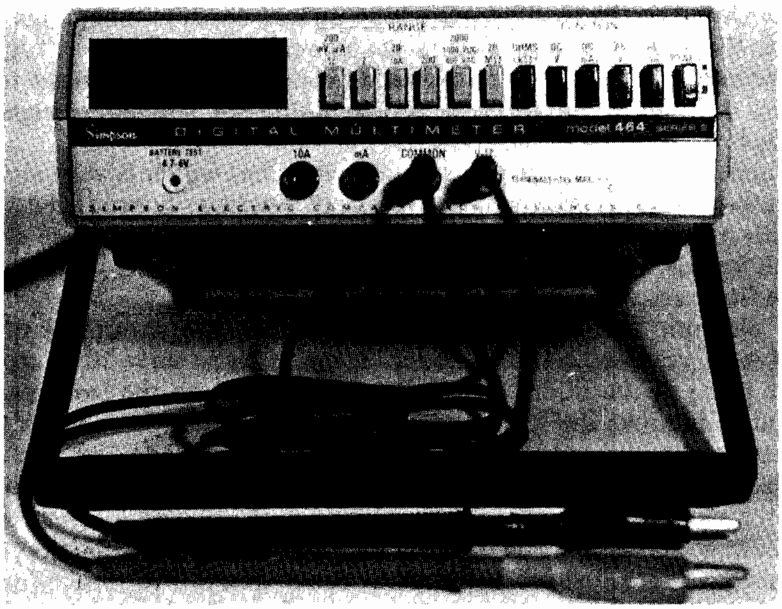


Fig. 1. **Bench digital multimeter (DMM).**

appropriate. The switches are mechanically interlocked so that only one switch or a proper combination of switches can be engaged at any one time. Other pushbutton switches permit range selection. A variation of the switching arrangement is found on a popular line of hand-held DMM. A rotary switch, similar to that of the older, analog VOM, permits the selection of both function and range.

The $3\frac{1}{2}$-digit DMM is adequate for the electronics training laboratory. This designation seems to be contradictory since four digits are visible on the front panel. The convenience and the limitation of this common arrangement can be demonstrated by a simple example. Suppose that the 1 V range has been selected. With only three digits available, the greatest reading would be 0.999 V. However, with $3\frac{1}{2}$ digits, the greatest possible reading is 1.999 V. The leftmost (most significant) digit can be zero but never greater than 1. Incidentally, instruments with more than four displayed digits are available at additional cost. Even more sophisticated digital multimeters are self-calibrating and have other programmable features to make the user more productive.

Even the least expensive DMM will automatically place the decimal point when the proper ranger, or a greater range, is selected. The best range selection is one that eliminates leading zeros (zeros on the left end of the displayed quantity). A distinctive indication tells the user when the range selection will not allow the value to be displayed.

The DMM is so easy to use compared with analog instruments that the inexperienced user might switch from the voltage function to the current function without changing the leads connected to the circuit. Any acceptable DMM has built-in protection against excessive current at the cost of fuse replacement. Nevertheless, the student should guard against this abuse of the instrument.

Before moving on to a new form of instrument, a few thoughts are in order. First, the measurement of ac quantities is essentially the same as that of dc. There is one fundamental difference that will be avoided in a first course but will be important later. Ac instruments, as mentioned before, have frequency limitations. Second, the field of measurements is large. Do not assume that your ability to perform these experiments places you in the ranks of fully qualified technicians. In these experiments and later, always be skeptical of the measurements, the circuits, and the instruments. The ability to detect invalid results is a skill to be learned through experience.

THE OSCILLOSCOPE

The cathode ray oscilloscope (CRO) is probably the most flexible, general-purpose measurement instrument in use today and, perhaps, for some time in the future. It is particularly important that the student be introduced to the oscilloscope at the earliest possible time in his or her training. It is also important that this equipment be used in the laboratory for different types of measurements under different circumstances. In this course we are concerned with the basic triggered-sweep oscilloscope. The many other CRO variations providing additional, specialized capabilities will be postponed to future courses.

The key element of the CRO is the cathode ray tube, which is very similar to the "picture tube" of a black-and-white television set. A stream of electrons is produced by a heated cathode acting together with other metallic elements to form the electron gun. The stream of electrons is accelerated by high voltage toward the inside surface of the tube face. Light is produced when the electrons strike the fluorescent screen coating this inside surface.

Between the electron gun and the fluorescent screen are a number of electrodes held at positive potentials with respect to the cathode. Some of these serve the purpose of focusing the electron beam to a point at the fluorescent screen. A control on the front panel, to be described later, can be caused to improve the focus and affect the size and appearance of the spot seen by the operator. Other electrodes cause the electron beam to be deflected. One pair of electrodes, called plates, causes horizontal deflection proportional to the impressed voltage. Another pair causes vertical deflection in the same way.

In the most commonly used mode of operation, the horizontal deflection is linear. The beam, and spot that it produces, move equal distances in equal intervals of time. For slow movement, as caused by the varying plate voltages, the spot can be seen moving to the right, leaving a rapidly disappearing trail. Upon reaching the end of its travel on the right, the spot disappears and quickly reappears on the left to repeat its linear journey. With fast movements of the beam, required for most electronic measurements, the beam cannot be seen, but its trace, repeated hundreds, thousands, and even millions of times per second, appears as a solid horizontal line.

The vertical deflection of the beam is usually caused by an amplified signal to be observed and measured. The amount of amplification, hence deflection, is controlled by a knob on the CRO panel.

The combined horizontal sweep motion and vertical signal deflection give a graphical picture of the signal waveform. If the controls are set to their calibration positions, two possibilities for measurement are obtained.

1. The peak value of the waveform can be accurately measured.
2. The period of the waveform can be measured and the frequency calculated. Other time intervals can also be measured.

The remaining description of the CRO stresses the terminals and controls on the front panel. The present intention is to introduce the basic nature of the general capabilities of this class of instrument. The operations manual should be consulted for the particular make and model of oscilloscope you will be using before attempting to turn it on. By consulting the manual and examing the front panel you will observe several prominent features of a high-quality CRO. First, terminals and controls having associated functions are usually grouped in the same area on the panel (see Fig. 2). Second, control knobs, switches, and panel markings may be color coded. This feature is particularly helpful when two knobs, an inner knob and an outer knob, occupy the same position on the panel. Third, there may be one or more lights to inform you of the status of some functions. Many of the controls to be described are shown in Fig. 3.

POWER: a knob setting or switch which turns on the CRO. It may be marked on the panel as ON/OFF. It provides a connection of the ac power to the CRO power supplies. This control is often accompanied with an indicator light.

INTENSITY: controls the brightness of the spot, horizontal sweep trace, or waveform. The intensity setting should be high enough to view the waveform, but not too high. Care should be taken to obtain a low brightness when the electron beam is not moving. A high-intensity spot can burn the phosphorescent coating called the phosphor.

FOCUS: controls the size of the spot or width of line. The sharpest line is usually desired and is obtained when the line-generating spot is in focus.

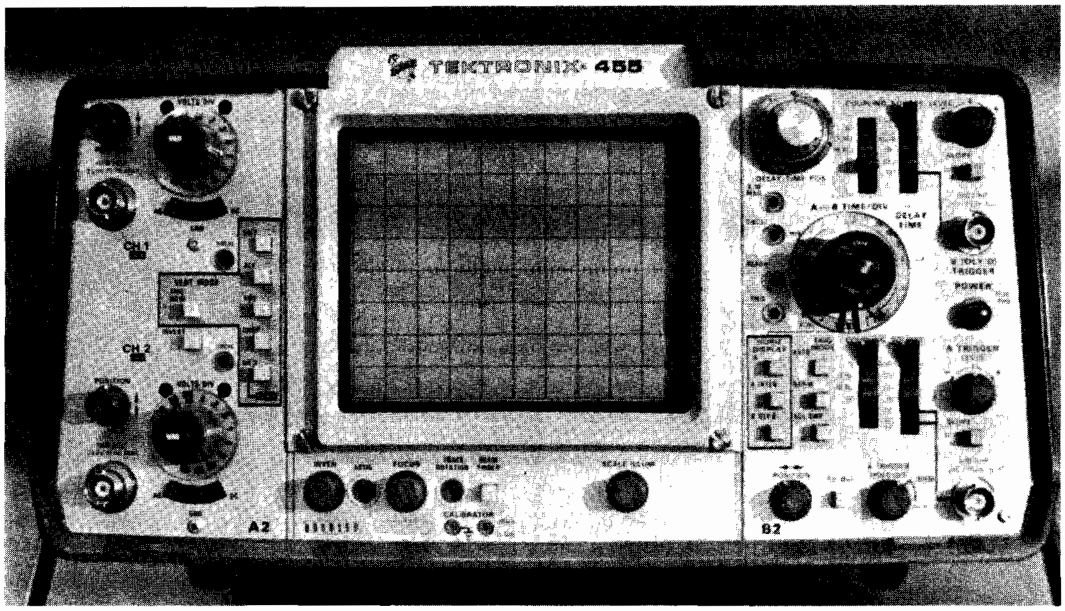


Fig. 2. Dual-trace triggered-sweep oscilloscope.

ASTIGMATISM: counteracts the tendency for the electron beam to defocus in some areas of the CRO tube face. This control, together with the FOCUS control, is used to obtain the sharpest line everywhere on the cathode ray tube face.

SCALE ILLUMINATOR: provides a variable level of illumination for the grid (called graticule) on the tube face.

HORIZONTAL POSITION: a control knob that moves the spot, sweep trace, or displayed waveform to the left or right horizontally.

VERTICAL POSITION: a control knob that moves the spot, sweep trace, or displayed waveform up or down vertically (lower right-hand knob of Fig. 4).

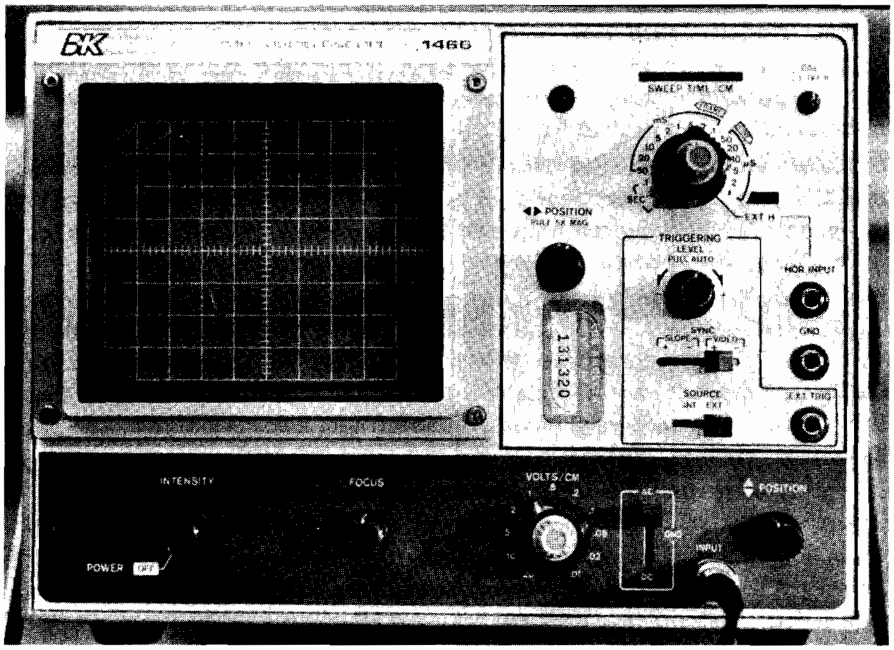


Fig. 3. Front panel of inexpensive cathode ray oscilloscope.

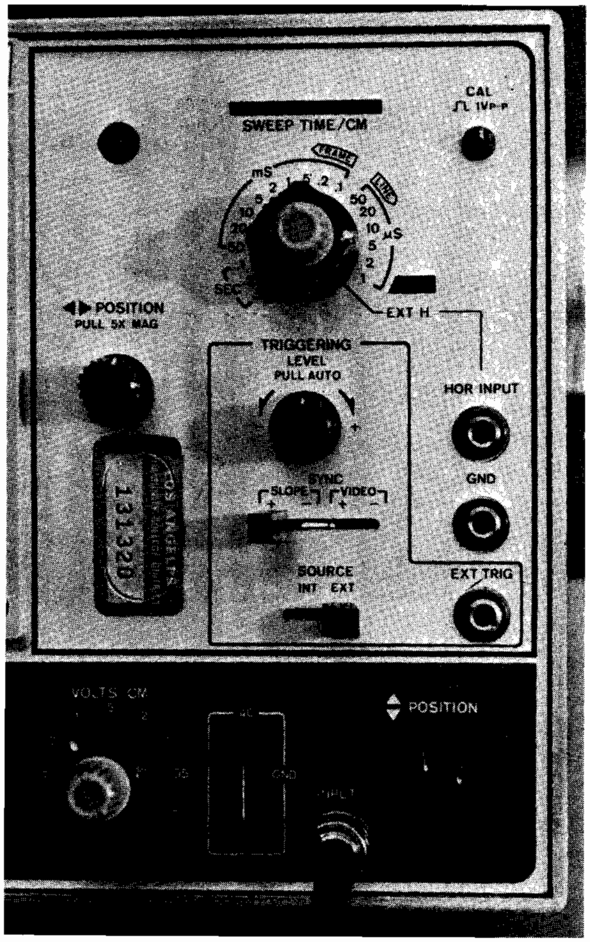


Fig. 4. Control knobs and switches for cathode ray oscilloscope.

INPUT: the input terminal for the signal to be observed and measured. Test leads or a probe are attached to this terminal and to the circuit under test. Many scope probes have an attenuation factor of 10, which must be taken under consideration in using the vertical calibration of the oscilloscope to measure voltage levels. The proper connectors and/or adaptors must be used for the scope leads or probes.

INPUT SELECTOR: for the purpose of our experiments the dc selection is used to measure dc levels with the CRO. AC selection permits the measurement of ac signals without regard for any direct current component that may be present. A GND selection places the input at ground level in preparation for centering or otherwise making VERTICAL POSITION adjustments.

TRIGGER MODE: the INTERNAL trigger mode causes the horizontal sweep to be triggered by the input signal being observed and measured. After being started the sweep moves the spot from the left side of the cathode ray tube to the right. Note that the HORIZONTAL POSITION control determines exactly where the sweep trace begins and ends without changing its length. In the absence of an ac signal, the sweep will not trigger and no sweep trace will be seen when the INTERNAL trigger mode is selected.

AUTOMATIC trigger: similar to INTERNAL. An important exception causes triggering of the sweep in the absence of any ac signal at the INPUT. This feature allows dc voltage level measurements. It also permits the trace and/or waveforms to be observed before other adjustments, not yet described, have been made.

EXTERNAL mode selection: results in the sweep being triggered by a signal other than that being observed on the CRO. The signal used for this purpose is connected to the EXTERNAL terminal of the CRO by means of a scope lead or probe. With the time of sweep triggering established by this means, phase comparisons can be made for all the voltages at points in a circuit.

TRIGGER LEVEL: establishes the voltage level on the waveform at which triggering occurs.

TRIGGER SLOPE: determines whether triggering occurs as the voltage is rising (+) or falling (-).

TIME/DIV: when set in the calibration position, the TIME/DIV control knob determines the time required by the sweep to travel the distance between two major division marks. On most modern oscilloscopes the major divisions marks are separated by 1 cm.

VOLTS/DIV: when set in the calibration position, the TIME/DIV control knob determines the voltage required to deflect the electron beam vertically one major division (usually 1 cm).

THE FUNCTION GENERATOR

The function generator is an ac source used in most electronics laboratories. Typically, the less expensive function generator will supply sine waves and square waves. Others will also provide triangular waves. The frequency can be controlled from a minimum of several hertz to a maximum of about 1 MHz. In addition, the peak values of the waves are controllable to about 10 V. The amplitude control is usually not calibrated, so that other instruments (e.g., the cathode ray oscilloscope) must be used in establishing the desired level. The frequency control, together with the frequency range selector, indicates the general order of frequency and cannot normally be depended on to provide an accurate value. This statement is intended to cover the function generators found in laboratories for training first- and second-year electronics students. If the frequency control is not accurately calibrated, other methods are required for measuring frequency in the ac experiments to follow.

The present generation of inexpensive function generators is based on integrated circuits. Older equipment suitable for the ac source in the present series of experiments may provide only sine-wave outputs and be known as signal generators or oscillators. These may be constructed of discrete semiconductors or vacuum tubes. Square-wave generators may also be found in the laboratory. Whenever the function generator is specified as equipment required for the experiment, an oscillator, signal generator, or square-wave generator having the necessary waveform, frequency range, and signal amplitude may be used.

The output impedance of function generators is small by design. This is to minimize the effect of loading on the output. Since it is always possible to overload the function generator, care must be taken that errors in circuit construction or circuit element values not result in overloading. Overloading will cause appreciable reduction in the output.

The student should be warned that many laboratory stockrooms have older-model signal generators or oscillators with relatively high output impedances. These voltage sources are incapable of delivering the voltage levels specified in the experiments to follow with the circuit elements given. In using these sources, some modifications of the experimental procedures may be necessary. Several possible modifications are suggested below.

1. Substitute larger circuit resistances and reactances so as to reduce the loading on the ac source. Note that different source frequencies can be adopted to provide larger reactance values in the external circuit.
2. Lower circuit voltages can be adopted without changing circuit impedances. A crucial item with any modification is the ability to reliably and accurately measure the voltages and currents.
3. A combination of frequency change, circuit element value changes, and voltage-level changes is possible. Measurement capability is the basic limitation in all cases.

SPECIAL AC MEASUREMENT CONSIDERATIONS

Whenever a meter is used in making dc measurements, the test leads are usually connected to the circuit without concern for the location of the ground in the circuit. For many dc circuits the ground is simply a convenient common point serving as a reference in stating the voltages at other points. In the interest of safety, the ground in ac circuits must be clearly established and carefully observed. Failure to do so can be fatal because of the ability of the ac power system to drive lethal currents through any body placed in contact with an energized conductor and ground. To protect against equipment malfunctions which will place dangerous voltages on the metal cabinet and chassis of test equipment, these parts of the equipment are commonly connected to the building ground (and to earth ground) by the third wire of the power cord and the third pin of the power cord plug.

The particular restriction of freedom in connecting such equipment results from the internal attachment of one terminal to the cabinet. To be more specific, a function generator (signal generator, oscillator, square-wave generator, etc.) usually has one output terminal grounded. An oscilloscope, with some important exceptions not discussed here, has one input terminal grounded. With this arrangement, all voltage measurements with this CRO are made with respect to the common ground.

One practical consequence of the grounding practices just described is the need to change the circuit in order that voltages for different elements connected in series can be measured with the CRO. It should be remembered that dc voltages for series circuits in previous experiments were easily measured by moving *both* voltmeter leads to the desired points in the circuit. Our inability to be free of the common ground existing at one terminal of the test equipment used in ac experiments requires that special steps be taken. These steps, as described in the experiments to follow, might appear to complicate the procedure needlessly. The student should be continuously aware of the ground situation and the necessity of altering the circuit to accomplish certain measurements.

A CRO is basically a voltage measurement instrument. Current probes are available but will not be used in these ac experiments. One technique for observing and measuring an ac waveform is relatively simple. If a small (compared with the other impedance values in the circuit) resistance is connected in series with any electrical path whose current is to be observed, a voltage of exactly the same waveform will appear across the leads of that resistor. Applying that voltage to the input of the CRO will permit its measurement, from which the equivalent current values can be calculated using Ohm's law.

There is still another practical consideration that causes some ac measurement techniques to differ from similar dc measurements. A dc voltage source, especially that provided by a regulated power supply, may have an essentially constant voltage level as the load is varied. The internal resistance (Thévenin resistance) is small and can often be considered to be negligible. Ac signal sources have internal impedances which may often cause the terminal voltage to vary under load, as mentioned before. This does not present serious procedural difficulties in the experiments with sine-wave voltages and currents when overloading is avoided. However, with other waveforms, such as square waves, both the waveform and amplitude may be changed when the load has reactive components. A user should be aware that a high-quality square wave may be present inside the function generator even though the terminal waveform appears distorted when supplying such a load. Experiments 29 and 30 are affected by the terminal waveform change. Other experiments, such as Experiment 37, are also influenced by the source internal resistance.

The preceding discussion of *special ac measurement considerations* has one important objective. A serious student must not only be able to perform the experiments, but also to understand the reasons for the procedural steps. Many of the reasons have been introduced in this discussion.

AC EXPERIMENTS 21 THROUGH 40: COMPONENTS AND EQUIPMENT REQUIRED

Basic Equipment and Instruments

Variable regulated dc power supply, 0-30 V

Function generator (sine/square wave), 0-10 V

Electronic voltmeter or digital multimeter

DC current meter

AC current meter

Cathode ray oscilloscope (triggered sweep)

Isolation transformer

Variable autotransformer

Filament transformer—115:6.3 or 115:12.6 or 115:25.2

Capacitance substitution box

Decade resistance box

Resistors (10%)

- 18 Ω, $\frac{1}{2}$ W
- 100 Ω, $\frac{1}{2}$ W
- 180 Ω, $\frac{1}{2}$ W
- 330 Ω, $\frac{1}{2}$ W
- 470 Ω, $\frac{1}{2}$ W
- 560 Ω, $\frac{1}{2}$ W
- 680 Ω, $\frac{1}{2}$ W
- 820 Ω, $\frac{1}{2}$ W
- 1000 Ω, $\frac{1}{2}$ W
- 1.5 kΩ, $\frac{1}{2}$ W
- 1.8 kΩ, $\frac{1}{2}$ W
- 2.2 kΩ, $\frac{1}{2}$ W
- 3.3 kΩ, $\frac{1}{2}$ W
- 10 kΩ, $\frac{1}{2}$ W
- Specific values depending on filament transformer secondary rating, 2 W

Inductors

- 30 mH
- 8 H

Capacitors (50 WV dc)

- 0.001 μF
- 0.005 μF
- 0.01 μF
- 0.02 μF
- 0.05 μF
- 0.1 μF
- 0.15 μF
- 0.18 μF
- 0.22 μF
- 0.27 μF
- 0.33 μF
- 0.39 μF
- 0.5 μF

Other

- Single-pole single-throw (SPST) toggle switch
- Protractor

Experiment 21

Square-Wave Voltage Levels

READING ASSIGNMENTS

Modern Electronics: A First Course, pages 438–446

Topics: Alternating-Current Fundamentals; Square Waves

OBJECTIVES OF EXPERIMENT

1. To employ a cathode ray oscilloscope (CRO) to measure dc voltage levels
2. To measure square-wave voltage levels using the CRO

COMPONENTS AND EQUIPMENT REQUIRED

1. Variable regulated dc power supply, 0-30 V
2. Direct-connection scope leads or scope probes
3. Function generator (square wave), 0-10 V (or more)
4. Meter: EVM
5. Cathode ray oscilloscope (CRO)

PROCEDURE

Preliminary Preparation

1. After having completed the reading assignment, consult the operating manual for the oscilloscope to be used. With the CRO on the bench, compare the list of controls from the equipment manual with those

described previously in this manual. You will probably find some differences in the names of some controls. There may be, in addition, some controls listed in the equipment manual that will not be used in this sequence of experiments. The instructor will inform you as to the proper settling of any extra, unused controls.

2. Examine the front panel of the CRO and locate the controls mentioned previously in this manual.
3. Turn on the CRO and wait a few minutes before proceeding to the next step. In the event that a bright dot appears on the cathode ray tube, reduce the intensity using the INTENSITY control so that the spot is barely visible. Otherwise, the tube may be damaged at the spot location. Be sure to turn the INTENSITY up after the first part of the next procedure step.
4. Set the TRIGGER control to AUTO. If a horizontal trace does not appear on the cathode ray tube, change the VERTICAL POSITION and HORIZONTAL POSITION controls first in one direction and then the other. If the trace still does not appear, move the INTENSITY control to increase the beam intensity (clockwise) and again look for the trace using the position controls. If the trace still cannot be found, ask your instructor for assistance.
5. Observing the visible trace, adjust the INTENSITY, FOCUS, and ASTIGMATISM controls to obtain a clearly visible, sharp horizontal line of low intensity.
6. Set the INPUT SELECTOR control (ac, dc, GND) to GND and adjust the VERTICAL POSITION so that the trace is lined with the center of the graticule (ruled squares). Now place the INPUT SELECTOR in the dc position.
7. Connect the INPUT terminal to the positive dc power supply output. Also connect the ground terminal of the CRO to the negative terminal of the power supply. Set the VOLTS/DIV on the CRO to 10.
8. Set the power supply for minimum output and turn it on. Adjust the power supply output until the trace moves upward 1 division. The dc voltage level should now be 10 V ***if the CRO is calibrated.***
9. Connect the EVM to the dc power supply output and read the voltage. If the EVM voltage differs significantly from 10 V, check to ensure that the VOLTS/DIV setting is calibrated. An inner knob with a detent position for calibration is present on most oscilloscopes. Failure to obtain 10 V (or approximately 10 V) on the EVM with a 1-division deflection of the CRO indicates that the oscilloscope needs to be recalibrated, for which the procedure in the CRO manual must be followed. The instructor should be consulted before considering recalibration.
10. Assuming that the EVM reading and CRO deflection match satisfactorily, change the power supply output while observing both the EVM reading and the CRO deflection. Turn off the power supply, reverse the power supply output leads if neither power supply terminal is grounded, and observe the CRO deflection for negative input voltage levels. Repeat with both positive and negative levels to fill in Table 21-1.
11. With various dc voltages levels, experiment with different settings of VOLTS/DIV. (You will later be asked questions about the effects on the deflection of different settings of this control.)
12. Disconnect the power supply from the INPUT terminals of the CRO. Use CRO leads or a probe to place

Table 21-1

EVM Reading (V)	*CRO Deflection Divisions*
+20	
+15	
+5	
0	
-5	
-10	
-15	
-20	

the function generator output signal on the INPUT terminal. Be sure that the ground side of the lead or probe is connected to the ground terminal of the function generator. If necessary, a similar connection should be made to the GND terminal of the CRO.

13. Set the output level control of the function generator fully counterclockwise for the lowest level of output. Set the function generator waveform selection switch to obtain a square wave. (Note that some function generators may have different output terminals for different waveforms.) Set the frequency at 1 kHz.
14. Turn on the function generator and check the TRIGGER MODE control on the CRO to ensure that it is still set in the AUTO position. Set the TIME/DIV control on the CRO to 1 ms. Also set the VOLTS/DIV to 1 V. Then change the INPUT SELECTION from dc to ac.
15. Assuming that only the sweep trace can be seen, increase the output level of the function generator until a waveform is visible. Continue to turn the output control knob on the function generator clockwise until the difference between the top and bottom levels of the observed waveform is four divisions.
16. A number of steady, complete square-wave cycles can now be seen. If the waveform is not stationary, the sweep is not being triggered properly and additional adjustments may have to be made. Read the operating instructions in the manual for the cathode ray oscilloscope being used, and make the additional adjustments to obtain the desired waveform.
17. At this time, if you have not done so before, check the TIME/DIV and VOLTS/DIV controls to ensure that calibrated measurements can be made. Most cathode ray oscilloscopes have an inner knob with a detent position indicating calibrated readings.
18. Readjust the function generator output level and if necessary, the CRO VERTICAL POSITION control so that the top of the square wave is positional on the top line of the graticule (grid). The bottom of the square wave should be on the bottom line of the graticule. The peak-to-peak value of the square wave is ________ divisions and the peak-to-peak voltage is ________ V. If you are using a × 10 oscilloscope probe, be sure to take the attenuation into consideration.
19. Observe what happens when the VOLTS/DIV control is set to a smaller number of volts. The peak-to-peak waveform is smaller or larger. (Underline one word.)
20. Set the output level of the function generator and the CRO VOLTS/DIV control to the numbers given in Table 21-2 and estimate the other peak-to-peak waveform deflections expressed in major divisions, for example, 2.5 and 3.7. Make these entries in Table 21-2. If your CRO has different markings, enter these in the table on the left with the corresponding vertical deflections of the square wave on the right.
22. Without changing the function generator output amplitude or waveform, connect the EVM to measure its output. The rms (effective) reading is ________ and the peak-to-peak reading (if there is such a scale on your EVM) is ________.
21. Set the VOLTS/DIV control to 0.5 and adjust the function generator for a peak-to-peak deflection of 4 divisions. Now move the inner control knob from the detent (calibrated) position and observe the effect on the deflection caused by the square wave. The peak-to-peak deflection has increased or decreased. (Underline one word.)

Table 21-2

Volts/Div.	*Peak-to-Peak Divisions*
0.1	8
0.2	
0.5	
1	
2	
5	
10	

QUESTIONS

1. Give the manufacturer's name and the model number for the oscilloscope used in this experiment. Also state the date of publication of the laboratory manual for the CRO.
2. List the actual names of the terminal and operating controls of the oscilloscope used in this experiment. The listing should be in the order discussed in the "Introduction to AC Measurements" section of this manual.
3. Why should not a bright, stationary spot be allowed to appear on the CRO tube face?
4. If no spot, sweep trace, or waveform is visible, how can you tell if the CRO has been turned on? Is there another way of knowing if the power is on?
5. What causes a waveform to be visible on a CRO?
6. What is meant by a linear sweep?
7. How much vertical deflection would you expect if a 5-V dc level is applied to the INPUT with the VOLTS/DIV set at 10 and the INPUT SELECTOR set at AC?
8. Consider that a dc voltage is being measured with the VOLTS/DIV set at 5 so that a vertical deflection of 1 division is obtained. If the VOLTS/DIV is changed to 2, what will be the new deflection?
9. What will be the result of accidentally not placing the VOLTS/DIV control in the calibrated position?
10. Explain differences for the measurements obtained with the oscilloscope and those obtained with the EVM. [This question should be postponed if you have not yet had the theory of effective (rms) values in class.]

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 22

Square-Wave Frequency

READING ASSIGNMENT

Modern Electronics: A First Course, pages 438–446

Topics: Alternating-Current Fundamentals; Square Waves

OBJECTIVES OF EXPERIMENT

1. To measure the period and determine the frequency with one cycle on the oscilloscope CRT
2. To determine the frequency with a number of cycles visible on the CRT
3. To investigate the functions of other sweep controls on the oscilloscope

COMPONENTS AND EQUIPMENT REQUIRED

1. Triggered-sweep oscilloscope (CRO)
2. Function generator with square-wave output

PROCEDURE

1. Connect the function generator output to the VERTICAL INPUT terminal of the oscilloscope. Also provide a connection between the chassis of both pieces of equipment for a common ground.
2. Set the output of the function generator to its lowest level. Turn on both pieces of equipment and allow to warm up for a few minutes.
3. Set the oscilloscope triggering mode to AUTO and the VOLTS/DIV control to the largest setting.

4. The horizontal sweep line should now be visible. If it is not, adjust the HORIZONTAL POSITION and VERTICAL POSITION controls and the INTENSITY CONTROL as necessary to see the trace. Unless someone has accidentally or deliberately altered a normal setting of these controls, these adjustments should not be necessary. However, do not overlook the possibility that your instructor has altered the settings with the objective of testing your oscilloscope application skills. It may also be necessary to adjust the FOCUS and ASTIGATISM controls for the best display with the horizontal sweep visible and later with the desired waveform visible.
5. Set the function generator frequency to 1 kHz with square-wave output.
6. Set the TIME/DIV control at 10 ms. Change the VOLTS/DIV control progressively to smaller numerical settings. (Most standard oscilloscopes require that the control knob be turned clockwise to achieve this.) You should be looking to see a waveform appear, whether or not it is stable. If no vertical deflection is visible, increase the function generator output until the appearance of the original horizontal trace changes appreciably. This means that the output of the function generator and the sensitivity of the oscilloscope are compatible, or nearly so.
7. Many square-wave cycles should now be visible on the CRT. To reduce the number, change the TIME/DIV control to obtain less time per division. The proper setting will give the least number of cycles with at least one complete cycle visible. Be sure that the calibrated triggered sweep is being used. Count the number of divisions and decimal parts of a division and fill in the first two columns of Table 22-1.

Table 22-1

Time/Div.	*Divisions*	*Period T*	*Frequency f*

8. Multiply the first two entries of Table 22-1 to obtain the period and then obtain the reciprocal to find the frequency. Enter the results in Table 22-1.
9. Change the triggering mode control to cause triggering on the square-wave input. For most oscilloscopes the INT (for internal) position of the control is the correct position. If the square wave disappears, adjust the TRIGGER LEVEL until the square wave is again visible. Continue experimenting with the triggering level control first in one direction and then the other. Make a mental note of what happens, then reposition the control to see the square wave.
10. Locate the TRIGGER SLOPE control and observe the waveform when the control is in the + then - positions. Sketch the waveforms in Fig. 22-1.

Multiple-Cycle Frequency Determination

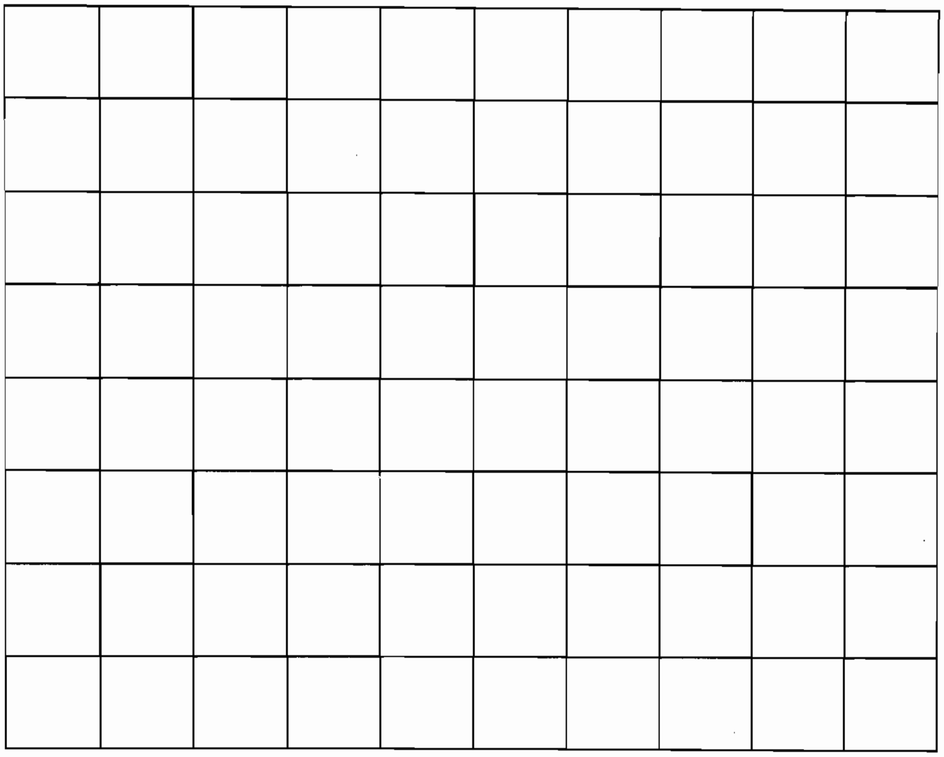
11. Change the TIME/DIV control so that a dozen or more complete cycles are visible. You should have a small enough number to be easily counted. Count the number of divisions and decimal parts of a division (by interpolation) between the start of the first cycle and the completion of the last whole cycle. Also count the number of whole cycles, *n*, in this space. Fill in the first three spaces in Table 22-2.
12. Calculate the period *T* using the formula

$$T = \frac{(\text{time/cm})(\text{divisions measured})}{n}$$

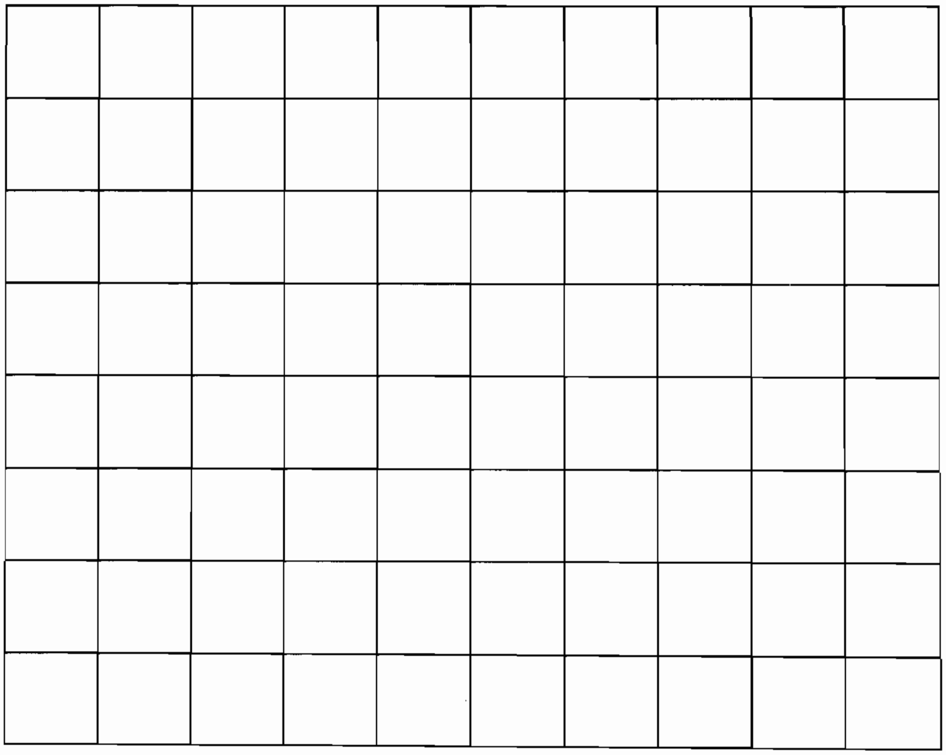
and then find the frequency by taking the reciprocal of *T*. Complete Table 22-2.

Table22-2

Time/Div.	*Divisions*	*Number of Cycles, n*	*T*	*f*



Trigger slope (+)



Trigger slope (–)

Fig. 22-1

Table 22-3

Func. Gen. *f*	*Time/Div.*	*Divisions*	*n*	*T*	*f*

13. Experiment with the function generator and the oscilloscope to determine the lowest and the highest frequencies that can be generated and measured. At least 5 cm (or horizontal divisions) must be used in the measurement. Fill in the first line (top line) and last line (bottom line) of Table 22-3 with these two limiting values. Note that $n = 1$ means that only one cycle is being used in the measurement. This corresponds to the method of steps 7 and 8. Any other value of n indicates the adoption of steps 11 and 12.
14. Determine three additional whole-number frequencies between zero and the upper limit. These should be selected so that there is approximately equal spacing between adjacent frequencies. Set the function generator to these frequencies and obtain the data to complete Table 22-3.

QUESTIONS

1. In step 11 are the positive and negative parts of the cycle of the same duration? (Consult Fig. 22-1 if you do not remember.)
2. As the triggering level control is changed in one direction or the other in step 10, why does the square wave disappear?
3. Why are the waveforms of Fig. 22-1 different in appearance?
4. If more cycles for a given function generator output (oscilloscope input) are to be observed, which oscilloscope control must be changed, and in what way?
5. Why is it necessary to divide by n in finding the period for step 13?
6. With our function generator/oscilloscope combination, what factor or factors limited the lowest frequencies that could be measured?
7. With our function generator/oscilloscope combination, what factor or factors limited the highest frequency that could be measured?
8. Describe the difference in appearance of the square wave at the highest frequency compared with the lowest frequency.
9. Compare the measured frequencies with the function generator frequency settings of Table 22-3. Assuming the oscilloscope calibration to be accurate, what can be said about the frequency accuracy of the function generator?
10. How does one know that the calibrated sweep is being used?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 23

Sine-Wave Alternating Current and Voltage Levels

READING ASSIGNMENT

Modern Electronics: A First Course, pages 446–453

Topic: Sine-Wave Alternating Current

OBJECTIVES OF EXPERIMENT

1. To employ a CRO to measure ac voltage levels
2. To determine effective ac voltages
3. To experiment with the TRIGGER LEVEL and TRIGGER SLOPE controls
4. To measure ac current
5. To demonstrate Ohm's law for a resistor

COMPONENTS AND EQUIPMENT REQUIRED

1. Triggered-sweep CRO
2. Function generator with sine-wave output
3. Meters: ac current; EVM and/or DMM
4. 680-Ω, $\frac{1}{2}$-W resistor

PROCEDURE

1. If the CRO being used is a different model from that used for Experiments 21 or 22, go back to Experiment 21 and review steps 1 through 6.

2. If the CRO has been used before, turn it on and obtain the horizontal line. With the INPUT SELECTOR control set to GND, adjust the line position to the center of the graticule. Change the INPUT SELECTOR control to AC.
3. Connect the function generator output terminals to the oscilloscope as was done in previous experiments. Place the function generator output level (amplitude) control to the middle position and the waveform selector to "SINE" and turn on the power. Adjust the TIME/DIV control to obtain one or several complete cycles that are stationary.
4. Adjust the VOLTS/DIV control of the CRO so that the maximum peak-to-peak sine wave is seen between the upper and lower graticule lines. Be sure that the control is set for calibrated readings.
5. At this time the sine-wave peak above the graticule centerline should equal the distance the minimum (negative peak) is below that line. (Distortion of the sine wave, or oscilloscope malfunction, may cause the two not to be equal.) Measure the peak-to-peak deflection, D_{pp}, and enter this number in Table 23-1. Calculate the rms value using the formula

$$V_{rms} = \frac{D_{pp} \times \text{volts/div.}}{2} \times 0.707 \tag{23-1}$$

   Enter this value in Table 23-1.
6. Connect the EVM, if one is available, across the function generator output terminals after selecting AC and the maximum range. Change the range setting to obtain the maximum scale deflection of the EVM pointer. Record the reading in Table 23-1.
7. Connect the DMM, if one is available, across the function generator terminals *after selecting AC and VOLTS.* Adjust the range to obtain the maximum number of digits and record the reading in Table 23-1.
8. Compare the values of V_{rms} obtained by the three methods. It is quite possible, although unlikely, that the three are the same. More likely, they will differ slightly. If the difference is greater than 10%, there are several possible reasons for the error or errors.
   a. Measurement procedure; repeat the steps to ensure that the readings are valid.
   b. One, and possibly two, or even all three instruments are malfunctioning or are out of calibration; try to determine which instrument(s) is at fault and consult the instructor.
9. Determine the maximum sine-wave output available from the function generator. If this maximum value is greater than 30 V, take 30 V to be the maximum. Divide this maximum level into 10 equal parts and adjust the function generator output in turn to 10%, 20%, and so on, of the maximum level, repeating steps 4 through 8 for each function generator output setting. Whole numbers are preferable for the voltage settings. Readings are to be taken using the CRO, EVM, and DMM. The results are to be recorded in a table to be constructed on a separate sheet of paper. This table, labeled Table 23-1A, should contain the columns of Table 23-1 and 10 rows for the 10 sets of measurement data.
10. Change the TRIGGER MODE control from AUTO to INTERNAL. If you are lucky, the sine wave will be seen, most likely displaced from its former position to the right or to the left. Very often, though, the sine wave will simply disappear. When this happens, adjust the TRIGGER LEVEL control until the sine wave reappears. If the sine wave cannot be made visible by this last adjustment, consult the CRO manual to confirm the functions of the controls and try again. Instructor assistance may be necessary to complete this step successfully.
11. Adjust the TRIGGER LEVEL control first in one direction and then the other just far enough so that the sine wave disappears. Try to understand what the appearance of the displayed sine wave is telling you about the function of the TRIGGER LEVEL control.

Table 23-1

CRO		*EVM*	*DMM*
D_{pp}	V_{rms}	V_{rms}	V_{rms}

12. Repeat step 11. However, upon reaching each extreme where the sine wave disappears, back off slightly so that the sine wave reappears. Sketch the appearance of the two waveforms in Fig. 23-1. *Use 10 divisions of this figure for one period of the sine wave.* Note that one division of the figure and one division of the cathode ray tube will not represent the same time span or fractional part of a cycle.

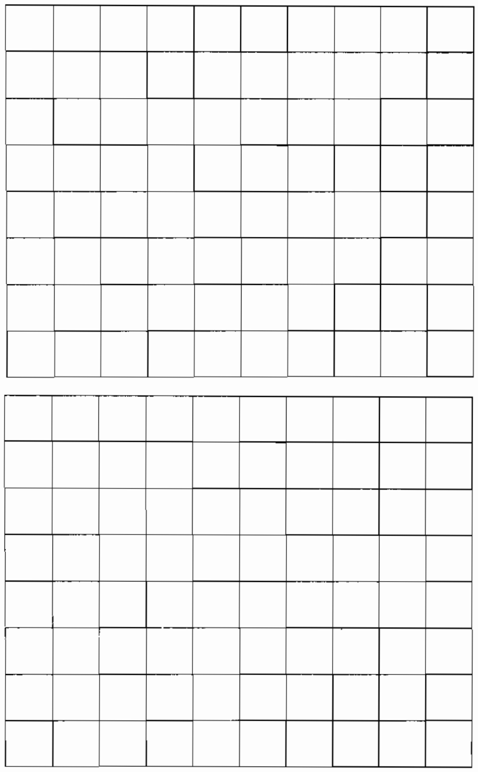
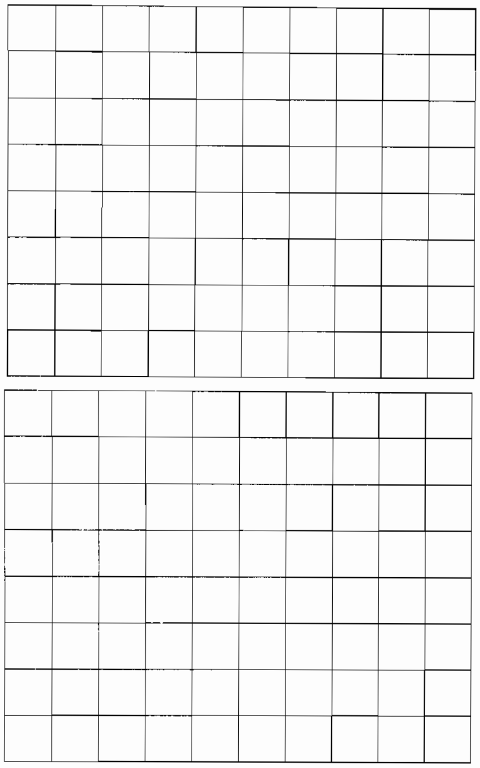


Fig. 23-1



13. Take a careful look at the **TRIGGER SLOPE** setting. This setting has not been previously specified. It may be either + or –. First adjust the **TRIGGER LEVEL** so that triggering occurs approximately midway between the maximum (peak) level and the minimum (negative peak) levels. Sketch the waveform in Fig. 23-2. Change the **TRIGGER SLOPE** setting from + to – or – to +. Observe the changed appearance of the sine wave and sketch this waveform in Fig. 23-2.

Fig. 23-2

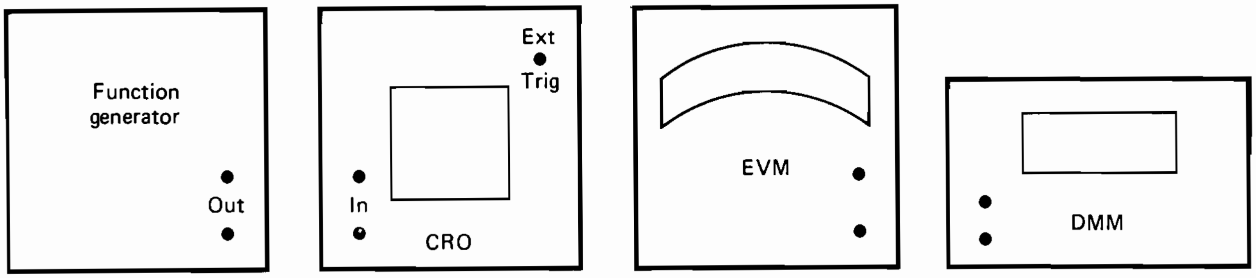


Fig. 23-3

14. Complete the wiring diagram of Fig. 23-3 so that it applies for the previous measurements using the CRO, the EVM, and the DMM.
15. Connect the circuit of Fig. 23-4 using an ac current meter and either an EVM or DMM to measure the voltage. Adjust the output levels of the function generator, set to deliver a sine wave, to approximately the same levels required in step 9. Measure the voltage and the current for each sine-wave voltage level and enter the measured voltages and current values in Table 23-2. Remove the resistor from the circuit and measure its value using the EVM or DMM. Enter this value in Table 23-2.

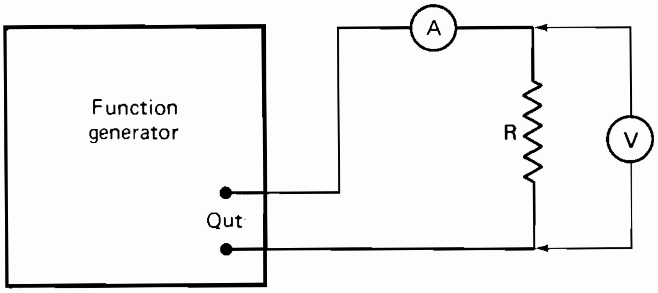


Fig. 23-4

Table 23-2

R (measured) = ____________

V	*I*	*R* (*Calculated*)

16. For each row in Table 23-2, determine the resistance from the measured values of voltage and current using Ohm's law. Enter the calculated values in Table 23-2.

QUESTIONS

1. Explain how you know that your CRO is set for calibrated voltage readings as requested in step 4.
2. In using an EVM, why is it desirable to obtain the maximum on-scale deflection?
3. Referring to step 10, can you explain why the waveform might disappear when the TRIGGER MODE control is changed from AUTO to INTERNAL? If not, review the procedure followed in step 11 and repeat it if you cannot recall what happens as the TRIGGER LEVEL control is adjusted in both directions.
4. Examine the sketched waveforms of Fig. 23-2. Indicate under each sketch whether triggering was "+ slope" or "- slope."
5. In Fig. 23-3 the CRO, function generator, EVM, and DMM are connected in ______________. (Fill in the blank with either "series" or "parallel.")
6. In Table 23-2, are effective or peak values of the voltages recorded? Are effective or peak values of the currents recorded?
7. Can a standard dc meter with a permanent magnet field (D'Arsonval movement) be used to measure alternating currents in the range 100 to 1000 Hz?
8. The resistance as found using Ohm's law is the ratio of voltage to current. Can effective values of voltage and current be used in the calculation? Can mixed peak and effective values be used, and if not, why not?
9. Comment on the comparison of the measured value of R and the calculated values of R using the V and I in Table 23-2.
10. Name one advantage in using the oscilloscope for making ac voltage measurements.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 24

Sine-Wave AC Voltage Timing

READING ASSIGNMENT

Modern Electronics: A First Course, pages 446–453

Topic: Sine-Wave Alternating Current

OBJECTIVES OF EXPERIMENT

1. To obtain the frequency of a sine wave with one cycle visible on the CRO
2. To obtain the frequency of a sine wave with a number of cycles visible on the CRO
3. To observe the effect of input frequency change on the cycles visible with a fixed time base
4. To explore the frequency-measuring capabilities of the CRO

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (sine wave)
2. Triggered-sweep CRO

PROCEDURE

1. Connect the output terminals of a function generator to the input terminals of the CRO as was done in previous experiments. Set the function generator output amplitude to midrange and the frequency to 1 kHz. Set the TRIGGER MODE control of the CRO to AUTO and the INPUT SELECTOR to AC.
2. Turn on both the function generator and the CRO. Using the procedures of previous experiments, obtain the least number of whole cycles (with TIME/DIV calibrated) having the waveform centered vertically

and with the peaks within the bounds of the graticule. The importance of being able to do this with confidence in a reasonable time cannot be overemphasized. If the students are working in teams, each team member should operate the controls to obtain the displayed waveform. Before leaving this step, each team member should demonstrate his or her ability to do so after the controls have been deliberately altered so that the waveform is not visible or is unusable as originally seen. Time spent in practice so as to understand the functions of the related controls will pay generous dividends later.

3. Assuming that the TRIGGER MODE control is presently on AUTO, reset it to INTERNAL and make the proper adjustment of the TRIGGER LEVEL control so that the sine wave is visible with triggering occurring halfway between the positive and negative peaks. Adjust the position controls so that the sine-wave cycle starts at the left end of the center horizontal graticule line. If all adjustments have been properly made, the peaks are equal distances above and below this centerline.
4. Count the number of divisions from the left zero crossing (start of cycle) to the next zero crossing with the same slope. In doing so, count the number of major divisions marks and subdivisions marks with interpolation as required. Fill in the data of Table 24-1 noting the sample values given for your convenience. Note that the measured period is the product of the number of DIVISIONS measured and the TIME/DIV. The calculated frequency f is the reciprocal of the period. Thus, for the sample,

Table 24-1

	Func. Gen. f	*Time/Div.*	*Divisions*	*Measured* T	*Calculated* f
Sample:	1 kHz	100 μs	9.9	990 μs	1100 Hz

$$T = 100 \times 9.9 = 990\ \mu s$$

$$f = \frac{1}{990 \times 10^{-6}} = 1100 \text{ Hz}$$

5. Change the TIME/DIV control so that at least 10 (the number should be easily counted) whole cycles are clearly visible. The triggering level should not have changed. Now count the number of scale divisions to the end of that last whole cycle and enter this number in Table 24-2. Also count the number of whole cycles. Enter this quantity in Table 24-2. The calculations are performed as before except that divisions by the number of whole cycles is necessary to obtain the period. Thus, for the sample,

Table 24-2

	Func. Gen. f	*Time/Div.*	*Divisions*	*Number of Cycles*	*Measured* T	*Calculated* f
Sample:	1 kHz	1 ms	9.9	10	990 μs	1100 Hz

$$T = \frac{1 \times 9.9}{10} = 0.99 \text{ ms} = 990\ \mu s$$

$$f = \frac{1}{990 \times 10^{-6}} = 1110 \text{ Hz}$$

6. Keeping the TIME/DIV the same, increase the function generator frequency while observing the displaced waveform. Fill in the blank of line 1 in Table 24-3. Use "Increase," "Decrease," or "Same" in the blanks. Repeat for a reduced frequency; fill in line 2.

Table 24-3

Time/Div.	*Func. Gen. f*	*Number of Cycles*
Same	Increase	
Same	Decrease	
Increase	Same	
Decrease	Same	

7. Return to 1 kHz and the TIME/DIV setting of Table 24-2. Increase the TIME/DIV without changing the frequency. Fill in line 3. Repeat for a decreased TIME/DIV and fill in line 4.
8. In this step and the one to follow, the techniques for measuring period and obtaining frequency will be applied. Start by measuring the highest possible frequency as limited by either the function generator or the CRO. In exploring the highest frequency, it is better to make gradual changes both in the increases in function generator frequency and decreases in TIME/DIV for the CRO rather than large, abrupt changes. The highest frequency that can be measured with the present instrument combination will be limited by one of the following:
   a. Highest frequency produced by the function generator
   b. Lowest TIME/DIV setting of CRO

   When the highest frequency that can be measured has been obtained, fill in Table 24-4. You may want to record additional data such as the maximum frequency setting of the function generator and the least setting of TIME/DIV for the CRO, as the Questions will require information of this kind.

Table 24-4

Func. Gen. f	*Time/Div.*	*Divisions*	*Number of Cycles*	*Measured T*	*Calculated f*

9. The lowest frequency that can be measured by the instrument combination depends on one of the following:
   a. Lowest frequency produced by the function generator
   b. Greatest TIME/DIV setting of CRO

   Proceed by reducing the function generator frequency and increasing TIME/DIV for the CRO until one of the preceding limitations is encountered. Then fill in Table 24-5. You may also want to record the maximum TIME/DIV setting for the CRO and the lowest frequency setting for the function generator.

Table 24-5

Func. Gen. f	*Time/Div.*	*Divisions*	*Number of Cycles*	*Measured T*	*Calculated f*

QUESTIONS

1. In steps 3 and 4, adjustments were made to count time divisions between zero crossings of the waveform. Can other reference points on the waveform be used?
2. The idea of TIME/DIV and its use in measuring period is based on a particular characteristic of the sweep. The sweep is said to be ____________. (Fill in the blank.)

3. In counting divisions it is usually necessary to interpolate. Why? Where have you used interpolation before?
4. The concept of "period" has been clearly demonstrated in this experiment. If you have exactly one period of a sine wave displayed, is it possible to predict exactly the waveform for a second period, a third period, and so on?
5. About how many cycles on the CRO do you believe can be easily and accurately counted? 10, 100, 1000, 10,000 (Circle one.)
6. Keeping the TIME/DIV the same while increasing the function generator frequency causes more cycles to be seen. Therefore, keeping the TIME/DIV the same while decreasing the function generator frequency will cause ____________ cycles to be seen.
7. Increasing the TIME/DIV setting while keeping the frequency the same causes more cycles to be seen. Therefore, decreasing the TIME/DIV setting while keeping the frequency the same causes ____________ cycles to be seen.
8. The ____________ causes the basic high-frequency measurement limitation for the CRO/function generator combination used.
9. The ____________ causes the basic low-frequency measurement limitation for the CRO/function generator combination used.
10. Select the one most valuable conclusion to be drawn from this experiment and describe it in one short paragraph.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 25

Power and Effective Value

READING ASSIGNMENT

Modern Electronics: A First Course, pages 453–457

Topics: AC Power; Effective Voltage

OBJECTIVES OF EXPERIMENT

1. To demonstrate the conversion of electrical energy to heat
2. To demonstrate the equal heating capability of dc and the equivalent effective ac
3. To derive, by graphical means, the factor for converting peak ac values to effective values

COMPONENTS AND EQUIPMENT REQUIRED

1. An available quantity of 18-Ω, $\frac{1}{2}$ W resistors (at least a dozen, from which two will be selected and used)
2. Adjustable dc power supply capable of providing at least 0.5 A at 3 V
3. Isolation transformer and variable autotransformer (60 Hz)
4. Meters: dc current; ac current; VOM, EVM, or DMM
5. CRO
6. Two toggle (or other) single-pole single-throw (SPST) switches

PROCEDURE

1. Connect the circuits of Fig. 25-1 using the isolation transformer and the variable autotransformer for the 60-Hz source after selecting resistors of the same type having nearly identical values. It is not necessary

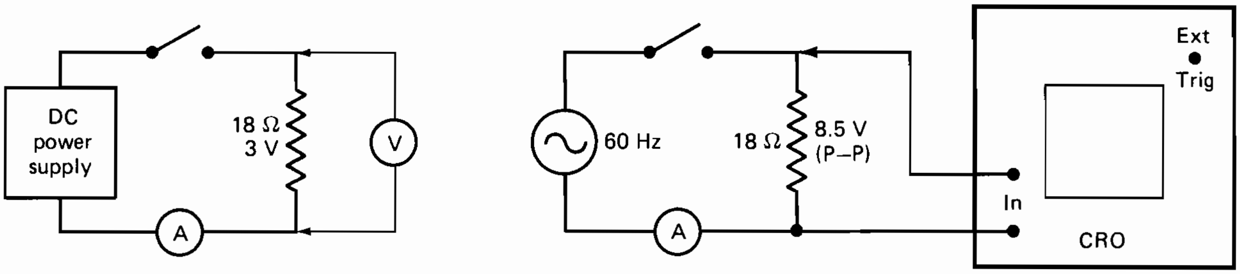


Fig. 25-1

that each be exactly 18 Ω, but rather that the difference in their resistances be small. By trial and error, match the resistors so that the resistances do not differ more than 1 Ω as measured by a VOM or other reasonably accurate means. Arrange the circuits so that each resistor has approximately the same thermal environment. That is, they should be in approximately the same location, without touching each other and supported by the same material on the bench top. Wood is satisfactory; avoid metal contacts with the resistors except for the leads, which should be connected close to the ends of the pigtails.

2. Close the switches at the same time after having adjusted the voltages as shown in Fig. 25-1. Immediately readjust the voltages to compensate for loading the sources. Read and record the current and voltages for the first four columns and the first row of Table 25-1. You will now allow the resistors to heat as you branch to another procedure.

Table 25-1

	DC Current	*AC Current*	*DC Voltage*	*AC Volts (p-p)*	*AC Volts (rms) (Calculated)*
Initial					
Final					

Graphical Analysis of Effective Value

3. Refer to Table 25-2. The first column contains the angles starting at zero and increasing by 15° increments to 360°. The assignment is to find the sine of the angle, place that value in the second column, square it and place the squared value in the third column. You will be using your calculator to do this, so the job is easy. Moreover, a number of checkpoint answers have been given as assistance so that you can be confident about your numbers.
4. For each sine value of A in Table 25-2, locate the point on Fig. 25-2. Make a dot at that location on the figure.
5. Sketch a smooth curve through each point. Depending on your ability to do this, the curve should more or less resemble the familiar sine graph.
6. Now plot the values for the third column of Fig. 25-2. Note that they are all positive ranging from 0 to 1.
7. The level, midway between 0 and 1, is the average value of the squared wave. Draw it in as a horizontal line on Fig. 25-2. The level of the average for this square is $\frac{1}{2}$ or 0.5.
8. Now, take the square root of 0.5. This is the effective value and what you see on the calculator is 0.707.

AC Power Dissipation

9. We return now to the circuits of Fig. 25-1. A quick touch of each resistor should indicate that each is warm. This is a clear indication of power dissipation. Electrical energy is being changed into heat energy. Heat energy raises the temperature of the object (the resistors in this case) so that it can be spread to the air and any solid objects in contact with the resistors. After a sufficient time the temperature will stop

Table 25-2

A (deg)	$\sin A$	$\sin^2 A$
0	0	0
15	0.2588	0.0670
30	0.5000	0.2500
45	0.7071	0.5000
60	0.8660	
75		
90		1.0000
105		
120		
135	0.7071	
150		
165		0.0670
180		
195	-0.2588	0.0670
210		
225		0.5000
240		
255		
270		
285		
300	-0.8660	
315		
330		
345		

rising so that the rate of energy transfer from each resistor will exactly balance the rate of energy conversion. Since each resistor has the same thermal environment, the temperature of the two should be equal if and only if the ac current has the same heating value as the dc current in the other circuit. Touch each resistor and judge for yourself whether they seem to be equally hot. They should be. Repeat the reading and recording of step 2 for the second row.

Effective Value

10. Assuming that the resistors seem to be at the same temperatures, we must conclude that the power source voltage levels must have the same effective values.
11. Calculate the effective value of the sine wave. Assuming no errors in the calculations, the effective value for the sine wave found this way should exactly equal the dc value. Enter the effective value in Table 25-1.

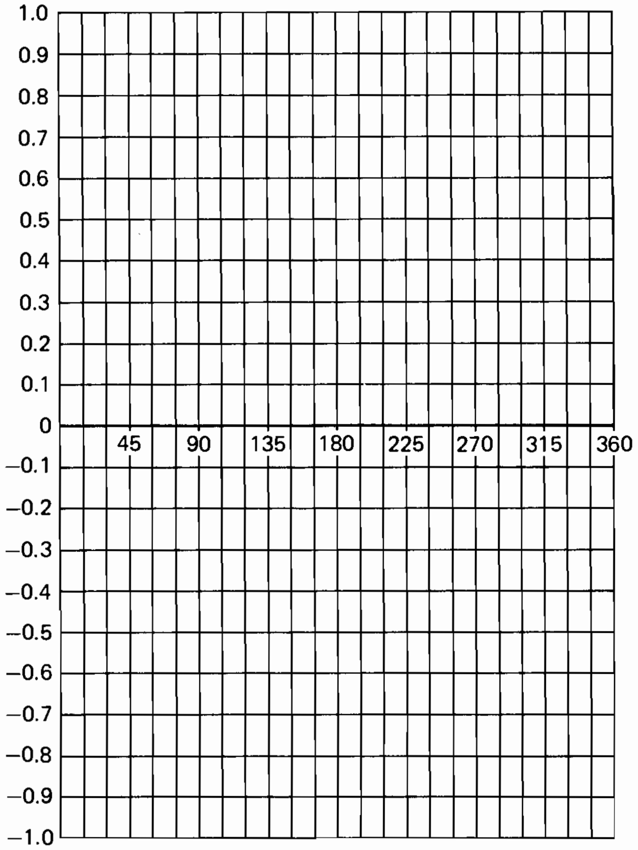


Fig. 25-2

QUESTIONS

1. What is (a) the maximum (peak) value of the sine wave for Table 25-2; (b) the minimum (least) value; and (c) the maximum value of $\sin^2 A$?
2. State the formula learned for dc circuits which is related to the squaring of the sine wave in Table 25-2.
3. Using the resistance values of Fig. 25-1 together with the applied voltages, calculate the power dissipated in the dc circuit using three different methods.
4. Perform the power calculations for the ac circuit (Fig. 25-1) using three different methods.
5. Review steps 3 through 8 of the procedure. Why do we refer to the effective value of an ac current (or voltage) waveform as the root-mean-square (rms) value? (*Hint:* Here average and mean have identical meanings.)
6. The ac voltage across a 180-Ω resistor is measured using an oscilloscope. The difference between the valley of the sine wave and the peak is 6.6 divisions and the setting of the oscilloscope is 0.1 volt per division. How much power is being dissipated as heat?
7. If you connected a standard resistor to the input of the oscilloscope and heated the resistor with a candle or other source of heat, what waveform will be observed on the oscilloscope? Choose from among (a) a dc change of level; (b) a sine wave; and (c) no sine wave or dc.
8. In Fig. 25-1, if the resistance value is halved, by what factor will the dissipated power be changed?
9. Find the peak-to-peak (p−p) value of the current drawn by a 60-W, 120-V incandescent lamp under rated conditions.
10. Referring to step 9, suggest a simple improvement for the experiment.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 26

Alternating Current in an Inductor

READING ASSIGNMENT

Modern Electronics: A First Course, pages 347–355, 459–464

Topics: Time Constant of an *LR* Circuit; AC in an Inductor

OBJECTIVES OF EXPERIMENT

1. To study phase angles in a series *RL* circuit with ac at 60 Hz
2. To observe the waveform of inductor voltage and resistor voltage for a series *RL* circuit with square-wave input
3. To observe phase angles of a series *RL* circuit in the frequency range 1 to 10 kHz
4. To compare the reactance and impedance of an inductor in the frequency range 1 to 10 kHz

COMPONENTS AND EQUIPMENT REQUIRED

1. Isolation transformer
2. Variable autotransformer (120-V, 60-Hz input)
3. Resistors: 100 Ω, 1000 Ω, 3300 Ω
4. Inductors: 8 H, 30 mH
5. Meters: ac current; EVM or DMM
6. Triggered-sweep CRO
7. Function generator (sine wave and square wave)

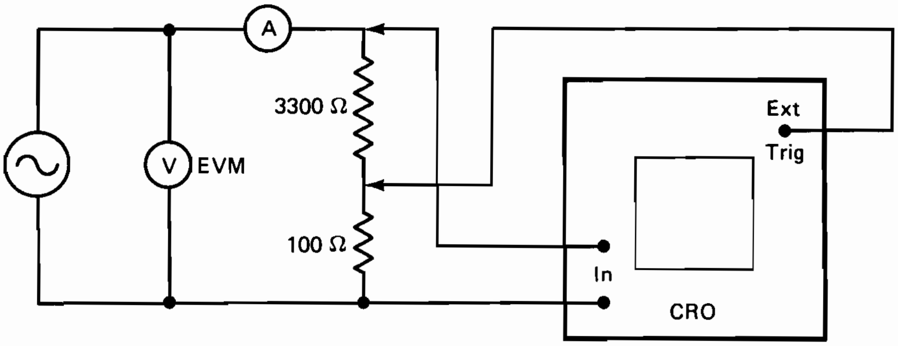


Fig. 26-1

PROCEDURE

1. Connect the circuit of Fig. 26-1 using a 3300-Ω resistor, a 100-Ω resistor, an EVM, a current meter, and a 60-Hz source. The 60-Hz source consists of an isolation transformer connected to the laboratory line source. The input plug of a variable autotransformer is connected to the secondary winding of the isolation transformer. The output terminals of the variable autotransformer become the terminals of the source, as shown in the figure.
2. Turn on the CRO and turn on the power for the 60-Hz source. Set the source output to 20 V. The current reading is ________ mA. With the proper settings of the CRO controls it should be possible to obtain a stable waveform on the CRO. Start by setting the TRIGGER MODE to AUTOMATIC, which will provide a horizontal trace with no signal input and some visible display with a signal input. Adjust the TIME/DIV to obtain a stable waveform. Adjust the VOLTS/DIV so that the entire waveform is visible from bottom to top.
3. Change the TRIGGER MODE to INTERNAL and adjust the TRIGGER LEVEL so that the sine wave displayed starts midway between the lowest and highest levels with the TRIGGER SLOPE set at +. In making this adjustment it is best that a single sine wave be visible. This can be achieved by using the VOLTS/DIV control uncalibrated.
4. Change the TRIGGER MODE to EXTERNAL. Triggering of the sweep has now been transferred from the CRO input waveform to that of the 100-Ω resistor. In both cases the *voltage* waveforms are responsible for triggering. (*Note:* If the level of voltage for your oscilloscope is too low, external triggering may not occur. A larger resistor may be required in place of the 100-Ω resistor shown in Fig. 26-1. A smaller resistor is more desirable for the purpose of this experiment. Any change in this resistance value should be noted on Fig. 26-1.)
5. Carefully observe the waveform as displayed and sketch it on Fig. 26-2.
6. Turn off the voltage source of Fig. 26-1 but do not turn off the CRO. Change the circuit of Fig. 26-1 to that of Fig. 26-3 by replacing the 3300-Ω resistor by an 8-H inductor. When you turn on the source power again the new current reading is ________ mA, which should not be greatly different from the reading recorded in step 2.

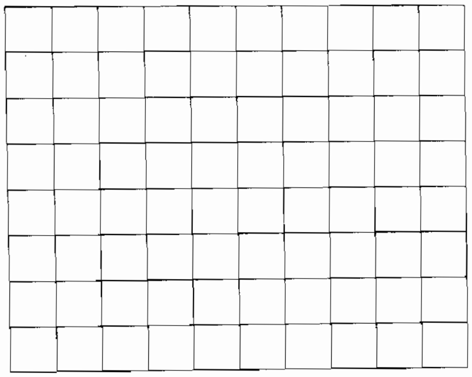


Fig. 26-2

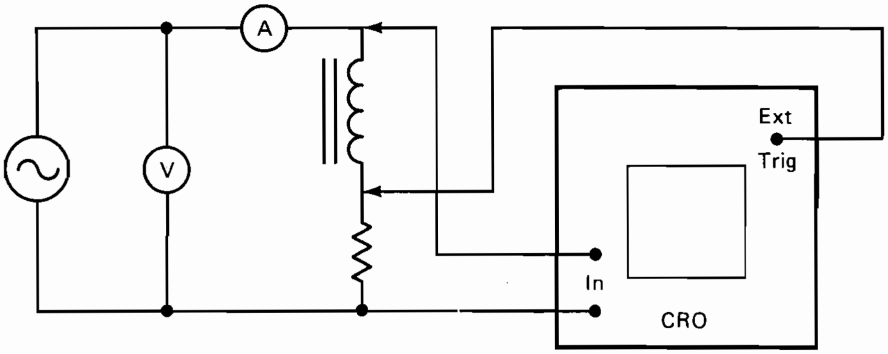


Fig. 26-3

7. A stable waveform should now be visible. However, it should not have the same phase angle as that of Fig. 26-2. Sketch the full waveform in Fig. 26-4.
8. In Figs. 26-1 and 26-3 the CRO is triggered by the voltage across the 100-Ω resistor. This voltage is in phase with the current passing through it. Based on this information, the applied voltage of Fig. 26-2 ______________ the current by ________. [Fill in using "leads," "lags," or "NA" (for "not applicable") and the number of degrees as either 0° or 90°.] The voltage in Fig. 26-4 ______________ the current by ________. (Select from among the answers given previously.)

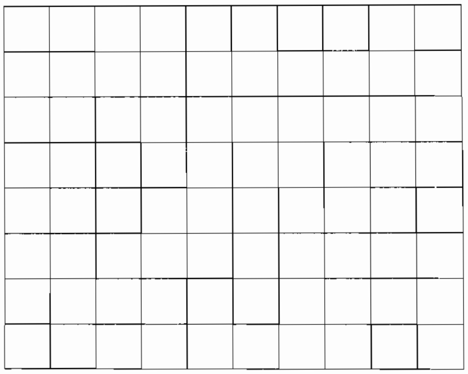


Fig. 26-4

9. Connect the 30-mH inductor in series with a 100-Ω resistor. Now place this combination across the output terminals of the function generator as shown in Fig. 26-5. Connect the EXTERNAL TRIGGER input terminal on the CRO to point *A*. Also connect the INPUT lead of the CRO to point *A*. The TRIGGER MODE control should be on EXTERNAL.
10. Turn on the function generator and set the controls to deliver roughly 5 V (p-p) with a square wave of 1000-Hz frequency. Many function generators will not deliver a square wave with the load of Fig. 26-5.

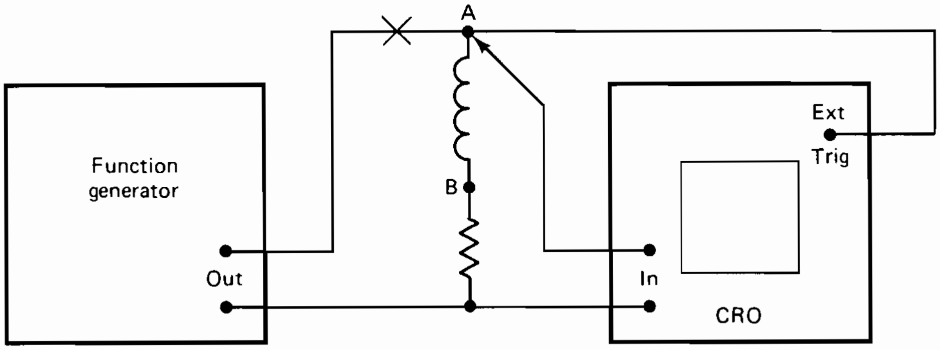


Fig. 26-5

The changing current in the circuit will cause an iR_o drop, where R_o is the output resistance (Thévenin resistance) of the function generator. This iR_o drop is superimposed on the internal square wave generated by the function generator. It may cause the terminal voltage waveform to be substantially different from a square wave. The greatest differences will be seen as the wave polarity changes. Similarly, the wave is nearest to the internal square-wave peak value immediately before the polarity change. For this reason the 5-V level difference control setting should be made so that the levels where the wave is nearly horizontal, are considered to be the peak values of the square wave.

11. Adjust the CRO controls to observe several cycles of the square wave. Using the calibrated VOLTS/DIV setting, adjust the function generator output to exactly 5 V (p-p).
12. Use the calibrated TIME/DIV control set at 1 ms and adjust the function generator frequency control so that exactly 10 square-wave cycles occupy the 10 major divisions across the CRO graticule. This means that the frequency has been adjusted to 1000 Hz in accordance with the CRO calibration.
13. Readjust the TIME/DIV control to observe one complete cycle. (*Note:* The TIME/DIV control need not be calibrated for this purpose.) Move the CRO input lead to point *B* to see the voltage across the resistor. The waveform seen is that of the circuit current, which builds up to the steady value after the voltage of one polarity is applied. It then begins to increase in the opposite direction after the voltage of the opposite polarity is applied. Sketch the waveform in Fig. 26-6.

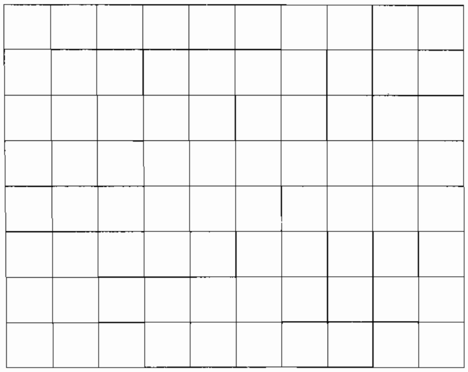


Fig. 26-6

14. Temporarily disconnect the function generator from the circuit without changing its control settings. Interchange the resistor and the inductor so that the resistor is now connected between points *A* and *B* while the inductor is now connected to *B* and the common terminal of the two equipments.
15. Reconnect the function generator and observe the voltage across the inductor. The peak voltage seen on the CRO is ________ V. Sketch the waveform carefully on Fig. 26-7.
16. Reconstruct the circuit of Fig. 26-5. Change the function generator output so that a sine wave is being delivered. Open the circuit at point *X* and insert a current meter, being careful that its range is adequate for the current anticipated. Also place the resistor and inductor in the positions shown in Fig. 26-5.

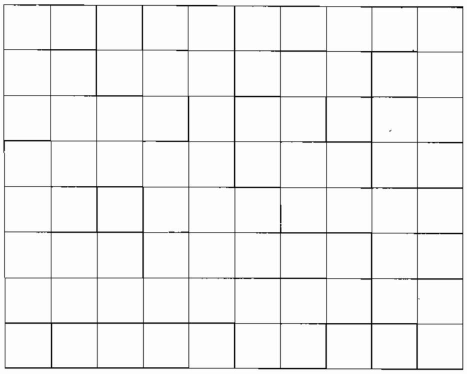


Fig. 26-7

Using the calibrated VOLTS/DIV setting of the CRO, adjust the function generator output to be 5 V (p-p). One full sine wave should be seen occupying the 10 major divisions across the CRO face. Make the appropriate adjustments with the TIME/DIV control (not calibrated) to obtain this waveform if necessary.

17. Carefully center the waveform in the vertical direction. Read the total voltage and the point, counting from the left, at which the waveform crosses the center, horizontal graticule in the upward direction (positive slope) with the CRO lead at point *A*. Also read the current and enter the data in Table 26-1 at the appropriate places.
18. Move the CRO lead from point *A* to point *B*. Read the resistor voltage and the new zero-crossing points. The difference between this point and the one observed in step 17 is a measure of the phase angle between the total applied voltage, which leads, and the resistor voltage, hence current, which lags. This phase angle can be found as follows:

$$\text{phase angle} = \frac{\text{zero-crossing difference}}{10} \times 360 \qquad (26\text{-}1)$$

Perform this calculation and enter the phase-angle value in the proper box in Table 26-1.

19. Convert the total voltage in Table 26-1 to effective (rms) values.

$$V_T(\text{rms}) = \frac{V_T(\text{p-p})}{2} \times 0.707 \qquad (26\text{-}2)$$

20. Using V_T(rms) and the I recorded in Table 26-1, find Z.

$$Z = \frac{V_T(\text{rms})}{I} \qquad (26\text{-}3)$$

Enter the Z value in Table 26-1.

Table 26-1

f (Hz)	*Total Volts* (p-p)	*Resistor Volts* (p-p)	*Zero Crossing* (*A*)	*Zero Crossing* (*B*)	*I*	*Phase Angle*	*Z*	*X* (*Calc.*)

21. Calculate the value of X using the rated inductance and the frequency

$$X(\text{calc.}) = 2\pi fL \tag{26-4}$$

Enter X(calc.) in Table 26-1.

22. Repeat steps 16 through 21 for each frequency in Table 26-1. The frequencies should all be adjusted using the CRO with calibrated TIME/DIV settings.

QUESTIONS

1. At several points in this experiment you were asked to make sure that the scope readings were calibrated. Different ways of stating this requirement were used, but the same meaning was intended. What is the consequence of not observing this precaution?
2. By way of review, what is the purpose of the *shunt* resistor of a VOM? (*Hint:* Is it to extend the voltage range or the current range of the basic instrument?)
3. Referring to Figs. 26-2 and 26-4, if there is not an exact 90° phase difference, what might be the reason?
4. A square wave can be produced using a dc source, apparently by causing the polarity of this source to be reversed using a ______________.
5. The time constant for the circuit of Fig. 26-5 is _______ μs. Is this value consistent with the waveform in Figs. 26-6 and 26-7? Indicate the time constants as horizontal lines drawn to scale just below the graticule lines of Figs. 26-6 and 26-7.
6. Equation (26-1) has the number 10 in the denominator. Why?
7. Equation (26-2) has the number 2 in the denominator. Why?
8. The calculated inductive reactance in Table 26-1 should always be less than the corresponding value of the impedance. If this is not always the case, what possible reason might be the cause?
9. The 30-mH inductor has resistance as well as inductance. According to the data in Table 26-1, at which frequency does this resistance cause the impedance and the inductive reactance to differ the most?
10. Assuming that X(calc.) is a reasonably accurate value at 1000 Hz in Table 26-1, the resistance of the inductor is _______ Ω.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 27

Alternating Current in a Capacitor

READING ASSIGNMENT

Modern Electronics: A First Course, pages 388–397, 467–470

Topics: Time Constant of *CR* Circuit; Alternating Current in a Capacitor; Capacitive Reactance

OBJECTIVES OF EXPERIMENT

1. To observe the waveform of capacitor voltage and capacitor current for a series *RC* circuit with square-wave input
2. To determine the capacitive reactance of a capacitor at different voltages
3. To determine the capacitive reactance of a capacitor at different frequencies
4. To determine the capacitive reactance of different capacitors at the same frequency
5. To observe the phase difference between the capacitor voltage and current

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator having square-wave and sine-wave outputs
2. Meters: ac current; EVM or DMM
3. Capacitor assortment: at lease five capacitors from 0.05 to 0.5 μF (nonpolarized), including 0.1 μF
4. Resistor: 120 Ω, 4.7 kΩ, 10%, $\frac{1}{2}$ W

PROCEDURE

1. Connect a 0.1-μF capacitor in series with a 1000-Ω resistor across the output terminals of a function generator as shown in Fig. 27-1. The CRO is connected with the VERTICAL INPUT lead at point *B* so

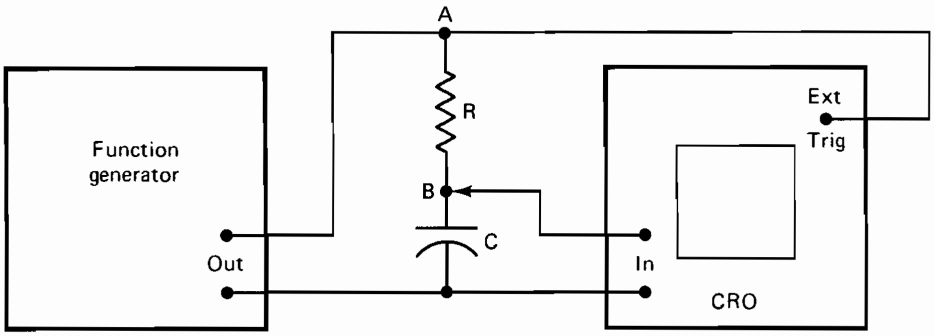


Fig. 27-1

that the capacitor voltage waveform is displayed. The EXTERNAL TRIGGER terminal of the CRO is connected to point A so that the sweep will be triggered by the function generator output. Set the CRO TRIGGER MODE to AUTOMATIC and the function generator to provide a 1000-Hz square wave. Turn on both pieces of equipment and adjust the CRO to obtain a stable waveform.

2. Set the VOLTS/DIV control to 1 V (calibrated) and adjust the function generator to obtain a peak-to-peak (p-p) voltage of 8 V with the input CRO lead temporarily placed at point A. The displayed square wave should be centered vertically.
3. Set the CRO TIME/DIV control to 1 ms (calibrated). Adjust the function generator frequency until exactly 10 full cycles are visible covering the 10 graticule divisions across the tube face.
4. Change the TIME/DIV control setting to 100 μs and a single cycle should be visible. Change the CRO TRIGGER MODE to EXTERNAL. The same waveform should be seen with a possible phase reversal. This waveform should be sketched on Fig. 27-2 and labeled "APPLIED VOLTAGE."
5. Move the CRO input lead from point A and place it a point B, as shown in Fig. 27-1. A new waveform should now be seen. Sketch this waveform on Fig. 27-2 atop the square wave drawn in step 4. Label the new waveform "CAPACITOR VOLTAGE."

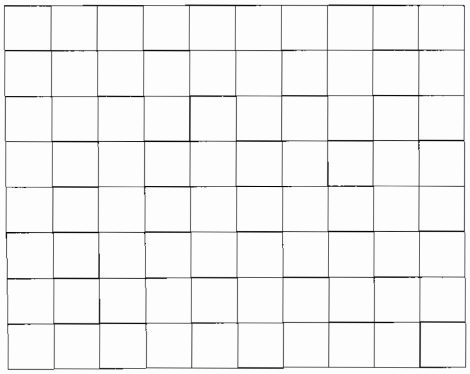


Fig. 27-2

6. Starting with 0 on the left, mark the time scale for Fig. 27-2. The numbers appearing at the bottom of the figure should be 0, 0.1, 0.2, . . . , 1.0 ms. Now calculate the time constant using the equation

$$\text{time constant} = RC \tag{27-1}$$

Record the time constant in Fig. 27-2 near the capacitor waveform.

7. Replace the 0.1-μF capacitor in Fig. 27-1 with a 0.5-μF capacitor. Check and adjust as necessary the function generator for an 8-V (p-p) square wave of 1000 Hz. An altered capacitor voltage waveform should now be seen. Sketch this new waveform in Fig. 27-3. Place the time scale on Fig. 27-3 as was done for Fig. 27-2. Calculate the new time constant using Eq. (27-1) and record it on Fig. 27-3.

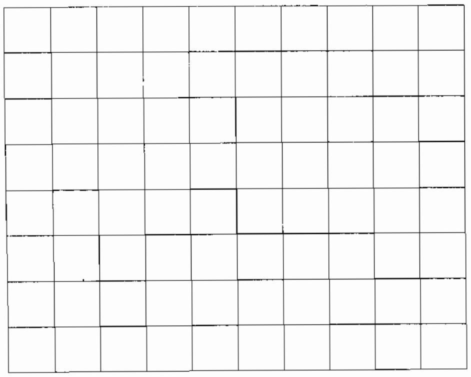


Fig. 27-3

8. Alter the circuit of Fig. 27-2 again. This time use $R = 4.7\ \text{k}\Omega$ and $C = 0.1\ \mu\text{F}$. Follow the procedures of the preceding steps to ensure an 8-V (p-p) square wave of 1000 Hz frequency output for the function generator. Observe the capacitor voltage waveform and sketch it in Fig. 27-4. Mark the time scale and time constant on this figure.

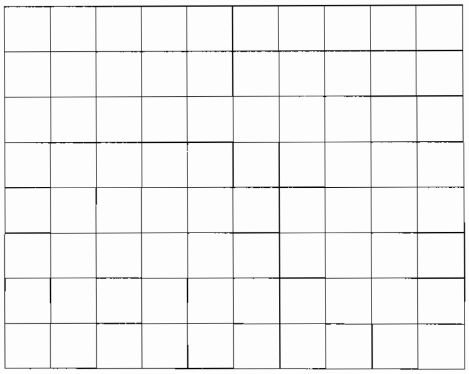


Fig. 27-4

9. Construct the circuit of Fig. 27-5 using the function generator, a 0.5-μF capacitor, an ac current meter, and an EVM or DMM to measure the voltage.
10. Adjust the amplitude control of the function generator to midrange and the frequency to 1 kHz with a sine-wave output. Turn on the power.
11. Adjust the function generator over the full range of other amplitudes available for which voltage and current readings can be taken. As the amplitude is increased, both the current and voltage readings should be seen to increase. Similarly, as the amplitude is decreased, both meter readings should be seen to decrease. Record nothing at this time.
12. Select a convenient value for the maximum voltage to be used and subdivide it into five equal parts, (e.g., 3, 6, 9, 12, and 15 V, or 2, 4, 6, 8, and 10 V).

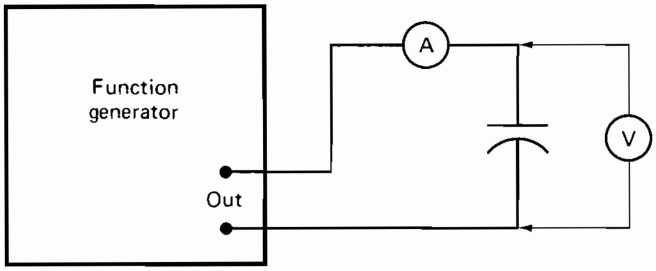


Fig. 27-5

Table 27-1

V	I	X_c

13. Adjust the applied voltage as read by the voltmeter to the lowest selected voltage, or to a value as close to this voltage as the function generator amplitude adjustment allows. Record the voltage and current readings in Table 27-1.
14. Repeat step 13 for the other four voltages selected in step 12.
15. Calculate X_c using Ohm's law:

$$X_c = \frac{V}{I} \tag{27-2}$$

and enter the calculated values in Table 27-1. This should be done for all the readings.

16. If there is a substantial difference (10% or more) between any two recorded values of X_c in Table 27-1, steps 13, 14, and 15 should be repeated and the erroneous entries corrected.
17. Using the highest voltage selected in step 12, measure I for $f = 1000$, 800, 600, 400, and 200 Hz and enter all values in Table 27-2.

Table 27-2

f (Hz)	V	I	X_c	X_c (*Formula*)
1000				
800				
600				
400				
200				

18. Using Eq (27-2), calculate each value of X_c for the values of V and I recorded in Table 27-2. Enter these values in the X_c column of Table 27-2 and mark these as points on a graph in Fig. 27-6. Draw a curved line passing through all the points on the graph. Label this curved line X_c.
19. Using the formula

$$X_c = \frac{1}{2\pi fC} \tag{27-3}$$

calculate the capacitive reactances using the rated C of the capacitor and the frequencies listed in Table 27-2. Enter these capacitive reactance values in the X_c (Formula) column in Table 27-2 and Fig. 27-6.

20. Starting with the capacitor having the least capacitance and the circuit of Fig. 27-5, measure V and I and enter the data in Table 27-3. It will be necessary for you to choose a convenient value of V and $f = 1$

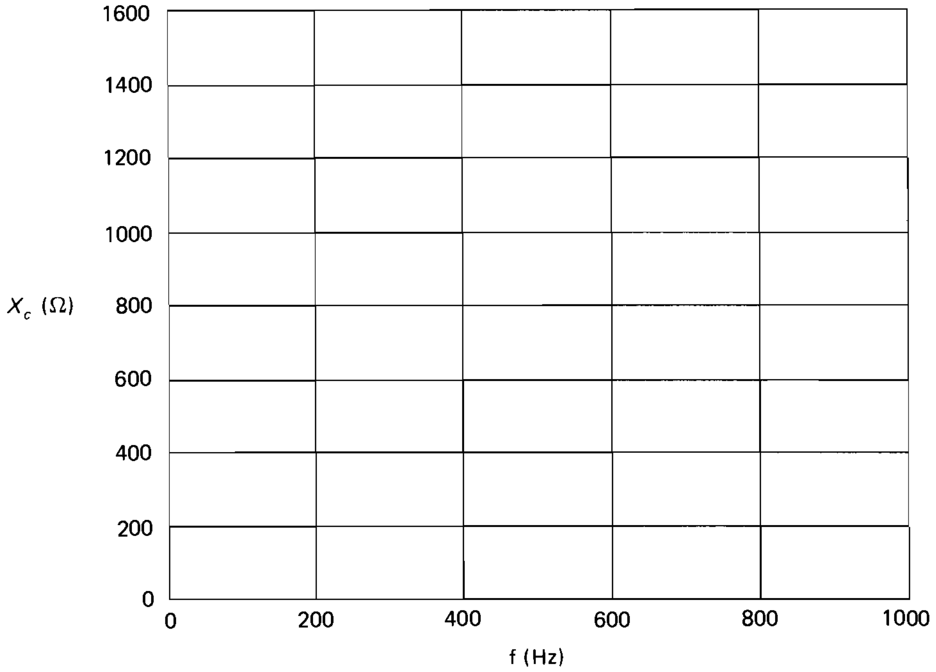


Fig. 27-6

kHz. The objective is to obtain accurate readings of V and I with the available range settings of the instruments.

21. Repeat step 20 for four more capacitors in increasing order of capacitance values. Enter the data in Table 27-3.
22. Solve for X_C using Eq. (27-2) and the V and I values of Table 27-3. Enter the values of X_C in Table 27-3.
23. Equation (27-3) can be rearranged to solve for C:

$$C = \frac{1}{2\pi f X_C} \tag{27-4}$$

Using this equation and the values of X_C in Table 27-3, find the corresponding values of C. Enter the C values in the C (Measured) column of Table 27-3.

24. Connect the circuit of Fig. 27-7. The function generator will be set to deliver a sine wave at 1 kHz. (The frequency to be used is not important. If better results can be obtained at a different frequency, it is quite proper to do so.) The CRO TRIGGER MODE control should be set to EXTERNAL. This means that the sweep is triggered by the voltage between ground and the ungrounded end of the 120-Ω

Table 27-3

C (*Rated*)	V	I	X_C	C (*Measured*)

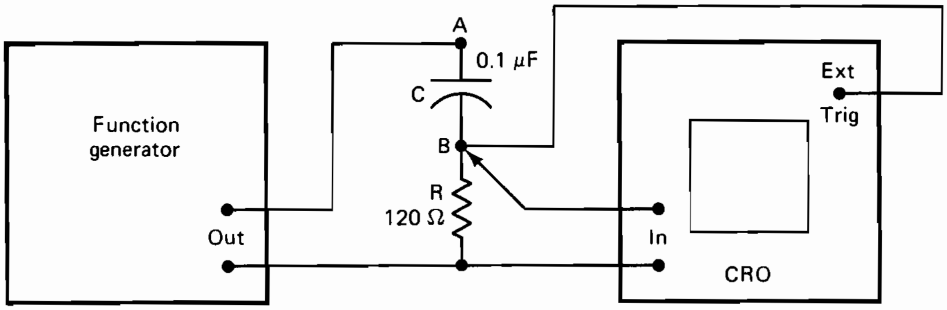


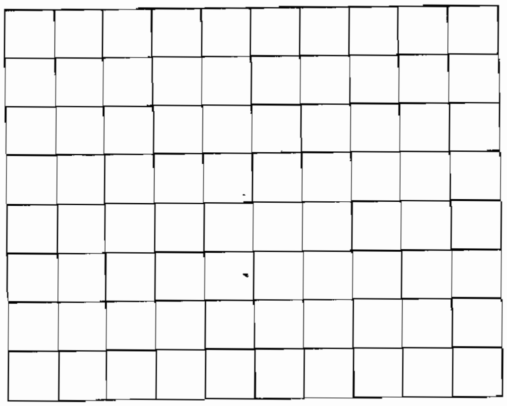
Fig. 27-7

resistor. Note that it is not necessary to find a place to connect the circuit to a water pipe or conducting stake driven into the earth to obtain the ground. The body (chassis) of the CRO and the function generator is the ground in our circuit. The capacitance of the capacitors need not be 0.1 μF. Any capacitance of roughly the same value should be equally effective.

25. Turn on the CRO and the function generator. Using the function generator amplitude control set to a high value, obtain a sine wave on the cathode ray tube face. This may require some experimentation, examination of the CRO operating manual, and instructor aid. Because of the large number of triggered sweep cathode ray oscilloscope makes and models, no general rules can be given to successfully trigger the sweep with an EXTERNAL signal. An attempt should be made to replace *R* with an even smaller value and still obtain proper trigger. Enter this new value on Fig. 27-7.

    You should recognize that the *R* in the circuit performs the same function as the shunt resistance in an ammeter. Its purpose is to provide a relatively low resistance path for current without significantly changing the voltage applied to the capacitor.

26. Temporarily move the CRO lead shown in Fig. 27-7 as attached to point *B* to point *A* in the same figure and adjust the VOLTS/DIV to see the entire waveform. The same waveform should be seen as before except that it may appear shifted on the time scale. Adjust the TIME/DIV setting to see a few (less than five) complete cycles. One cycle is best. Sketch the sine wave on Fig. 27-8, taking reasonable care to indicate the starting point in the figure. The waveform you have drawn is that of the capacitor voltage with the sweep triggered by that voltage at point *B*.
27. Move the same scope lead from point *A* to point *B* as shown in Fig. 27-7. Observe the new waveform and sketch it on Fig. 27-8, being careful to show the starting point and peak values as related to those of Fig. 27-7. This last waveform is that of the current flowing through the capacitor. This is the true current waveform which should be sketched on Fig. 27-8 and labeled *i*. The very first waveform should be labeled v_c.
28. Using the graticule markings as represented in Fig. 27-8, estimate the fractional part of a cycle that the current leads the voltage. Do not try to be extremely accurate. Does the current lead by one-fourth cycle or one-half cycle? Mark the amount below Fig. 27-8.



i leads v_c by ____________ cycle

Fig. 27-8

QUESTIONS

1. The waveforms drawn on Figs. 27-3 and 27-4 should be similar in appearance. Why?
2. Do your readings indicate that the current through a capacitor is proportional to the applied voltage with a fixed frequency? Stated another way, is the current doubled as the voltage is doubled? (In answering this question, you must realize that the readings are not perfect because of instrument errors and possible human errors.)
3. Refer to step 15 and Table 27-1. Does it appear that X_c depends on the voltage and current values?
4. Refer to step 17 and Table 27-2. As the frequency is increased, the capacitive reactance does what? As the frequency is lowered, the capacitive reactance will become smaller or larger?
5. Examine the X_c curve in Fig. 27-6 and the X_c (Formula) points in the same figure. Assuming the measurements to be accurate, what opinion do you have about the rating of the capacitor?
6. Referring to Table 27-3, a larger capacitance gives a smaller or larger capacitive reactance at the same frequency? Does your conclusion fit Eq. (27-3)?
7. In looking at Eq. (27-3), if the frequency is doubled with the C halved, what will be the change in X_c?
8. What is the phase relationship between the current in a resistor and the voltage across the resistor?
9. Why was the external trigger mode used starting with step 24?
10. The current flowing through a capacitor leads the voltage across the capacitor by how many degrees?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 28

AC Circuit with Resistors in Series

READING ASSIGNMENT

Modern Electronics: A First Course, pages 437–472

Topic: Alternating Currents

OBJECTIVES OF EXPERIMENT

1. To investigate the resistance, voltage, current, and phase-angle relationships in a series ac circuit
2. To calculate the powers for the individual resistors and for the circuit as a whole

COMPONENTS AND EQUIPMENT REQUIRED

1. Triggered-sweep CRO
2. Isolation transformer and variable autotransformer
3. Meters: ac current, EVM
4. Resistors: $\frac{1}{2}$ W, 10%, 180 Ω, 330 Ω, 470 Ω, 820 Ω

PROCEDURE

Determination of the Total Equivalent Resistance

1. Measure the values of the resistors unless the values have been measured previously for another experiment. Enter the nominal (color code) and measured values in Table 28-1. See Fig. 28-1 for the identification of the resistors.

Table 28-1

	R_1	R_2	R_3	R_4
Nominal				
Measured				

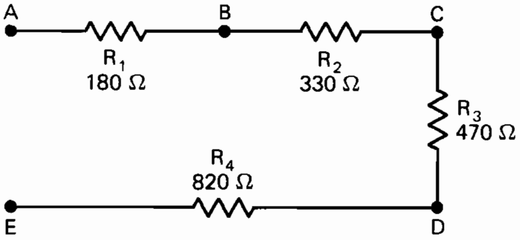


Fig. 28-1

2. Construct the circuit of Fig. 28-1. Measure the total resistance of the series combination and enter into the third line (last line) of Table 28-2. Complete this table by summing the nominal values (first line) and summing the measured values (second line).

Table 28-2

	R_T
Sum of nominal values	
Sum of measured values	
Measured value	

Voltage Measurements

3. Connect the circuit of Fig. 28-2 using the isolation transformer and variable autotransformer as the ac source.

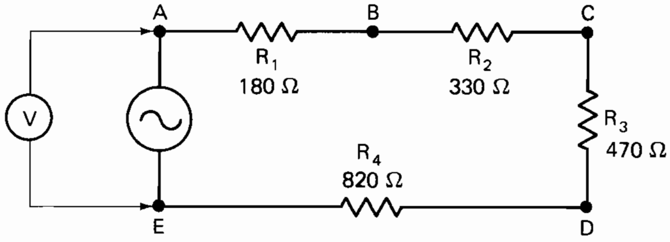


Fig. 28-2

4. Set the ac voltage source to deliver a sine wave of 20 V rms using the EVM connected between points *E* and *A* to measure this voltage. Enter the voltage in Table 28-3 as V_A.
5. Complete the measured values in Table 28-3 by moving one lead of the EVM to points *B*, *C*, and *D* in turn, reading and recording the voltages. Keep the other lead at point *E*.
6. Move the EVM to measure the voltages between the points in the circuit. Fill in Table 28-4.

Table 28-3

	V_A	V_B	V_C	V_D
Measured				
Calculated				

Table 28-4

V_{AB}	V_{BC}	V_{CD}	V_{DE}

Assuming that the resistor voltages are directly additive, as in a dc circuit, complete Table 28-3 using the values measured and entered in Table 28-4.

Oscilloscope Measurements

8. Connect the CRO oscilloscope for EXTERNAL signal triggering with the probe or lead at point A in the circuit (Fig. 28-2). Point E should be connected to the CRO chassis (ground). Set the CRO controls for EXTERNAL TRIGGER.
9. Connect the INPUT probe or lead to point A and adjust the controls to observe one or a small number of complete sine waves. Be sure that the VOLTS/DIV control is set for calibrated readings. Since time measurements will not be made, the TIME/DIV control need not be set for calibrated readings.
10. Be sure that the entire waveform is visible. Adjust the TRIGGER controls so that triggering occurs about midway between the bottom and top levels of the waveform with positive slope.
11. Measure the peak-to-peak amplitudes of V_A (V_{AE}) and enter this value in Table 28-5. Also sketch the waveform in the space provided.
12. Continue filling Table 28-5 after measuring V_B, V_C, and V_D.
13. Complete Table 28-5 by calculating the rms values.

Table 28-5

	V_A	V_B	V_C	V_D
P-P amplitude measured				
Waveform				
Rms value calculated				

Current Measurements

14. Remove all CRO connections from the circuits. Make a preliminary estimate of the current in the circuit and set the current instrument to a higher range. It can be reset to a lower range to obtain more accurate readings after it is found safe to do so.
15. Disconnect the ac voltage source, open the circuit at point A, connect the current instrument in series with the circuit, and reconnect the ac source. Measure the current I_A and enter the value in Table 28-6.
16. Repeat the procedure of step 15 to obtain all measured values for Table 28-6.
17. Using the most accurate values of individual resistor voltages available, calculate the currents and enter in Table 28-6.
18. Using the voltages of Table 28-4 and the measured currents of Table 28-6, calculate the individual powers for the resistors and enter into Table 28-7.

Table 28-6

	I_A	I_B	I_C	I_D	I_E
Measured					
Calculated					

Table 28-7

P_1	P_2	P_3	P_4	P_T
		$P_T = I_{AVE} \times V_A =$		

19. Add the individual resistor powers in Table 28-7 and place in the upper position under P_T.
20. Average the currents of Table 28-6 and multiply by the rms calculated voltage V_A from Table 28-5. Enter this result in the space provided in Table 28-7.

QUESTIONS

1. Why is it possible to find the total resistance in a series-connected ac circuit by adding the individual values?
2. Does the comparison of the sum of measured values and the measured total value of Table 28-2 support the assumption of Question 1?
3. If the resistors in Fig. 28-2 were moved (i.e., exchanged) to occupy different positions in every conceivable order, will different currents be measured?
4. Explain the assumption of step 7 in terms of the resistances placed in series in Fig. 28-2.
5. Why was the EXTERNAL TRIGGER used in the oscilloscope measurements?
6. What primary conclusion can be drawn from a comparison of the waveforms in Table 28-5?
7. What primary conclusion can be drawn from a comparison of the measured and calculated values of the voltages in Table 28-3?
8. What is the relationship between the peak-to-peak value and the rms value for a sine wave?
9. What general conclusion can be supported by the measurement data of Table 28-6?
10. Which method of voltage measurement, EVM or CRO, is likely to be more dependable if the waveform is not that of a sine wave?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 29

Resistors and Inductors in Series

READING ASSIGNMENT

Modern Electronics: A First Course, pages 347–355, 483–488

Topics: *LR* Circuit Time Constant; Series Circuit with Resistance and Inductive Reactance

OBJECTIVES OF EXPERIMENT

1. To investigate the current and voltages in a series *LR* circuit with a square-wave voltage source
2. To investigate the voltage, current, and phase-angle relationships for a series *LR* circuit with a sine-wave voltage source

COMPONENTS AND EQUIPMENT REQUIRED

1. Triggered-sweep CRO
2. Function generator (square wave and sine wave)
3. Meters: ac current; EVM or DMM
4. Resistors: $\frac{1}{2}$ W, 1000 Ω, 2200 Ω
5. Inductor: 30 mH
6. Protractor

PROCEDURE

1. Construct the circuit of Fig. 29-1 with $R = 1$ kΩ and $L = 30$ mH. Turn on the CRO with the TRIGGER MODE on AUTO. Turn on the function generator and select the square-wave output waveform at 1

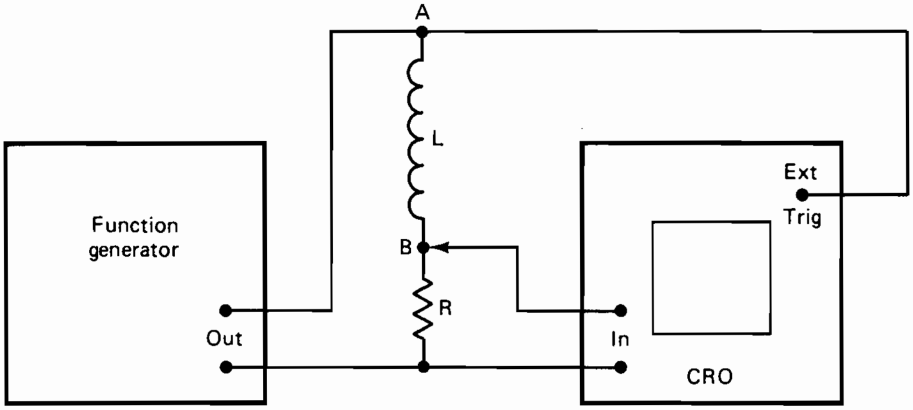


Fig. 29-1

kHz. Using the oscilloscope, adjust the observed waveform to 10 V (p-p). The TIME/DIV control should be set at 1 ms (calibrated). After the frequency is set, the TIME/DIV control can be reset (uncalibrated) to allow one or several whole cycles to be seen.

2. Increase the frequency of the square wave and observe the effect on the waveform. Do no recording at this time. Also decrease the frequency and observe the effect, but do no recording at this time.
3. The voltage you are observing is directly proportional to the current. What you see is the increase of current, first in one direction and then in the other direction as the output of the function generator reverses. Select settings of the function generator frequency and the TIME/DIV controls of the CRO so that the current nearly levels off just before each reversal. More specifically, attempt to make the settings such that five time constants are contained in each half-period of the sine wave. Figure 29-2 reminds you of the relationship between the time constant and the waveform. You are attempting to make the square-wave period equal to 10 time constants and the appearance should be similar to Fig. 29-2.

Fig. 29-2

4. Sketch one full period of the observed waveform on Fig. 29-3.
5. Assuming that the frequency of the function generator, as given by the control setting is accurate, obtain an estimate of the circuit time constant. The time constant is approximately ________ ________. (Be sure to insert the time units.)
6. Disconnect the function generator and interchange the inductor and resistor of Fig. 29-1. Put the *L* where the *R* is and the *R* where the *L* is without any other changes in the circuit.

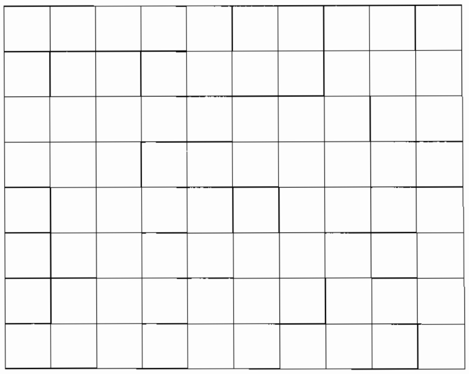


Fig. 29-3

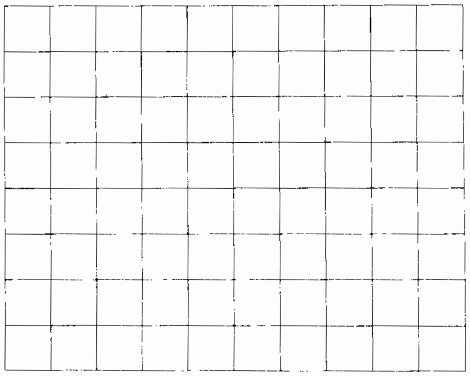


Fig. 29-4

7. Reconnect the function generator without adjusting the amplitude of the output. Do not alter the CRO control settings. Sketch the waveform in Fig. 29-4.
8. Reduce the function generator output to zero and rebuild the circuit of Fig. 29-1 using $R = 100\Omega$ this time. Repeat steps 1 through 5 but with different CRO control settings and a different function generator frequency setting. When these steps have been performed properly, the relationship between the time constant and the period should give a waveform like that appearing in Fig. 29-2.
9. Considering the present control settings, the new time constant is ________ ________.
10. Using Eq. (29-1), find the total circuit resistance.

$$R_T = \frac{L}{\text{time constant}} \tag{29-1}$$

11. Connect the circuit of Fig. 29-5 using a 2200-Ω resistor and a 30-mH inductor. The current meter should be connected in series as shown and the EVM or DMM prepared to measure the voltages.

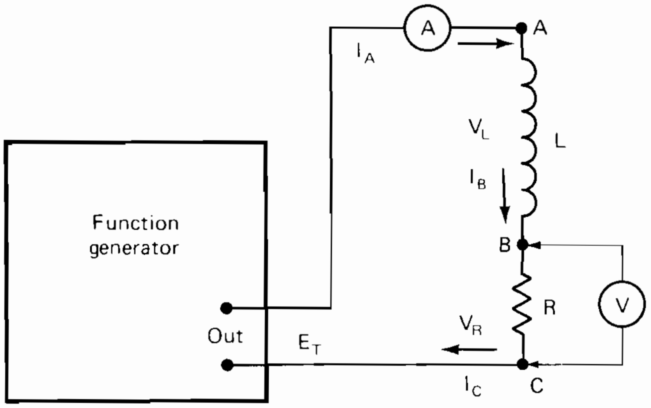


Fig. 29-5

12. Set the function generator to deliver a sine wave of 10 kHz. Connect the voltmeter to the output terminals. Turn on the function generator power and adjust the output voltage to 20 V (or any other convenient value) using the amplitude control; read the voltage using the EVM or DMM. Record the value as E_T in the first row of Table 29-1. Also record the current as I_A in the table.
13. Move the current meter to positions B and C in turn, measure the current at those points, and record the readings in the first row of Table 29-1.

Table 29-1

E_T	I_A	I_B	I_C	V_R	V_L

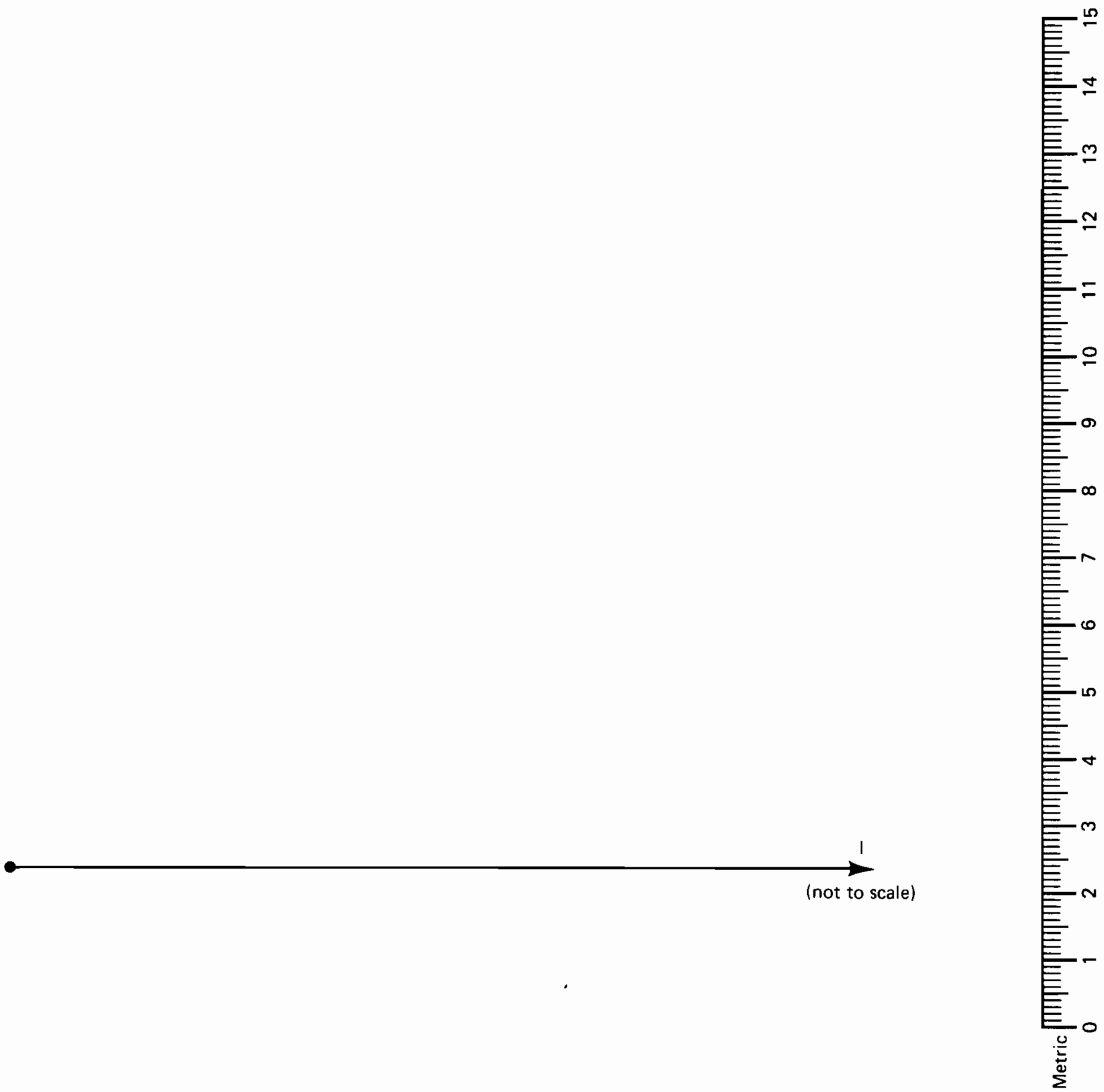
14. Move the voltmeter leads and read the voltages across R and L. Record these readings in Table 29-1.

15. Before proceeding to take measurements, check the data obtained so far. The three current readings should be identical or nearly the same.

16. Also check the voltages by constructing a phasor diagram in Fig. 29-6. In this figure the current phasor is taken as the reference. Construct a voltage phasor, V_R, along the same line as the current phasor. Its length in centimeters should be equal to V_R in volts. At the rightmost end of V_R place an arrowhead. (See Fig. 29-7 as an example.) Also construct a vertical line at the arrow end of V_R whose length in centimeters is equal to V_L taken from Table 29-1. An arrowhead should be attached to the upper end of the V_L phasor. Draw the hypotenuse of the right triangle as shown in Fig. 29-7.

17. Calculate the length of the right triangle hypotenuse using the equation

$$E_T = \sqrt{V_R^2 + V_L^2} = \underline{\qquad\qquad} \tag{29-2}$$



(not to scale)

Fig. 29-6

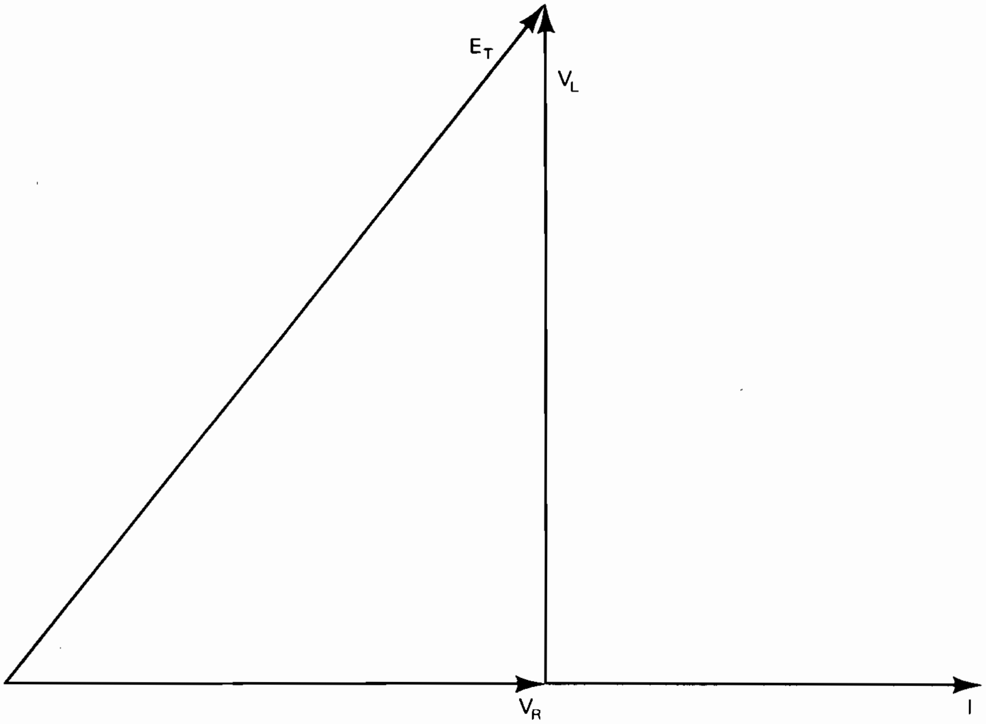


Fig. 29-7

The calculated value of E_T should be less than the measured value recorded in Table 29-1. Because the inductor has a substantial amount of resistance, the V_L phasor will not be vertical, as shown in Fig. 29-7. It will rather be inclined to the right so that the angle between it and I will be less than 90°. In other words, the total phasor resistance drop will be greater than V_R in Fig. 29-6.

18. Construct the circuit of Fig. 29-8. Leave the function generator settings so that it delivers a sine wave of 20 V at 10 kHz as before with one full cycle visible. It is not necessary that the TIME/DIV control on the CRO be in the calibrated position. Sketch the waveform observed and label it on Fig. 29-9.
19. Move the CRO INPUT lead from point A to point B and observe a new waveform. This waveform is that of V_R and is in phase with the current.
20. Count the total number of horizontal divisions for one complete cycle of either waveform as sketched or actively observed on the CRO. Enter this information in the first column of Table 29-2. Now count the number of divisions between the peak of E_T and V_R. Enter these data in the second column of Table 29-2. (*Note:* Measuring the number of divisions corresponding to the phase-angle difference may

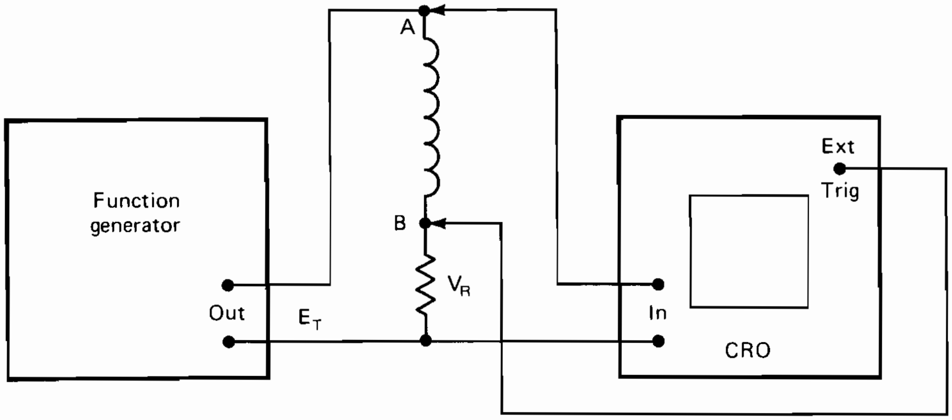


Fig. 29-8

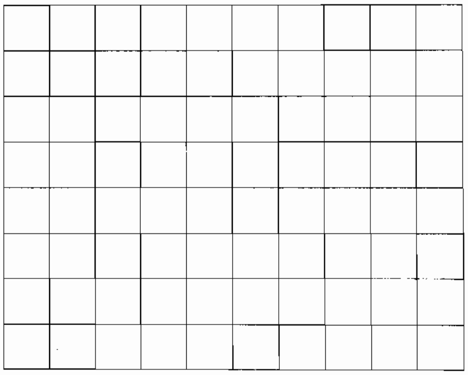


Fig. 29-9

Table 29-2

Divisons/Cycle	*Divisons between Peaks*	*Phase Difference*

be easier and more accurately done by using zero crossings rather than waveform peaks. The zero crossings occur midway between the peaks, so adjust the vertical position of the waveform on the CRO or sketch waveforms accordingly.)

21. Calculate the phase difference using the equation

$$\text{phase difference} = \frac{\text{divisions between peaks}}{\text{divisions/cycle}} \times 360 \qquad (29\text{-}3)$$

and enter the result in Table 29-2.

QUESTIONS

1. Are the current readings at points A, B, and C of Fig. 29-5 the same? If they are not, what reasons can you think of for different measured values?
2. Refer to the right triangle constructed in Fig. 29-6. Measure the length of the hypotenuse in centimeters. Compare that length with the reading for E_T in Table 29-1. Should they be approximately the same? If they are different, why?
3. In constructing the phasor diagram of Fig. 29-6 you were told to place V_R along the same line as the current phasor. State the reason you can do this.
4. Compare the calculated value of E_T (step 17) with the measured value recorded in Table 29-1.
5. In Fig. 29-10, modify Fig. 29-7 by tilting V_L clockwise to resemble Fig. 29-11. The actual data from Table 29-1 are to be used. If you do not own a scale with centimeter divisions, construct one of paper using the one in Fig. 29-10 to obtain the markings. Unless you know a better way, the direction of E_T should be estimated and its length scaled. The length of V_L should then be checked. This may be repeated a number of times until E_T is so oriented that the scaled voltages correspond to those measured.
6. Use a protractor and measure the angle between E_T and I. The angle is ______.
7. Compare the angle from the answer of Question 6 with that entered in Table 29-2.
8. Calculate and express the impedance of the circuit.

Z = ______ angle = ______

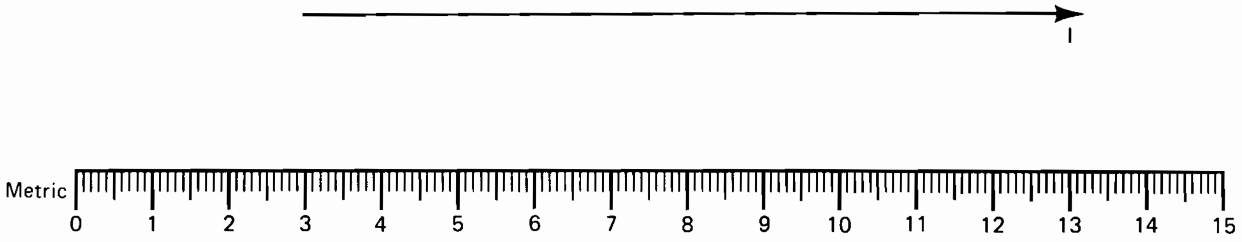


Fig. 29-10

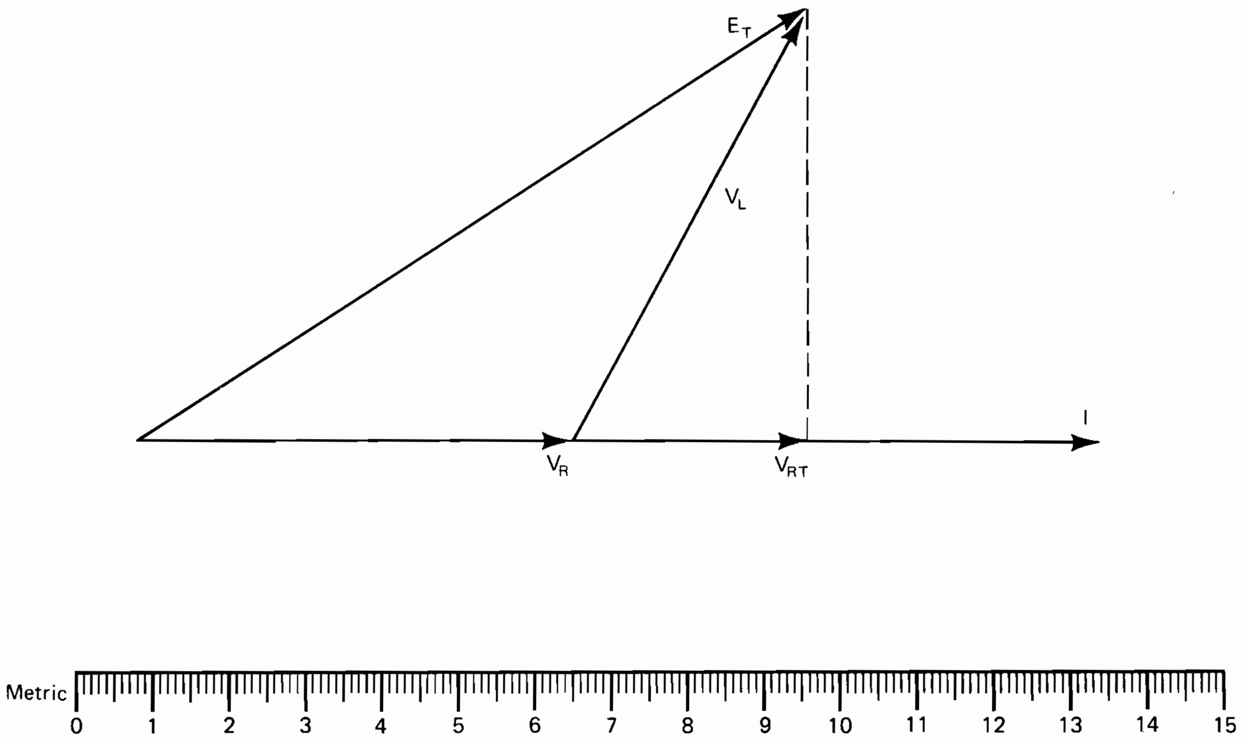


Fig. 29-11

9. As a special assignment, find the total voltage in phase with the current and the total equivalent series resistance.

V_{RT} = ________

R_T = ________

10. Will the resistance of the inductor remain the same as the frequency is changed?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 30

Resistors and Capacitors in Series

READING ASSIGNMENT

Modern Electronics: A First Course, pages 388–398, 483–488

Topics: Time Constant of *CR* Circuit; AC Series *CR* Circuits

OBJECTIVES OF EXPERIMENT

1. To observe the waveforms of current and voltages for a series *CR* circuit with a square-wave source voltage
2. To measure the voltages and current of a series *CR* circuit and to confirm the validity of the phasor diagram and the calculation technique
3. To measure the phase-angle difference between the voltages across the *C* and *R* elements of a series *CR* circuit
4. To measure the voltages across the circuit elements for a series circuit having two resistors and two capacitors, and to confirm the validity of the calculation technique.

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (square wave and sine wave)
2. Triggered-sweep CRO
3. Resistors: 1 kΩ, 1.5 kΩ, 470 Ω, $\frac{1}{2}$ W
4. Capacitors: 0.1 μF, 0.15 μF, 0.33 μF
5. Meters; ac current; EVM or DMM

PROCEDURE

In procedure steps 1 through 6, you will establish the circuits and observe waveforms with square wave source waveforms.

1. Connect a 0.1-μF capacitor and a 1-kΩ resistor in series across the function generator output terminals shown in Fig. 30-1. Temporarily move the CRO input lead from *B* to *A*. Turn on the function generator with square-wave output selected. With the CRO turned on, adjust the function generator output to obtain 10 V (p-p). The function generator frequency should be set to 100 Hz as indicated by the frequency control setting.
2. Move the CRO input lead back to point *B* in Fig. 30-1. Increase the frequency and observe the altered appearance of the waveform. Do no recording at this time. Decrease the frequency and observe the effect. Do no recording at this time, but do try to understand what is happening as a result of the decreased frequency.

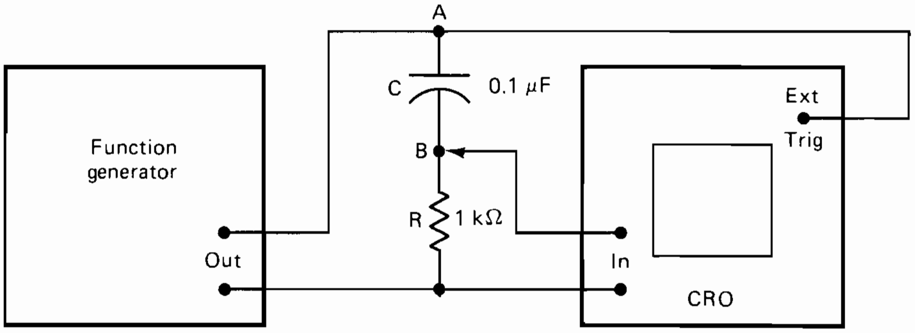


Fig. 30-1

3. The voltage you are observing is directly proportional to the current passing through the capacitor and resistor. Notice that this current is initially large in one direction and then decreases with time. As the polarity of the applied voltage reverses, the current also reverses and again decreases with time. The frequency control of the function generator and the TIME/DIV (uncalibrated) should be adjusted so that one (or at most a few) cycles can be seen, and for which five time constants of the *RC* circuit occupy a span equal to one-half the period. In other words, you want 10 time constants for one period. Figure 30-2 illustrates the relationships desired.

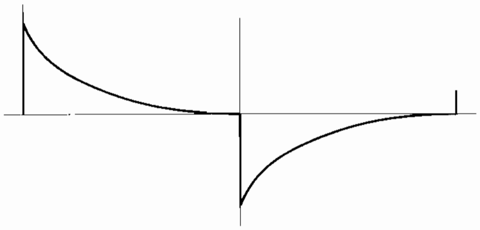


Fig. 30-2

4. Sketch one full period of the observed waveform on Fig. 30-3.
5. Assume that the frequency indicated by the control setting of the function generator is accurate. Now obtain an estimate of the circuit time constant. The time constant is approximately ________ ________.
6. Temporarily disconnect the function generator output to zero and interchange *R* and *C* to the positions opposite those in Fig. 30-1, reconnect and observe the capacitor voltage. Note that it builds in one direction and then levels out. It then proceeds in the opposite direction and again levels out to complete the cycle. Sketch this waveform in Fig. 30-4.

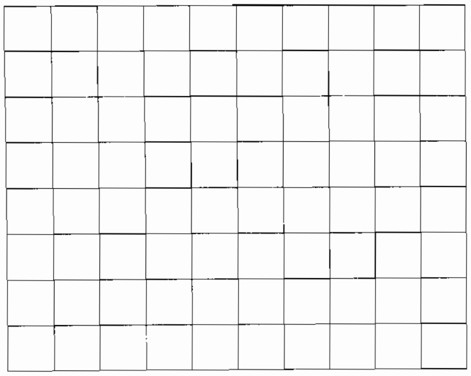


Fig. 30-3

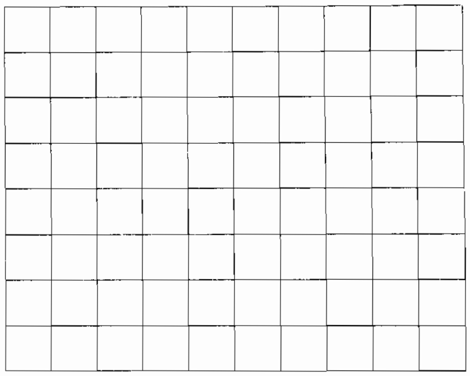


Fig. 30-4

In steps 7 and 8, the sine-wave voltages across R and C of a series circuit will be measured. In step 9, the total voltage of the series circuit will be determined by means of a phasor diagram drawn to scale. In step 10, the total voltage is calculated by formula.

7. Connect the circuit of Fig. 30-5 using a 1500-Ω resistor and a 0.1-μF capacitor. The EVM or DMM shown on the right in the figure can be connected to various points in the circuit to measure voltages.
8. Set the function generator to deliver a sine wave of 1 kHz. Connect the voltmeter to the output terminals. Turn the function generator on and adjust the output voltage to 10 V (or any other convenient, larger if possible, value) using the amplitude control and reading the voltage using the EVM or DMM. Record the value of E_T in the first row of Table 30-1. Also record the current under I in the table. Move the voltmeter leads and read the voltages across R and C. Record these readings in Table 30-1.

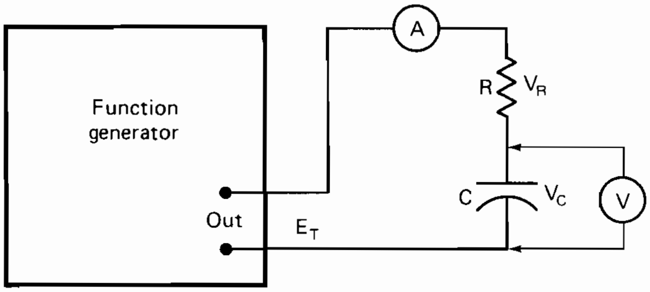


Fig. 30-5

Table 30-1

E_T	I	V_R	V_C

9. Check the voltage obtained by constructing a phasor diagram in Fig. 30-6. In this phasor diagram the current is taken as the reference. Construct a voltage phasor V_R along the same line as the current phasor. Its length in centimeters should be equal to V_R in volts. At the rightmost end of V_R, place an arrowhead. (See Fig. 30-7 as an example.) Also construct a vertical line at the arrow end of V_R whose length in centimeters is equal to V_C taken from Table 30-1. An arrowhead should be attached to the lower end of the V_C phasor. Draw the hypotenuse of the right triangle as shown in Fig. 30-7. The length of the hypotenuse is ________ cm. Therefore, E_T = ________ from Fig. 30-6.

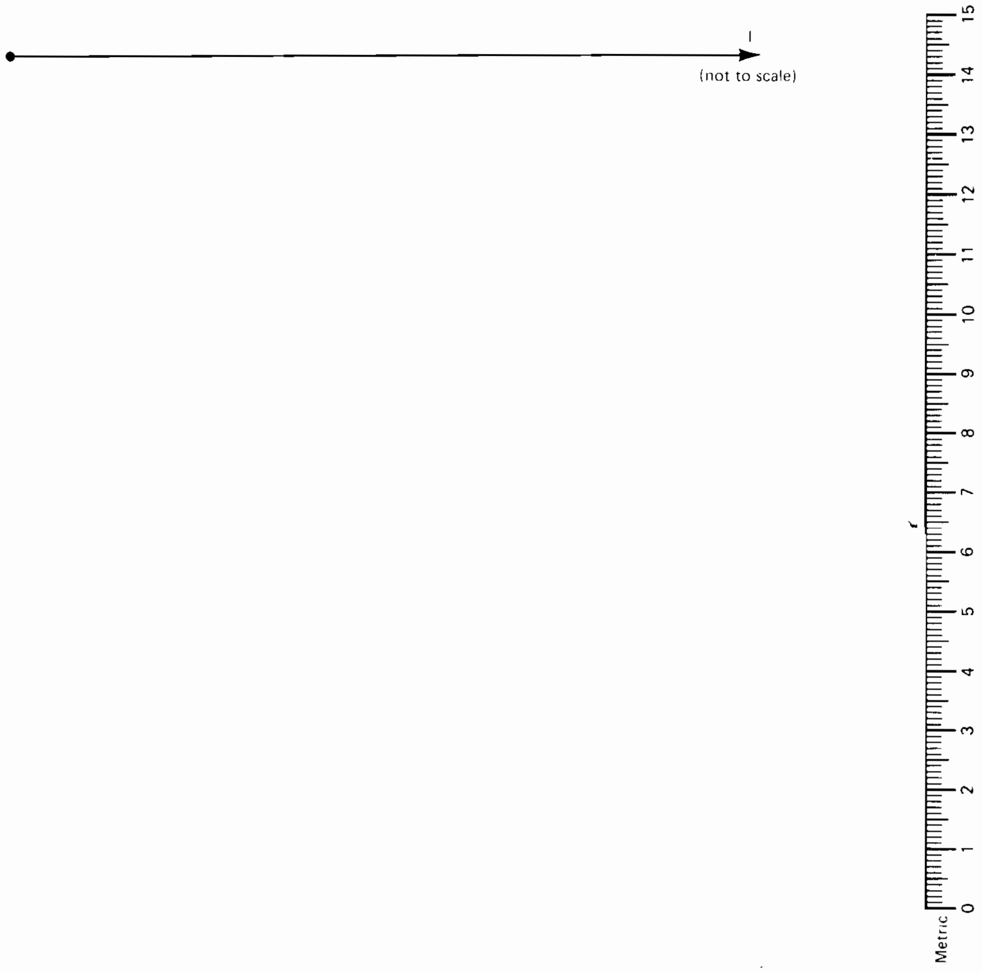


Fig. 30-6

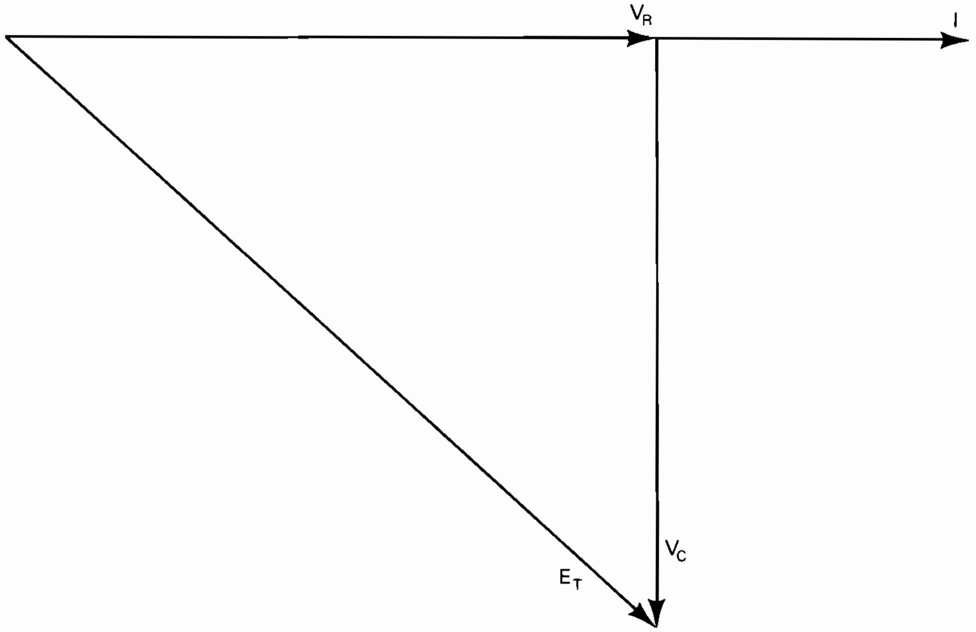


Fig. 30-7

10. Calculate the length of the right triangle hypotenuse using

$$E_T = \sqrt{V_R^2 + V_C^2} = \underline{\qquad\qquad} \tag{30-1}$$

If the calculated value of E_T is not within 10% of the measured value, repeat steps 8 through 10 with a different value of E_T and enter the data in the second row of Table 30-1.

In steps 11 and 12, the waveforms of the voltages across R and C are observed and sketched. The purpose is to relate the two waveforms graphically in preparation for determining the angle difference between the two. The numerical phase difference is established in step 13.

11. Construct the circuit of Fig. 30-1 using the values given. Set the function generator frequency to 1 kHz and the amplitude control to midrange with a sine-wave output. Turn on the function generator and the CRO. Adjust the CRO controls to obtain a stable waveform with one full cycle visible. It is not necessary that the TIME/DIV control on the CRO be in the calibrated position. Sketch the waveform observed and label it v_R on Fig. 30-8.

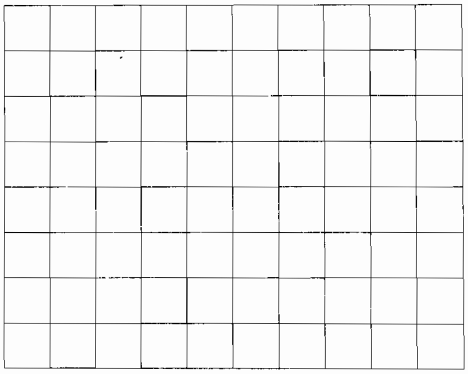


Fig. 30-8

12. Temporarily disconnect the function generator. Then interchange C and R. Reconnect the function generator and observe the new waveform. Sketch in on Fig. 30-8 and label it v_C. Count the total number of horizontal divisions for one complete cycle of either waveform as sketched or actually observed on the CRO. Enter this information in the first column of Table 30-2. Now count the number of divisions between the peaks of v_C and v_R. Enter this information in the second column of Table 30-2. (*Note:* Measuring the number of divisions corresponding to the phase-angle difference may be easier and and more accurately done by using zero crossings with the same waveform slope rather than waveform peaks. The zero crossings occur approximately midway between the peaks. They will occur at the center graticule line when the waveform is centered vertically.)
13. Calculate the phase difference using the equation

$$\text{phase difference} = \frac{\text{divisions between peaks}}{\text{divisions/cycle}} \times 360 \tag{30-2}$$

and enter the result in Table 30-2. This phase difference should be close to 90°.

Table 30-2

Divisions/Cycle	*Divisions between Peaks*	*Phase Difference*

The series *CR* circuit is expanded in the next step to include four elements in series: two resistances and two capacitances. All voltages are measured. Step 15 repeats the same measurements with different frequencies. The data of all steps are recorded in tabular form. In step 16 the measured *R* and *C* element voltages are combined to obtain calculated values of the total applied voltage.

14. Connect the following elements in series:

$$R_1 = 470\ \Omega \qquad R_2 = 1000\ \Omega$$
$$C_1 = 0.15\ \mu\text{F} \qquad C_2 = 0.33\ \mu\text{F}$$

and an ac current meter. This series combination is to be supplied by a function generator set for sine-wave output at 1 kHz. The total supply voltage E_T should be approximately the maximum available from the function generator but not more than 30 V. Measure the quantities listed in Table 30-3 and enter the readings into the proper row.

Table 30-3

f (Hz)	V_{R1}	V_{R2}	V_{C1}	V_{C2}	E_T	E_T (*Calculated*)
125						
250						
500						
1,000						
2,000						
4,000						
6,000						
8,000						
10,000						

15. Repeat the measurements of step 14 for the other frequencies listed in Table 30-3 and record the readings. Omit measurements that cannot be completed because of instrument limitations.
16. Perform these calculations:

$$V_R = V_{R1} + V_{R2}$$
$$V_C = V_{C1} + V_{C2}$$
$$E_T \text{ (calculated)} = \sqrt{V_R^2 + V_C^2}$$

Enter the computed values of E_T in Table 30-3.

QUESTIONS

1. Refer to the right triangle of Fig. 30-6. Measure the length of the hypotenuse in centimeters. Compare that length with the reading for E_T recorded in Table 30-1.
2. In Fig. 30-6, what is the phase relationship between V_R and I? What is the phase relationship between V_C and I?
3. Compare the calculated value of E_T (step 10) with the measured value recorded in Table 30-1.
4. Give one reason why the results of the comparison in question 3 might be more favorable than a comparable comparison for a series *RL* circuit.

5. Name two reasons why the phase differences of step 13 might be different from 90°.
6. Why can V_{R1} and V_{R2} be combined by direct addition?
7. Why can V_{C1} and V_{C2} be combined by direct addition?
8. In Fig. 30-6 construct a phasor diagram which shows V_{R1} and V_{R2} as well as V_{C1} and V_{C2}. Select one frequency from Table 30-3 so that no one phasor is too small to be seen clearly.
9. Compare E_T and E_T (calculated) in Table 30-3. Try to explain possible reasons for any significant differences.
10. Explain the trend in V_{R1} and V_{R2} in Table 30-3 as the frequency is increased.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 31

Resistors in Parallel

READING ASSIGNMENT

Modern Electronics: A First Course, pages 116–159, 488–497

Topics: Resistors in Parallel; Combining Parallel Resistors

OBJECTIVES OF EXPERIMENT

1. To investigate the voltage, current, and phase relationships with two resistors in parallel
2. To investigate the voltage and current relationships with three resistors in parallel

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (sine wave)
2. Meters: ac current; EVM or DMM
3. Resistors: 100 Ω, 680 Ω, 1000 Ω, 1500 Ω, $\frac{1}{2}$ W

PROCEDURE

In steps 1 through 11, the branch currents are measured and the total current is measured. This will allow the confirmation of Kirchhoff's current law for two resistors in parallel. The measurements are repeated for different frequencies.

1. Connect the circuit of Fig. 31-1 with $R_1 = 680\ \Omega$ and $R_2 = 1000\ \Omega$ and with a single ac current meter and an EVM or DMM. Use the most accurate instruments available so that the best possible results can be obtained.

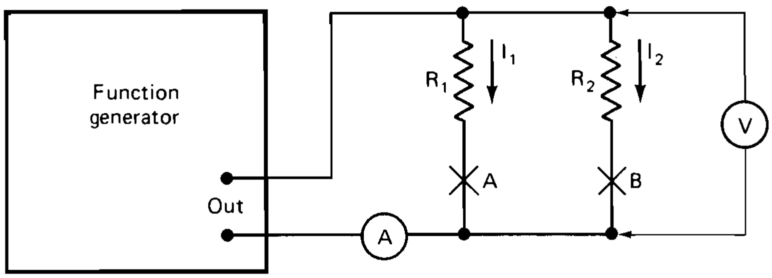


Fig. 31-1

2. Set the function generator to obtain a 1-kHz sine wave with 5 V output as measured by the EVM or DVM.
3. Turn the function generator on and proceed through the next four steps without recording data. The reason for doing this is to allow the temperatures in the function generator and resistors to more nearly stabilize and to rehearse the procedure.
4. Check to ensure that 5 V is applied to the circuit, then read the ac current meter to obtain I_T.
5. Open branch 1 at A, readjust the applied voltage as necessary, and read the same current meter to obtain I_2.
6. Reclose branch 1 so that current will again flow through R_1. Open branch 2 at B, readjust the applied voltage as necessary, and read the same current meter to obtain I_1.
7. If the proper results are being obtained, the current readings obtained for step 5, when added to the current reading for step 6, should equal the reading obtained for step 4 within a few percent, hopefully less than 5%.
8. Repeat steps 4 through 7 and record the current readings in Table 31-1. Also record the sum as I_T (calculated).
9. Immediately remove R_1 and R_2 from the circuit and measure their resistances using the most accurate instrument available. (A DMM has a good accuracy for this purpose.) Enter the resistance values in Table 31-1 in the same row.
10. Reset the frequency of the function generator to 100 Hz with 5 V output and measure the currents following steps 4 through 8. Record the readings in Table 31-1.
11. Repeat step 10 for a frequency of 2000 Hz. If your instruments are not capable of accurate measurement at this frequency, set the function generator to the highest frequency for which accurate readings can be made. Delete the 2000 Hz in Table 31-1 and enter the actual frequency used in the table.

Table 31-1

f (Hz)	V	I_1	I_2	I_T (*Measured*)	R_1	R_2	I_T (*Calculated*)
100					☒	☒	
1000							
2000					☒	☒	

In steps 13 and 14 the phase angle between the voltage waveforms for a parallel combination of two resistors is measured. The parallel resistors are R_1 and R_2. A third resistor, R_4, is placed in series with the parallel combination. The purpose of R_4 is to provide a voltage that is in phase with the total current. The purpose of the circuit change in step 14 is to allow the voltage across R_4 (with respect to ground) to be observed.

12. Construct the circuit of Fig. 31-2 using the same values of R_1 and R_2 as before. Use $R_4 = 100\ \Omega$.
13. Set the function generator to provide a 1-kHz sine wave. Turn on both equipments and adjust them to

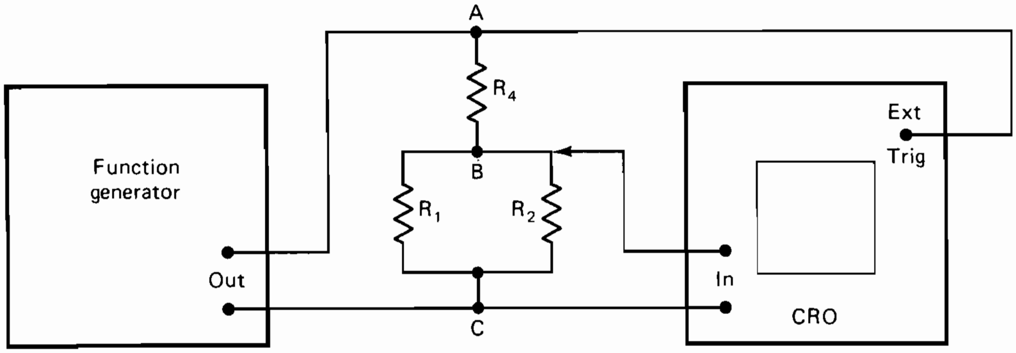


Fig. 31-2

display a stable single cycle with 5-V (peak) amplitude. The TRIGGER MODE control should be set to EXTERNAL so that phase comparisons can be made as the CRO input leads are moved.

14. Temporarily disconnect the function generator and then reverse the positions of R_4 and the parallel combination of R_1 and R_2. After making the preceding change R_4 will be connected between points B and C while R_1 and R_2 will be connected in parallel between points A and B. Based on the waveforms seen in steps 13 and 14, the phase difference between the two is ________.

Steps 16 and 17 are similar to steps 1 through 11. The principal difference is having three resistors in parallel at this time.

15. Construct the circuit of Fig. 31-3 the same values for R_1 and R_2. Set $R_3 = 1500\ \Omega$.
16. With the function generator set to deliver a sine wave at 1000 Hz, adjust the output level to 5 V. Read each branch current I_1, I_2, and I_3 one at a time by opening the other two branches. For example, to read I_2, open the first branch at A and the third branch at C. Be sure that the output level is adjusted to 5 V before taking a reading. Record the readings in Table 31-2. Also record the measured total current as I_T.
17. Immediately remove R_1, R_2, and R_3 from the circuit and measure their resistances using the most accurate instrument available. Enter the resistance values in the same row.
18. Reset the frequency of the function generator to 100 Hz with 5-V output and measure the current as described in step 16. Also record the quantities according to the procedure given in that step.

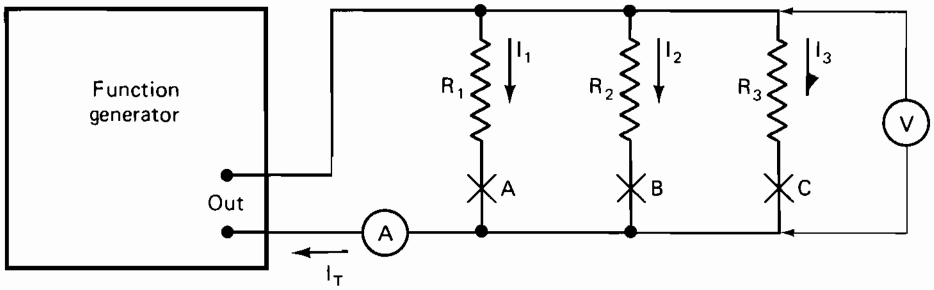


Fig. 31-3

Table 31-2

f (Hz)	V	I_1	I_2	I_3	R_1	R_2	R_3	I_T
100					☒	☒	☒	
1000								
2000					☒	☒	☒	

19. Repeat step 18 for 2000 Hz. If your instruments are not capable of accurate measurements at this frequency, set the function generator to the highest frequency for which accurate readings can be made. Strike out the 2000 Hz in Table 31-2 and enter the actual frequency used in the table.

QUESTIONS

1. In step 5, why may it be necessary to readjust the applied voltage as the different branches are opened and reclosed?
2. In step 5, with one of the two branches opened, what is the simplest description of the resulting circuit?
3. Study the circuit of Fig. 13-1. What precaution has been taken in steps 5 and 6 to make the values of I_1 and I_2 measure the same as those that will actually flow in the complete parallel circuit?
4. Calculate R_1 and R_2 using the measured values of V, I_1, and I_2 from Table 31-1 and the equations

$$R_1 = \frac{V}{I_1} \tag{31-1}$$

$$R_2 = \frac{V}{I_2} \tag{31-2}$$

Compare these values of R_1 and R_2 with those measured directly and recorded in Table 31-1.

5. Refer again to Table 31-1. The current readings should not be greatly different for the different frequencies. If there are any significant differences, what cause might be responsible for such differences?
6. Based on the data taken for Fig. 31-2, is it reasonable to state that "the currents in our parallel circuit are in phase with the applied voltage"? If you disagree, give reasons for your disagreement.
7. Some people will argue that the circuit of Fig. 31-2 is not really a parallel circuit at all, and they are correct. What part of this circuit is really a parallel circuit?
8. What single feature of the circuit in Fig. 31-3 qualifies it as a parallel circuit?
9. Refer to Table 31-2 and Question 4. Extending the calculations to those of three parallel branches, compare the calculated values of R_1, R_2, and R_3 with the measured values.
10. Judging from the data of Table 31-2, what is the effect of changing the frequency?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 32

Resistors and Inductors in Parallel

READING ASSIGNMENT

Modern Electronics: A First Course, pages 488–492

Topics: Combining Resistors and Inductors in Parallel; Parallel Phase Angles

OBJECTIVE OF EXPERIMENT

To investigate the voltage, current, and phase relationships with a resistor in parallel with an inductor

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (sine wave)
2. Cathode ray oscilloscope
3. Inductor: 30 mH
4. Resistors: $\frac{1}{2}$ W, 100 Ω, 1500 Ω
5. Meters: ac current; EVM or DMM

PROCEDURE

Take it easy for the first four steps. Vary the frequency and observe the total current reading. Record no readings but try to understand what is happening.

1. Construct the circuit of Fig. 32-1 with $R = 1500\ \Omega$ and $L = 30$ mH. Set the function generator to provide a 5000-Hz sine wave. Turn on the function generator and adjust the output to 5 V.

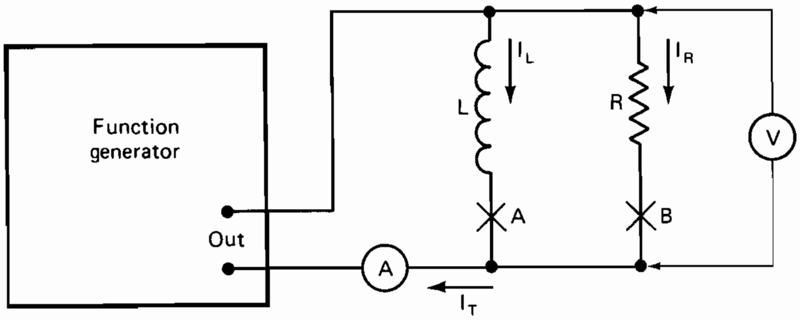


Fig. 32-1

2. Also turn on the CRO, but do not connect it to the circuit at this time.
3. Without recording data, vary the frequency of the function generator while maintaining the voltage at 5 V. Observe the current reading as the frequency is varied. Note that the current decreases with frequency.
4. Also notice the effect on the current as the inductive branch is opened at point *A*, or the resistive branch is opened at point *B*.
5. Connect the input terminals of the CRO to the output terminals of the function generator. Use AUTO or INTERNAL for the TRIGGER MODE and obtain a stable display. Make the adjustments necessary to make a rough measurement of the period from which the frequency can be calculated as the reciprocal of the period. It may be necessary to review the techniques for frequency measurement using the CRO as described in Experiments 22 and 24.

In step 6, the CRO is used to set the function generator frequency. In step 7 through 9, the individual branch currents and the total current are measured. The current measurements are repeated for different function generator frequencies in steps 11 and 12.

6. The frequency determined in the previous step should be approximately 5000 Hz. This is because most inexpensive function generators suitable for general laboratory work do not have accurately calibrated frequency dials. To remedy this limitation you will next adjust the frequency of the function generator so that the period as measured by the CRO is 200 μs for $f = 5000$ Hz.
7. Remove the CRO leads from the function generator output terminals. Do not turn the power of the CRO off, as it will be used again in this experiment.
8. Maintain V at 5 V, open the branch at point *A*, and measure I_R using current meter A as located in Fig. 32-1. Record the measured value in the proper row of Table 32-1.
9. Close the circuit at point *A*. Open the circuit at point *B*. Readjust the voltage to 5 V and read I_L. Record this reading in Table 32-1.
10. Close the circuit at point *B* so that both branches now carry current. Readjust for 5 V and read meter A to obtain I_T, which is to be recorded in Table 32-1.
11. Repeat steps 5 through 10 using $f = 3000$ Hz instead of 5000 Hz. In step 6, the period corresponding to $f = 3000$ Hz is 333 μs.
12. Repeat steps 5 through 10 using $f = 10{,}000$ Hz instead of 5000 Hz. In step 6, the period corresponding to $f = 10{,}000$ Hz is 100 μs.

Table 32-1

f (Hz)	V	I_R	I_L	I_T	I_T (*Calculated*)	L (*Calculated*)
3,000						
5,000						
10,000						

The remaining steps have the purpose of measuring the phase angle between the total current and the voltage across the parallel combination of R and L. The procedure is similar to that employed in Experiment 31. For better comprehension, all the steps should be carefully read and understood before proceeding. As each step is completed, the results should be analyzed. If the results do not conform to those anticipated, the step should be repeated.

13. Modify the circuit of Fig. 32-1 to match Fig. 32-2. Use $R_S = 100\ \Omega$ and the R and L as before.
14. Set the CRO TRIGGER MODE to EXTERNAL. Adjust the CRO to obtain a stable waveform and the function generator for 20 V (peak) at 5000 Hz, more or less (the exact amplitude is not important). Center the observed waveform in the vertical direction. It is important at this point to understand the waveform that is displayed and the phase relationships. First, the waveform is that for the voltage across R_S. This waveform shape is, therefore, exactly the same as that for I_T. Here is another important point. The sweep is triggered with EXTERNAL for the TRIGGER MODE. Therefore, the waveform observed has voltage applied as the reference.

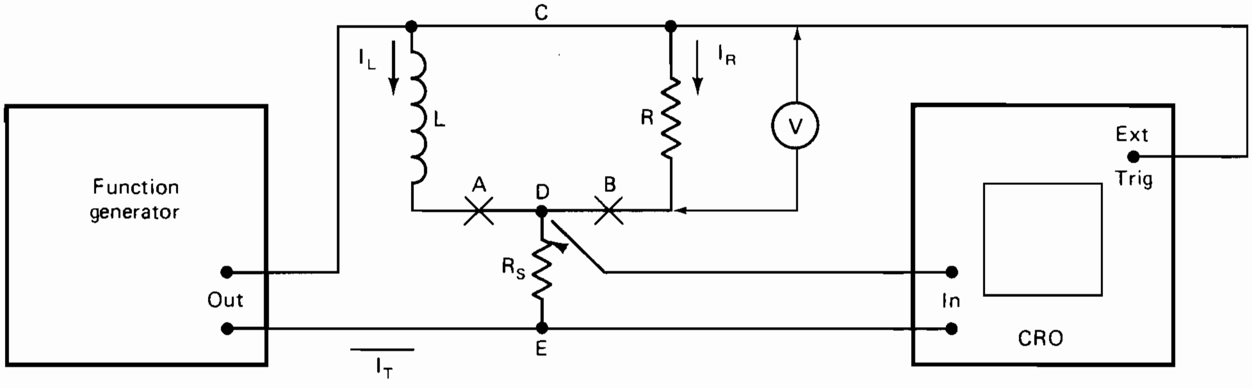
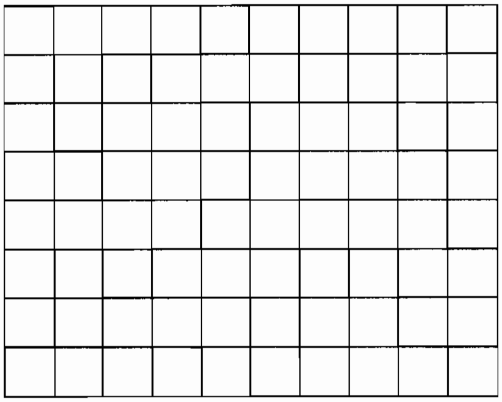


Fig. 32-2

15. Figure 32-3 represents the graticule rulings on the CRO display. You are carefully to transfer to this figure the waveform now being seen. Be sure to count squares in doing this. Label the waveform I_T. Once again before starting, make sure that the sine wave is centered and that the smallest number of full cycles is seen. Note that a calibrated sweep is not required for this purpose. However, once set, the TIME/DIV adjustment should not be altered. Record the meter reading in Fig. 32-3.
16. Temporarily disconnect the function generator. Rearrange the circuit of Fig. 32-2 so that R_S is now connected between points C and D. Also move the parallel combination of L, R, and the meter so that it is connected between D and E. Open one branch at A so that $I_T = I_R$. Adjust the function generator



Meter reading ______________

Fig. 32-3

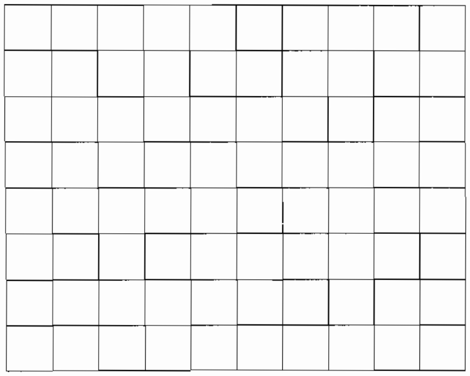


Fig. 32-4

output level so that the meter reads the same voltage. (This means that the current in the resistive branch is the same as before.) Examine the waveform with the CRO lead connected to point *D*. Sketch the waveform on Fig. 32-4. Label it I_R.

17. Close the branch at *A*, again allowing current to flow. Open the other branch at *B*. Again adjust the function generator output level so that the voltage reading across *L* is the same. Without altering the TIME/DIV setting of the CRO, sketch the waveform on Fig. 32-5 with the waveform labeled I_L.

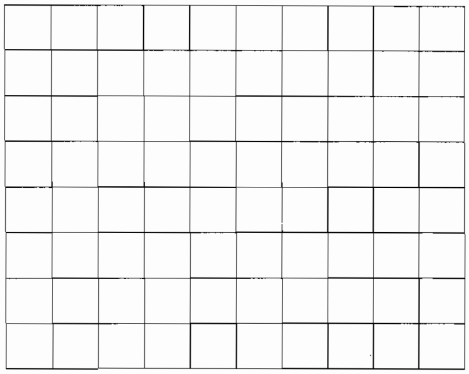


Fig. 32-5

18. Pick any one of the waveforms in Fig. 32-3, 32-4, or 32-5 and count the number of divisions for one complete cycle. The most accurate way of doing this is to count between zero crossings having the same slope (up or down). This number should be the same for all three waveforms except for inaccuracies in the sketches, in division counting, and so on. Let us call this quantity divisions/cycle.
19. Using the waveform in Fig. 32-4 (I_R, which is in phase with *V*) as the reference, count the difference in divisions where the zero crossings occur for Figs. 32-4 and 32-5. (*Hint:* Transfer the point of zero crossing of Fig. 32-4 by marking it on Fig. 32-5.) Now count the number of divisions and call this number the number of divisions between peaks. Calculate the phase difference:

$$\text{phase difference} = \frac{\text{division between peaks}}{\text{divisions/cycle}} \times 360 \qquad (32\text{-}1)$$

The number of degrees of phase shift obtained with this calculation should be less than 90°. This is the angle between I_L and *V*. The phase difference = ________.

20. Using the same methods of step 19, find the phase difference between I_T and *V*. Phase difference = ________.

QUESTIONS

1. Referring to Table 32-1, calculate I_T using

$$I_T = \sqrt{I_R^2 + I_L^2} \tag{32-2}$$

for the three sets of measurements. Enter the three calculated values in the table. Compare the calculated and measured values of I_T.

2. To emphasize the independence of the parallel branches, apply

$$X_L = \frac{V}{I_L} \tag{32-3}$$

$$L = \frac{X_L}{2\pi f} \tag{32-4}$$

to the data of Table 32-1. Record L (Calculated) in the table. Compare these values with the rated value.

3. Name one reason for consistent errors in the comparisons for Questions 1 and 2.
4. With a branch opened at A or the other branch at B, what word best describes the resulting circuit?
5. In Fig. 32-2, assume that the left branch is opened at A and the electron current at one particular moment is at the negative peak value such that the voltage at the top end of R is positive. At that moment what will be the polarity of the voltage at the top of R_S?
6. In observing the voltage across R_S in Fig. 32-2, why is it not necessary to have a calibrated position for TIME/DIV?
7. Consider a new equation for phase difference:

$$\text{phase difference} = \frac{\text{divisions between peaks}}{\text{divisions/cycle}} \times 2\pi \tag{32-5}$$

Compare this equation with Eq. (32-1). In what units will the phase difference of Eq. (32-5) be stated?

8. Name one reason, other than errors,why the angle between I_L and V will be less than 90°.
9. Describe briefly how a dual-trace oscilloscope might be used to measure phase difference.
10. Calculate the phase difference at 5000 Hz using

$$\text{phase difference} = \tan^{-1} \frac{I_L}{I_R} \tag{35-6}$$

How does this compare with the phase difference found in step 19?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 33

Resistors and Capacitors in Parallel

READING ASSIGNMENT

Modern Electronics: A First Course, pages 492–496

Topics: Capacitive Reactance; Parallel *CR* Circuits

OBJECTIVES OF EXPERIMENT

1. To measure the applied voltage, the branch currents, and the total current for a single resistor and a single capacitor in parallel
2. To measure the applied voltage, the branch currents, and the total current for four parallel branches containing resistors and capacitors
3. To match predicted values of total circuit current against measured values
4. To extend the measurement techniques to a higher range of frequency

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (sine wave)
2. Cathode ray oscilloscope
3. Capacitors: 0.01 μF, 0.02 μF
4. Resistors: $\frac{1}{2}$ W, 100 Ω, 560 Ω, 1000 Ω

PROCEDURE

1. Connect the circuit of Fig. 33-1 using $R = 1000\ \Omega$ and $C = 0.01\ \mu\text{F}$ with $R_S = 100\ \Omega$. Temporarily move the CRO input lead to point *A* and adjust the function generator controls to provide a 25-kHz sine

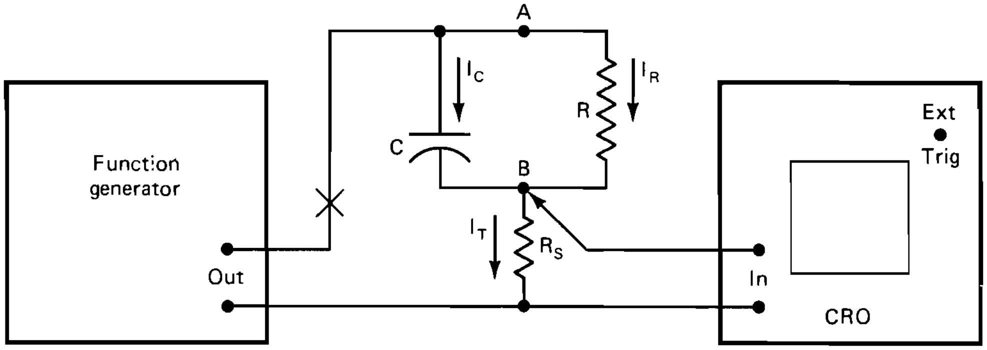


Fig. 33-1

wave. Turn on the function generator and adjust the output amplitude to 5 V (p-p) as measured by the CRO.

2. Move the CRO input lead to point B (as shown in Fig. 33-1). Measure the p-p voltage at point B. Use Ohm's law to find I_T by dividing this voltage by the value of R_S. Enter I_T in Table 33-1.
3. Replace R_S with a short circuit. Move R_S to point X in the circuit. Move the CRO input lead to point A and measure the voltage across the parallel combination. Record this voltage as V_T in Table 33-1.
4. Reconnect the circuit as shown in Fig. 33-1. Confirm that no changes have occurred by measuring 5 V (p-p) with the CRO input lead at point A. Any significant change will require that the preceding steps be repeated.
5. Again replace R_S with a short circuit and move R_S to point X as before. To measure one branch current, open the other branch circuit and readjust the voltage at A to measure the same as V_T in Table 33-1. Reconnect the circuit so that R_S is in the same position as in Fig. 33-1 and with no resistance at point X. Measure the voltage across R_S by placing the CRO input lead at point B. Use Ohm's law to find the branch current by dividing the voltage by the value of R_S. Enter the branch current in the table.
6. Repeat step 5 to find the other branch current.
7. Perform the following calculations to calculate the values of I_C, I_R, and I_T to be entered in Table 33-1 (second row):

$$X_C = \frac{1}{2\pi fC} \tag{33-1}$$

$$I_C = \frac{V_T}{X_C} \tag{33-2}$$

$$I_R = \frac{V_T}{R} \tag{33-3}$$

$$I_T = \sqrt{I_R^2 + I_C^2} \tag{33-4}$$

8. Apply Eq. (33-4) to find I_T using the measured values of I_C and I_R from Table 33-1. Enter this value in the first row of Table 33-1.

Table 33-1

	V_T	I_C	I_R	I_T	*Eq. (33-4)*
Measured					
Calculated					

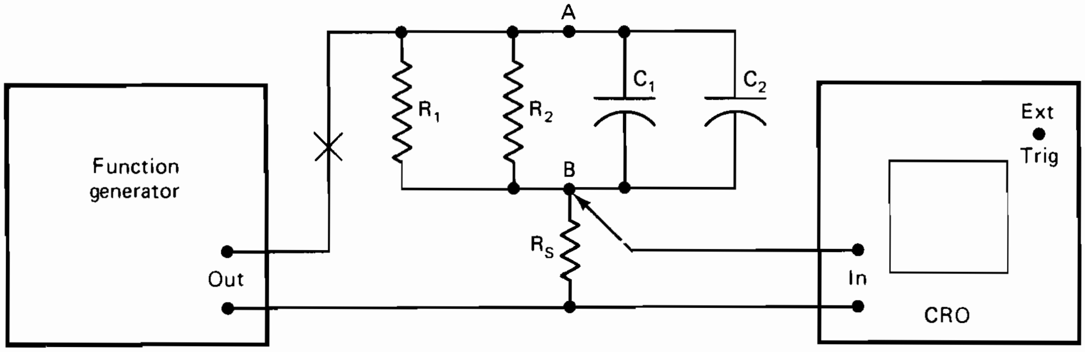


Fig. 33-2

9. Construct the circuit of Fig. 33-2 with $R_1 = 560\ \Omega$, $R_2 = 1000\ \Omega$, $R_S = 100\ \Omega$, $C_1 = 0.01\ \mu F$, and $C_2 = 0.02\ \mu F$. In this step the voltage and currents in Table 33-2 are to be measured with the same V_T as in Table 33-1. This will require a different function generator voltage than before. You should start by moving R_S to point X so that point B is connected to the leads common both to the function generator and the CRO. That is, replace R_S by a short circuit and move R_S to point X. Move the CRO input lead to point A, and, using the proper VOLTS/DIV (calibrated), adjust the function generator output so that the measured voltage, V_T, is the same as that recorded in Table 33-1. This process must be repeated each time before a different current is measured.

   Modify the procedure in step 5 to measure $I_{R1}, I_{R2}, I_R = I_{R1} + I_{R2}, I_{C1}, I_{C2}, I_C = I_{C1} + I_{C2}$, and I_T. Note that the unwanted currents can be eliminated from that being measured by opening the proper branches prior to setting V_T. Measured values are to be entered in Table 33-2.

Table 33-2

	V_T	I_{C1}	I_{C2}	I_{R1}	I_{R2}	I_C	I_R	I_T
Measured								
Calculated								

10. Use Eqs. (33-1), (33-2), and (33-3) to calculate I_{R1}, I_{R2}, I_{C1}, and I_{C2}. Next use

$$I_C = I_{C1} + I_{C2} \tag{33-5}$$

$$I_R = I_{R1} + I_{R2} \tag{33-6}$$

Finally, apply Eq. (33-4) to obtain I_T. The calculated currents should be entered in Table 33-2.

QUESTIONS

1. Compare the measured and calculated currents appearing in the second, third, and fourth columns of Table 33-1. If there are differences, name one possible reason for such differences.
2. Compare I_T and the value obtained by applying Eq. (33-4) in the first row of Table 33-1. Will Eq. (33-4) be valid if there is a substantial resistive component in the capacitor branch?
3. Why is it necessary to readjust to obtain the same V_T in measuring the branch currents for the parallel circuit of Fig. 33-1?
4. If the function generator frequency in Fig. 33-1 is doubled with no other changes, the total circuit current will be ________.
5. If the resistance R_S is 10% greater than the nominal value, what measurements in Table 33-1 will not be in error?
6. In Fig. 33-2, which branches should be opened to measure I_R?
7. In Fig. 33-2, which branches should be opened to measure I_{C1}?

8. Assume that 5 V (p-p) is provided at the terminals of the function generator with the complete circuit of Fig. 33-2. If the C_1 branch is now opened, what will happen to V_T if no other changes are made?
9. What assumptions are made in writing Eqs. (33-5) and (33-6)?
10. Name one type of procedure improvement that will make the measured and calculated values of Table 33-2 match more closely.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 34

Series *RLC* Circuits

READING ASSIGNMENT

Modern Electronics: A First Course, pages 497–509

Topics: Combining Inductive and Capacitive Reactance; Impedance

OBJECTIVES OF EXPERIMENT

1. To investigate the voltage, current, and phase relationships of a series *RLC* circuit for which the inductive reactance is greater than the capacitive reactance
2. To investigate the voltage, current, and phase relationships of a series *RLC* circuit for which the capacitive reactance is greater than the inductive reactance
3. To determine the impedances of series *RLC* circuits

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (sine wave)
2. Triggered-sweep CRO
3. Inductor: 8 H
4. Capacitors: three 0.01 μF, 0.5 μF
5. Resistors: $\frac{1}{2}$ W, 1800 Ω, 10 kΩ
6. Meters: ac current; EVM or DMM

PROCEDURE

1. Construct the circuit of Fig. 34-1 using R = 10 kΩ, L = 8 H, and C = 0.03 μF (three 0.01-μF capacitors in parallel).
2. Turn on the function generator and adjust the sine-wave output to 10 V at 500 Hz using an EVM or DMM connected across the function generator output terminals for the voltage measurement.

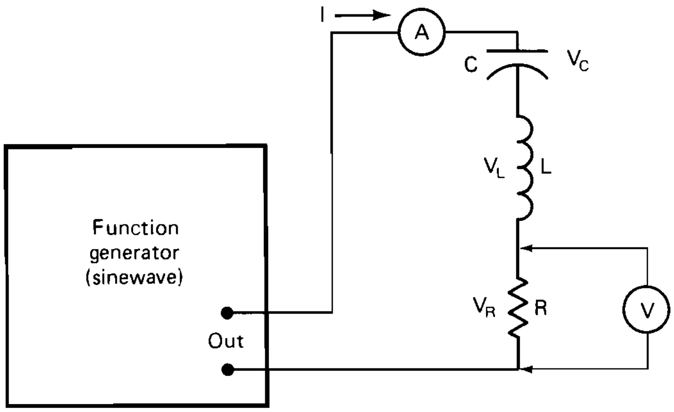


Fig. 34-1

3. Measure the voltages across R, L, and C. Enter V_R, V_L, V_C, and V_T in Table 34-1. Read the current and enter this value in the table.
4. Calculate V_T using the equation

$$V_T = \sqrt{V_R^2 + (V_L - V_C)^2} \tag{34-1}$$

and the data in Table 34-1. Enter the calculated value in Table 34-1.

Table 34-1

f (Hz)	I	V_T	V_R	V_L	V_C	V_T (*Calculated*)
200						
300						
400						
500						

5. Repeat steps 2 through 4 for all other frequencies listed in Table 34-1.
6. Construct the circuit of Fig. 34-2 making $R = 1800\ \Omega$, $L = 8$ H, and $C = 0.5\ \mu$F. Adjust the function generator to deliver 20 V (p-p) at 100 Hz. The TRIGGER MODE control on the CRO should be set to EXTERNAL and the other controls to view one full cycle.
7. No calibrated readings will be taken so that the amplitude can be set to any convenient high level with the waveform centered vertically. If the amplitude is adjusted to fill the graticule from bottom to top, the centering is easily done.

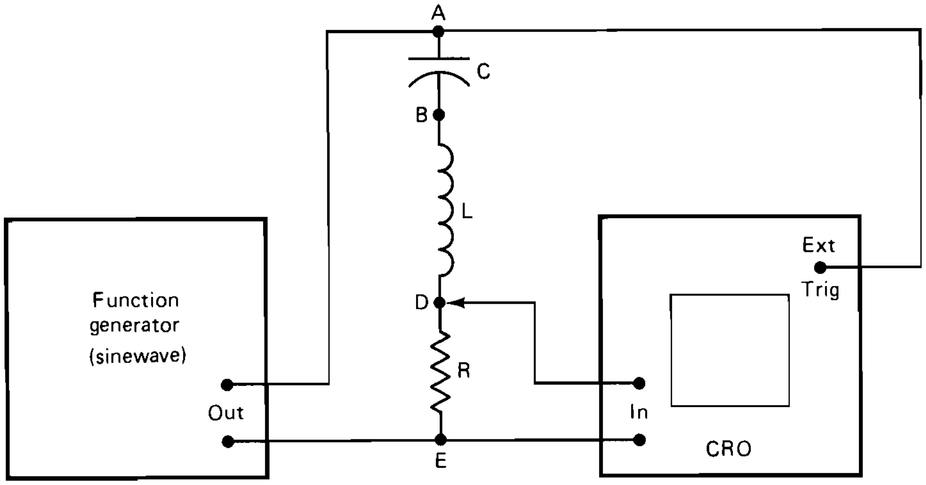


Fig. 34-2

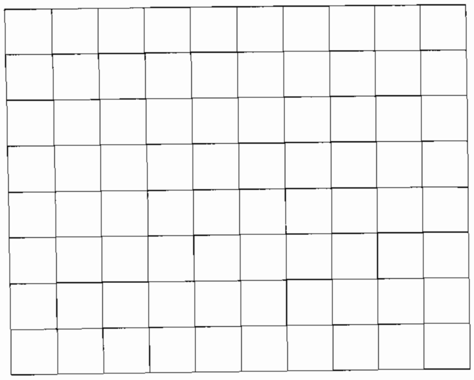


Fig. 34-3

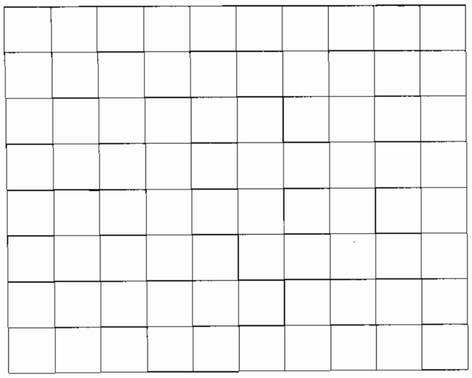


Fig. 34-4

8. Sketch the waveform on Fig. 34-3, being particularly careful in showing where the wave crosses the center (horizontal) graticule line.
9. Temporarily disconnect the function generator and rearrange the circuit so that the capacitor is connected between *D* and *E* and the resistor is connected between *A* and *B*. Adjust the amplitude as before and sketch the waveform on Fig. 34-4.
10. Move the CRO lead from point *D* to point *B* so that the waveform seen is that for the *LC* series combination. Again adjust the amplitude and sketch the waveform on Fig. 34-5.

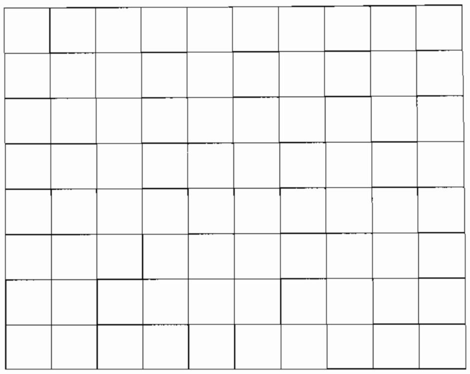


Fig. 34-5

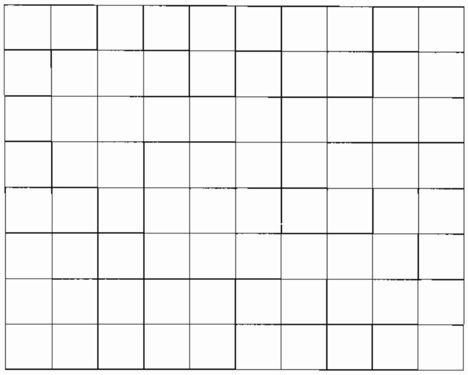


Fig. 34-6

11. Rearrange the circuit as shown in the schematic diagram of Fig. 34-2 with the following differences: The inductor should appear between *D* and *E* and the resistor between *B* and *D*. Adjust the amplitude and sketch the waveform on Fig. 34-6.
12. Move the CRO lead from point *D* to point *B* so that the waveform of the voltage for the *RL* combination is seen. Adjust the amplitude and sketch the waveform on Fig. 34-7.

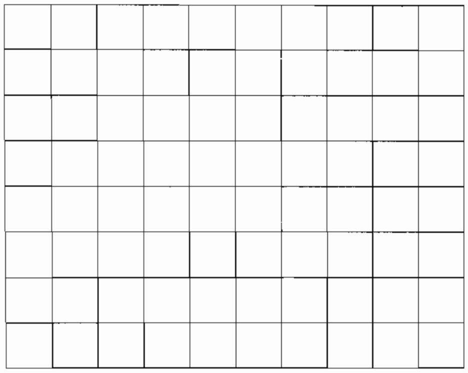


Fig. 34-7

QUESTIONS

1. Referring to Table 34-1, did V_L increase or decrease as the frequency increased?
2. Referring to Table 34-1, did V_C increase or decrease as the frequency increased?
3. Do the values of V_T (calculated) of Table 34-1 match the applied voltage reasonably well? Name one reason why there may be errors in applying Eq. (34-1) using the measured values.
4. If, for one set of measurements recorded in Table 34-1, V_L or V_C is greater than the total applied voltage, pick one case for closer examination. In Fig. 34-8 sketch the phasor diagram, demonstrating why one component voltage can be greater than the total applied voltage.
5. Calculate the impedance of the circuit using the total applied voltage, the current readings of Table 34-1, and

$$Z = \frac{V}{I} \tag{34-2}$$

   Record these calculated values of Z in Table 34-2. Does Z increase or decrease with frequency?
6. What is the phase relationship between the voltage across the LC arrangement in Fig. 34-5 and that across R in Fig. 34-3?

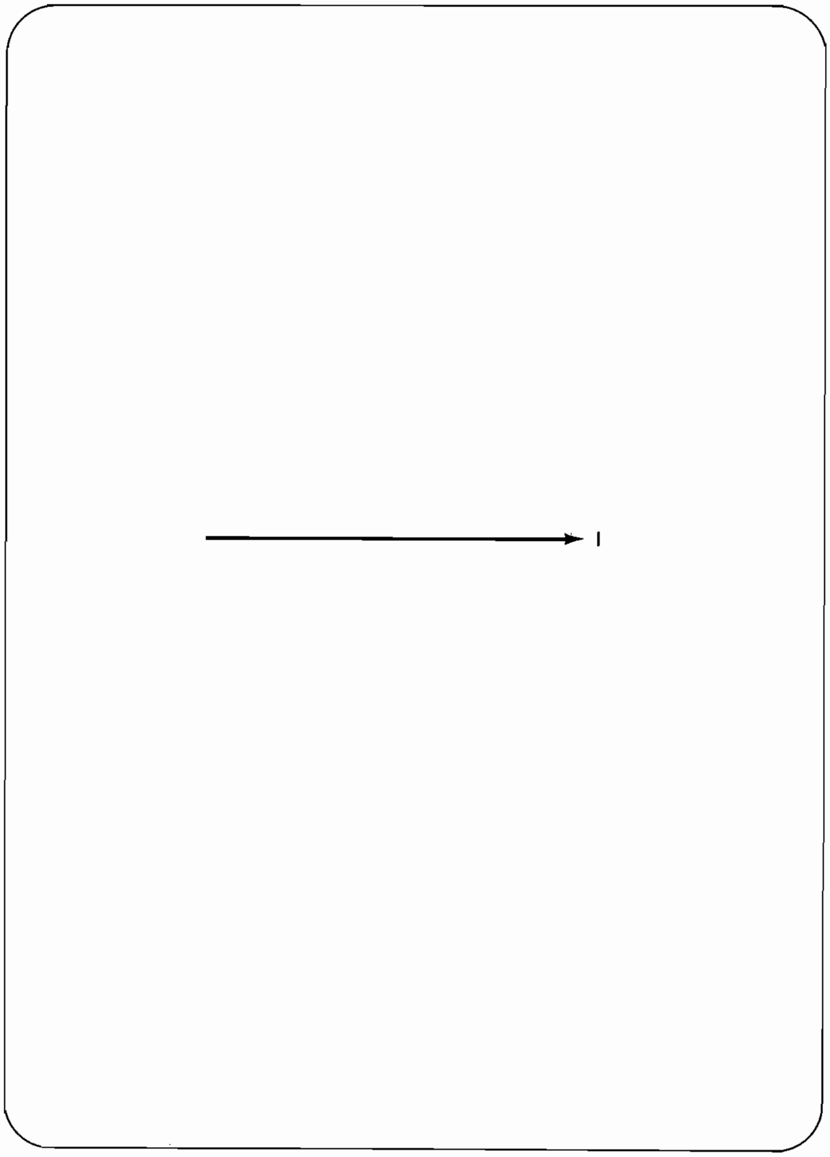


Fig. 34-8

Table 34-2

f (Hz)	Z (*Calculated*)
200	
300	
400	
500	

7. What is the phase relationship between the voltage across L in Fig. 34-6 and that across R in Fig. 34-3?
8. What is the phase relationship between the voltage across RL in Fig. 34-7 and that across R?
9. In Eq. (34-1), why is it possible to take the difference $V_L - V_C$?
10. Select the one particular point demonstrated by the experiment and comment on it briefly.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 35

RLC Parallel Circuit

READING ASSIGNMENT

Modern Electronics: A First Course, pages 509–519

Topics: Inductive and Capacitive Reactance; Parallel AC Circuits

OBJECTIVES OF EXPERIMENT

1. To investigate the voltage and current relationships for a parallel circuit in which the reactance of the capacitive branch is greater than the reactance of the inductive branch
2. To investigate the voltage and current relationships for a parallel circuit in which the reactance of the capacitive branch is less than the reactance of the inductive branch
3. To determine the impedance of parallel *RLC* circuits

COMPONENTS AND EQUIPMENT REQUIRED

1. Meters: ac current; EVM or DMM
2. Triggered-sweep CRO
3. Function generator (sine-wave output required)
4. Inductor: 30 mH
5. Capacitor: 0.1 μF
6. Resistors: 680 Ω and assortment having values of less than 10 kΩ, $\frac{1}{2}$ W

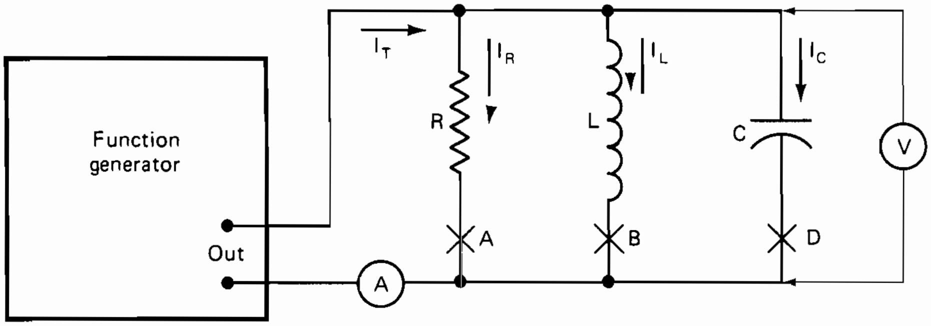


Fig. 35-1

PROCEDURE

1. Connect the circuit of Fig. 35-1 using a function generator, a current meter, an EVM or DMM, and $R = 680\ \Omega$, $L = 30$ mH, and $C = 0.1\ \mu$F.
2. Adjust the function generator to deliver a sine wave of 5 V using the EVM or DMM to measure the applied voltage. Set the frequency at 2 kHz.
3. Maintaining the applied voltage at the same level, open one branch at B and another at D. Measure I_R and record the measured value in Table 35-1.
4. Maintaining the applied voltage at the same level, open one branch at A and another at D. Measure I_L and record the measured value in Table 35-1.
5. Maintaining the applied voltage at the same level, open one branch at A and another at B. Measure I_C and record the measured value in Table 35-1.
6. Maintaining the applied voltage at the same level and, with all three branches intact, read I_T and record the value in Table 35-1.

Table 35-1

V	f (kHz)	I_R	I_L	I_C	I_T	I_T (*Calculated*)	$Z\angle\theta$ (*Calculated*)
	2						
	3						
	4						
	5						

7. Record V and f in Table 35-1. Calculate I_T using

$$I_T = \sqrt{I_R^2 + (I_L - I_C)^2} \tag{35-1}$$

Record the calculated value. If there is not a reasonable check between the measured I_T and I_T (Calculated), repeat steps 3 through 7 to ensure that no instrument reading or calculation errors have been made.

8. Repeat steps 2 through 7 for each of the frequencies 3000, 4000, and 5000 Hz.
9. Construct the circuit of Fig. 35-2 using the function generator, CRO, and the circuit elements $R = 680\ \Omega$, $L = 30$ mH, and $C = 0.1\ \mu$F. In this circuit the sweep is triggered by the applied voltage. While the waveform seen is that of the $I_T R_S$ drop, it has the same shape as I_T. The circuit then provides a means of comparing the common voltage of the parallel circuit with that of the current. This will be done for all frequencies listed in Table 35-2. Note that the resistor R_S is in series with the parallel combination of R, L, and C. For this reason the voltage that is triggering the oscilloscope sweep is not *exactly* the same as that across the parallel circuit. A small value of approximately 10 Ω or even less for R_S will cause the parallel circuit voltage to be nearly the same as the total output voltage of the function generator.

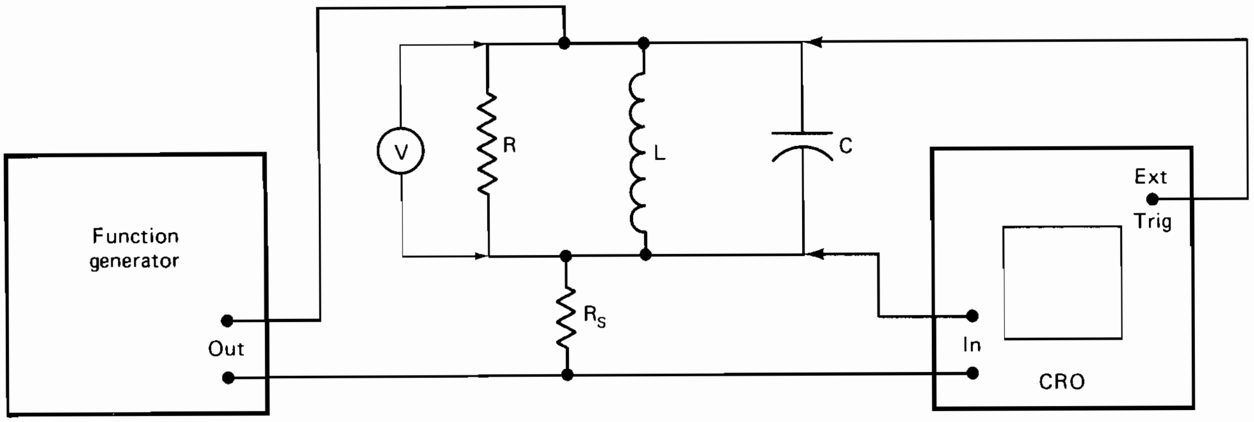


Fig. 35-2

In the measurements to be made using the overall circuit of Fig. 35-2, use the least value of R_S that will allow the waveform to be clearly seen and measured. The amount of R_S needed will depend on the sensitivity of the oscilloscope being used. (*Suggestion:* Place additional resistors in parallel to form R_S and enter the calculated value of R_S in Table 35-2. It is important that you understand why R_S should be relatively small and how to make the value small before starting.)

10. Attach the EVM or DMM as shown in Fig. 35-2 to read the voltage across the parallel combination. Adjust the function generator to provide 5 V there with a frequency of 2000 Hz.
11. Set the TRIGGER MODE control on the CRO to EXTERNAL. Adjust the controls to obtain the least number of cycles with the TIME/DIV calibrated. The VOLTS/DIV control need not be calibrated and it is best to obtain a large-amplitude waveform centered on the middle horizontal line of the graticule. Note the position of the zero crossing as seen on the CRO. This is the display of the current waveform corresponding to the current phasor.
12. Move the input CRO lead from point *B* to point *A* and adjust the VOLTS/DIV control (calibrated) only to obtain the voltage waveform. Note the position of its zero crossing. Carefully count the graticule marks between the zero-crossing point in step 11 and the present zero-crossing point. Proceed slowly. There is no hurry. Move the CRO lead back and forth between *B* and *A* several times, if necessary, to be sure of the zero-crossing points.
13. If the difference between the zero-crossing points seen in steps 11 and 12 is small compared with the horizontal span of the oscilloscope sweep, you may wish to try another plan. That is, when the separation of the two zero-crossing points is small, the numerical value of this difference, which is required, will not be very accurate. Therefore, the zero-crossing points may be spread by using a different setting of the TIME/DIV control. It is not necessary that an entire cycle be seen for this measurement. It is only necessary that one zero crossing be visible with the CRO lead at *A* and the other with lead at *B*. None of these measurements is of any value unless the TIME/DIV is calibrated.
14. Determine the separation between the two points expressed in DIVISIONS of graticule markings. (The grid markings are separated by one DIVISION. The other markings allow interpolated values to be estimated.) If two or more students are working together on this experiment, each is advised to make the adjustments and readings independently of the other(s).

Table 35-2

f (kHz)	*Time Separation*	*T*	*Phase Angle*	*Current* I_S	$Z\angle\theta$ (*Calculated*)
2					
3					
4					
5					

15. Multiply the separation between the points found in step 14 by the TIME/DIV setting on the CRO and enter the time separation found in Table 35-2 together with the frequency f setting of the function generator.
16. Readjust the TIME/DIV control (calibrated) on the CRO so that the least number of whole cycles is seen. With the waveform centered vertically, determine the difference between zero crossings of the waveform. In other words, determine the span of one cycle expressed in DIVISIONS of the graticule. Multiply the span by the TIME/DIV set on the CRO. Place this time in the T column of Table 35-2. The unit of time (μs, ms, or s) should also be entered. You have just measured the period of the sine wave. As a quick check, the value of T should be approximately equal to the reciprocal of the f setting. A large discrepancy at this point indicates the need to review all the preceding steps and, perhaps, to start over.
17. Find the phase angle using the equation

$$\text{phase angle} = \frac{\text{time separation}}{T} \times 360^\circ \tag{35-2}$$

If the angle is substantially greater than 90°, there has been some error. If, for example, the phase angle calculated is 100° or more, there is definitely an error that needs to be identified and corrected. Enter the phase-angle value in Table 35-2.

18. In the next-to-last column of Table 35-2, indicate whether the current is leading or lagging the voltage by simply writing "Leading" or "Lagging" in the table. This answer should be determined from the appearance of the voltage and current waveforms. However, it should match reasonably well the predicted estimate obtained by theory.
19. Repeat steps 10 through 18 using, one at a time, the frequencies listed in Table 35-2.
20. Calculate the impedance for the data in Table 35-2 using the equations

$$Z = \frac{V}{I} \tag{35-3}$$

$$\theta = \tan^{-1} \frac{I_L - I_C}{I_R} \tag{35-4}$$

$$\theta = -\tan^{-1} \frac{I_C - I_L}{I_R} \tag{35-5}$$

in which I is understood to be total current. Equation (35-4) is used when I_L is greater than I_C and Eq. (35-5) is used when I_C is greater than I_L. [Many students will have noticed that Eqs. (35-4) and (35-5) state exactly the same mathematical relationship. If you see this, fine. If you do not, don't worry. You will see it later.]

QUESTIONS

1. In steps 3, 4, and 5, the instructions specified that the same level of applied voltage be maintained. Will the measured currents be the true branch currents if this precaution is not taken?
2. Name the property of the function generator that may cause the output voltage level to change as the load is changed.
3. In order that Eq. (35-1) apply, I_R should lead I_L by ________ degrees and I_C should lead I_L by ________ degrees.
4. Assuming no human error or instrument errors, state one reason why the calculated total current might not be the same as the measured total current in Table 35-1.
5. Again referring to Table 35-1, for which frequencies is the capacitive reactance greater than the inductive reactance?
6. For which frequencies is the inductive reactance greater than the capacitive reactance as indicated by the data in Table 35-1?

7. Estimate the voltage across R_S in Fig. 35-2 for that frequency that is greatest. Express this voltage drop as a percentage of the total voltage.
8. Based on the numerical result obtained in Question 7, does the existence of R_S in the circuit have a significant effect on the phase-angle measurements of this experiment?
9. In Table 35-1, $Z\underline{/\theta}$ is the impedance expressed in ____________ form.
10. Do you believe that Eqs. (35-4) and (35-5) require the same conditions as those mentioned in Question 3?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 36

Maximum Power Transfer

READING ASSIGNMENT

Modern Electronics: A First Course, pages 207–214, 545–550, 553, 558

Topics: Maximum Power Transfer for DC and AC Circuits; Quality Factor

OBJECTIVES OF EXPERIMENT

1. To investigate the power transfer as the load reactance is varied for a source having internal resistance and reactance
2. To investigate the power transfer as the load resistance is varied for a source having internal resistance and reactance
3. To formulate a general rule for maximum power transfer

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (sine wave), 10 V (rms) capability
2. Meters: ac current (25 mA to 5 kHz); two EVMs or DMMs
3. 30-mH inductor
4. Resistors: 100 Ω, 330 Ω ($\frac{1}{2}$ W)
5. Capacitor substitution box (to 1 μF), 0.033 μF
6. Decade resistance box

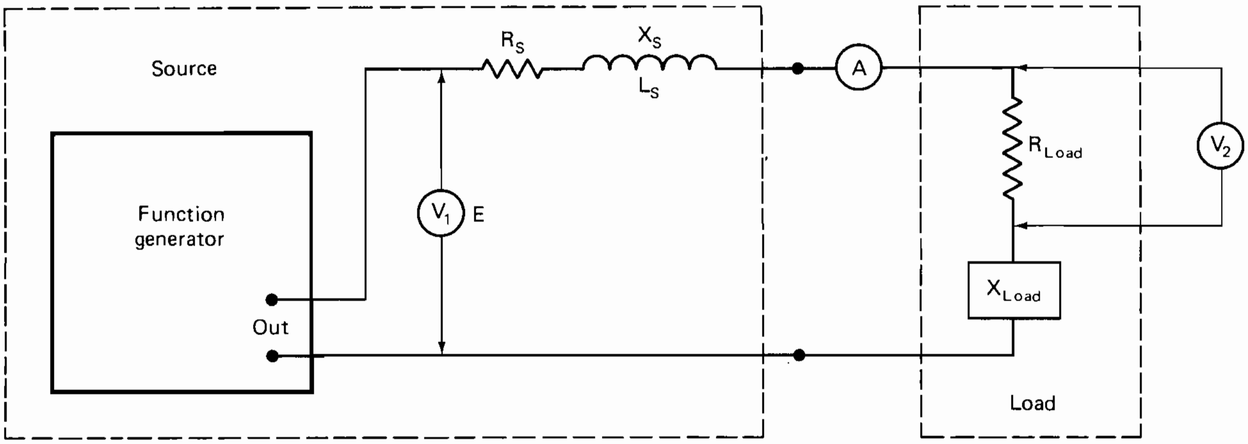


Fig. 36-1

PROCEDURE

1. Connect the circuit of Fig. 36-1 using the function generator, R_S = 100 Ω and L_S = 30 mH to represent the source. The function generator will be set to deliver 10 V as measured by an EVM or DMM labeled V_1 with a sine wave of 5000 Hz. The load consists of R_{LOAD} and X_{LOAD}, a capacitor substitution box, in series. Initially, R_{LOAD} = 330 Ω and X_{LOAD} is the reactance of a 0.033-μF capacitor. Another EVM, called V_2 in the figure, measures the voltage across R_2. A current meter, A, measures the load current.
2. Calculate X_S and X_{LOAD} for the circuit using

$$X_S = 2\pi f L_S \tag{36-1}$$

$$X_{\text{LOAD}} = \frac{1}{2\pi f C_{\text{LOAD}}} \tag{36-2}$$

Remember that X_{LOAD} represents the *load* reactance, not the *inductive* reactance, for this experiment. Enter the value of R_S and X_S in the spaces provided at the top of Table 36-1.

3. Turn on the function generator and verify that the circuit is working properly. The frequency should be set to 5000 Hz with sine-wave output. Enter f in the space provided at the top of Table 36-1.
4. Leave the function generator turned on. Using a variation of Eq. (36-2),

$$C = \frac{1}{2\pi f X_{\text{LOAD}}} \tag{36-3}$$

calculate the values of C needed to obtain 20, 40, 60, 80, 100, 120, 140, 160, 180, and 200% of the value of X_S as determined in step 2. Enter these in the row labeled C (Calculated) in Table 36-1, starting with the largest C (smallest X_{LOAD}) on the top row. Examine the capacitor substitution box and select the values available closest to the calculated capacitances and place these in the second column, labeled C (Used). Also calculate the corresponding values of X_{LOAD} using Eq. (36-2). Enter these in the third column.

5. Connect the capacitor substitution box into the circuit at the position designated X_{LOAD} in Fig. 36-1.
6. Set the capacitance to the first value of C (Used) in Table 36-1. Adjust V_1 to 10 V at 5000 Hz. Read and record V_1, I, and V_2.
7. Repeat step 6 for all the other capacitances in Table 36-1.
8. Calculate P_{LOAD} for all measurements recorded in Table 36-1 using

$$P_{\text{LOAD}} = \frac{V_2^2}{R_{\text{LOAD}}} \tag{36-4}$$

Record the calculated values of P_{LOAD}.

Table 36-1

$f =$ ______ $R_S =$ ______ $X_S =$ ______

C (*Calculated*)	C (*Used*)	X_{LOAD} (*Used*)	V_1	I	V_2	P_{LOAD} (*Calculated*)

9. Now compare the calculated values of P_{LOAD} recorded in Table 36-1. The maximum value of P_{LOAD} should appear in the row for which $X_{\text{LOAD}} = X_S$. If it does not, set the capacitor substitution box to the value nearest that for which $X_{\text{LOAD}} = X_S$ and then, by trial and error, set the capacitance manually to obtain a revised value for maximum power. Be sure that $V_1 = 10$ V for each setting. Note that V_2 and I are involved and that the power must be calculated each time a new capacitor setting is tried. Finally, when you are convinced that further trials will not provide any higher value of P_{LOAD}, record the C (Used), V_1, I, V_2, and P_{LOAD} (Calculated) in the last row of Table 36-1. Calculate X_{LOAD} using Eq. (36-2) and record its value in the table.
10. You will now experiment with different values for R_{LOAD} in seeking maximum power transfer. Remove the present fixed resistor labeled R_{LOAD} in Fig. 36-1. Connect a decade resistance box, set to 330 Ω, in its place. The instrument readings should not greatly change. Now, change the decade resistance box settings in searching for maximum load power. The power must be calculated for each resistance setting using Eq. (36-4). A piece of scratch paper is recommended for this purpose. A rough table resembling Table 36-2, but having only the last four columns, will be useful. Maximum power transfer will be found for a particular resistance R_{LOAD} when two conditions are met.

    1. Any increase in R_{LOAD} will cause P_{LOAD} to decrease.
    2. Any decrease in R_{LOAD} will cause P_{LOAD} to decrease.

    The value of R_{LOAD} for maximum power transfer is ______.
11. Calculate 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, and 150% of R_{LOAD} from step 10. Enter these values in the first column of Table 36-2 starting with the smallest value at the top. Also enter the values for f, R_S, X_S, and X_{LOAD} in Table 36-2.
12. Maintain V_1 at 10 V, set the decade box to the value nearest to the first R_{LOAD} (Calculated), record R_{LOAD} (Used) read, and record V_1, I, and V_2.
13. Repeat step 12 for the next R_{LOAD} (Calculated) until readings have been taken and recorded for all.
14. Calculate P_{LOAD} using Eq. (36-4) for each row of Table 36-2. Record the calculated values of P_{LOAD} in the last column.

Table 36-2

f = ______ R_S = ______ X_S = ______ X_{LOAD} ______

R_{LOAD} *(Calculated)*	R_{LOAD} *(Used)*	V_1	I	V_2	P_{LOAD} *(Calculated)*

QUESTIONS

1. If only the load reactance can be changed, for what condition will maximum power transfer occur?
2. If the data in Table 36-1 do not indicate maximum power transfer for $X_{\text{LOAD}} = X_S$, give a possible reason.
3. Assuming that the frequency is raised to 10 kHz, what value of C will provide X_{LOAD} for maximum power transfer?
4. Examine Table 36-2. Does maximum power transfer occur for $R_{\text{LOAD}} = R_S$?
5. If your answer to Question 6 is "no," give one reason maximum power transfer does not occur when $R_{\text{LOAD}} = R_S$.
6. Examine the data of Tables 36-1 and 36-2. Is the current maximum for maximum power transfer?
7. Is V_2 maximum for maximum power transfer?
8. Estimate the equivalent resistance of the 30-mH inductor using the data from this experiment.
9. Determine the inductance of the coil used assuming exact capacitance values for the capacitor substitution box and the experimental data of Table 36-1.
10. Find the Q of the 30-mH coil. Consult *Modern Electronics: A First Course* if you do not remember the formula for the Q for a series circuit.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 37

Series Resonance

READING ASSIGNMENT

Modern Electronics: A First Course, pages 550–561

Topics: Quality Factor; Resonance; Bandwidth

OBJECTIVES OF EXPERIMENT

1. To find the series resonant frequency by measurement
2. To explore the voltages appearing across the elements of a series resonant circuit
3. To test the effects of increased circuit resistance on the voltages in a series resonant circuit
4. To measure the bandwidth of series resonant circuits

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator
2. Cathode ray oscilloscope with 10:1 probe
3. Inductor: 30 mH
4. Resistors: 100 Ω, 560 Ω ($\frac{1}{2}$ W)
5. Capacitors: 0.01 μF, 0.001 μF

PROCEDURE

1. Construct the circuit of Fig. 37-1 using R = 100 Ω, L = 30 mH, and C = 0.01 μF. Set the function generator to deliver about 1 V (p-p) sine wave at 10 kHz. The CRO TRIGGER MODE should be set to

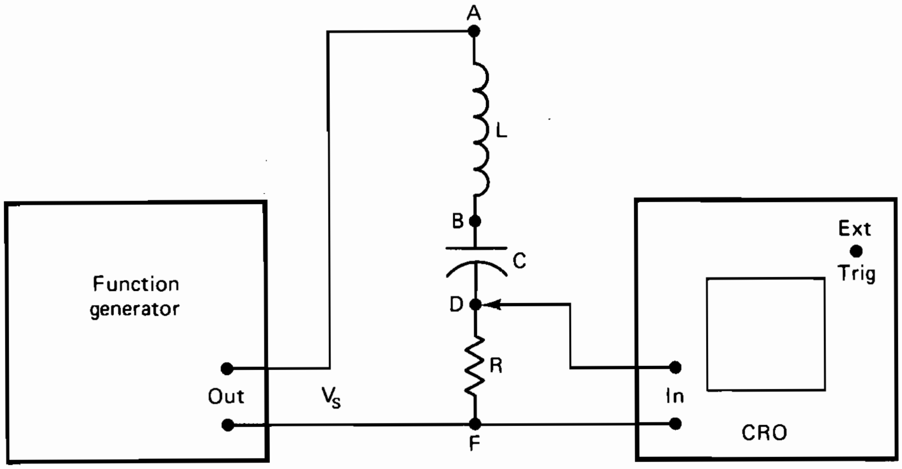


Fig. 37-1

AUTO or INTERNAL and the other controls set to obtain a stable waveform. The number of cycles observed is not important. A scope probe having a factor 10 of attenuation is preferred for the CRO input because of the voltage magnification effect in series resonant circuits. (*Warning:* Do not exceed the maximum input voltage rating of the oscilloscope. Use the lowest value of V_S for which satisfactory measurements can be made.)

2. To observe the waveform it may be necessary to change the VOLTS/DIV (calibrated) control on the CRO. Now adjust the frequency control on the function generator in such a direction as to increase the amplitude of the observed waveform, changing the VOLTS/DIV (calibrated) control as necessary.
3. Find the frequency for which the observed waveform amplitude is maximum. This is the point for which further change in the frequency causes a decrease in the waveform amplitude. Determine the frequency using the CRO and the procedure of Experiments 22 and 24 and record it in Table 37-1, center row.
4. Move the CRO probe from point D to point A. Determine V_S and record the value in Table 37-1. Move the probe back to point D.
5. Temporarily disconnect the circuit from the function generator and interchange R and C. In this arrangement R will be between B and D in Fig. 37-1 and C will be between D and F. Reconnect the circuit to the function generator. Determine V_C and report the value in Table 37-1.
6. Temporarily disconnect the circuit from the function generator, Now rearrange the circuit so that R is between A and B, C is between B and D, and L is between D and F. Reconnect the circuit to the function generator. Determine V_L and enter the value in Table 37-1.
7. Again temporarily disconnect the circuit from the function generator. Rearrange the circuit to the original form of Fig. 37-1. Determine V_R and record the value in the table.
8. Reduce the frequency until V_R reaches 0.707 (70.7%) of that recorded for V_R in step 7. (*Note:* It may be necessary to readjust V_S to retain the same numerical value as was measured in step 4.) Now repeat steps 4 through 7 for the new, lower frequency. The new data should be recorded in the top line of Table 37-1.
9. Repeat step 8 modified to read "increase the frequency" and "bottom line."

Table 37-1

f	V_S	V_R	V_C	V_L	*Comments*

Table 37-2

f	V_S	V_R	V_C	V_L	*Comments*

10. Modify the circuit of Fig. 37-1 using $R = 560\ \Omega$. Now repeat steps 1 through 9 using any convenient function generator sine-wave voltage. A larger value than 1 V (p-p) may make the measurements easier. Whichever value is adopted for V_S should be maintained as stated in step 8. The data should be recorded in Table 37-2.
11. Again start with step 1 using $R = 100\ \Omega$ and $C = 0.001\ \mu\text{F}$ with $L = 30$ mH as before. Repeat steps 1 through 9 using these values and any convenient source voltage V_S. Record the data in Table 37-3.

Table 37-3

f	V_S	V_R	V_C	V_L	*Comments*

12. Again start with step 1 using $R = 560\ \Omega$ and $C = 0.001\ \mu\text{F}$ with $L = 30$ mH as before. Repeat steps 1 through 9 using these values and any convenient source voltage V_S. Record the data in Table 37-4.
13. Each of Tables 37-1 through 37-4 has a Comments column reserved for a very brief description of the meanings of the three frequencies. Please fill them in using not more than five words for each space. For example, if the frequency has a technical name, write the name in the box.

Table 37-4

f	V_S	V_R	V_C	V_L	*Comments*

14. Determine the bandwidths for the data given in Tables 37-1 through 37-4. Identify each using the middle frequency and C in each table. This information should be entered in Table 37-5.
15. Using the equation

$$Q = \frac{2\pi f_r L}{R} \qquad (37\text{-}1)$$

calculate the Q for each row of Table 37-5.

16. Finally, find f_r/Q for each row in Table 37-5. The significance of this ratio will be probed in the questions at the end of the experiment.

Table 37-5

Table	f_r	C	*Bandwidth*	Q *Eq. (37-1)*	f_r/Q
37-1					
37-2					
37-3					
37-4					

QUESTIONS

1. In Fig. 37-1, the frequency for which the maximum V_R occurs is called the ____________ frequency.
2. At the resonant frequency $V_C = V_L$. In examining Tables 37-1 through 37-4, do the data verify the $V_C = V_L$ at resonance? Why do they not match?
3. What is another name for the frequency at which the current is 0.707 (70.7%) of that at resonance?
4. In referring to Fig. 37-1, what limits the current at resonance?
5. When the resistance in the series resonant circuit is decreased, the bandwidth ____________ (increases, decreases).
6. In what other way might the resonant frequency be found?
7. Name two ways that the resonant frequency of a series circuit can be increased.
8. Name one way in which the Q of a circuit can be increased.
9. From the data obtained in this experiment, show two examples that indicate the effect of Q on bandwidth.
10. The resonant frequency can be calculated using the equation

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (37\text{-}2)$$

Calculate the resonant frequency using the nominal values of L and C. Compare these with the measured values.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 38

Parallel Resonance

READING ASSIGNMENT

Modern Electronics: A First Course, pages 562–571

Topic: Parallel Resonance

OBJECTIVES OF EXPERIMENT

1. To find the parallel resonant frequency by measurement
2. To explore the currents in the branches of parallel resonant circuits
3. To test the effects of a resistor placed in parallel with the inductor and capacitor
4. To measure the bandwidths of parallel resonant circuits

COMPONENTS AND EQUIPMENT REQUIRED

1. Function generator (sine wave)
2. Cathode ray oscilloscope
3. Inductor: 30 mH
4. Capacitor: 0.01 μF
5. Resistors: $\frac{1}{2}$ W, 100 Ω, 6800 Ω

PROCEDURE

1. Construct the circuit of Fig. 38-1 using $L = 30$ mH, $C = 0.01$ μF, and $R = 100\ \Omega$. Adjust the function generator to supply approximately 5 V (p-p) with sine wave selection and a frequency of approximately 10 kHz.

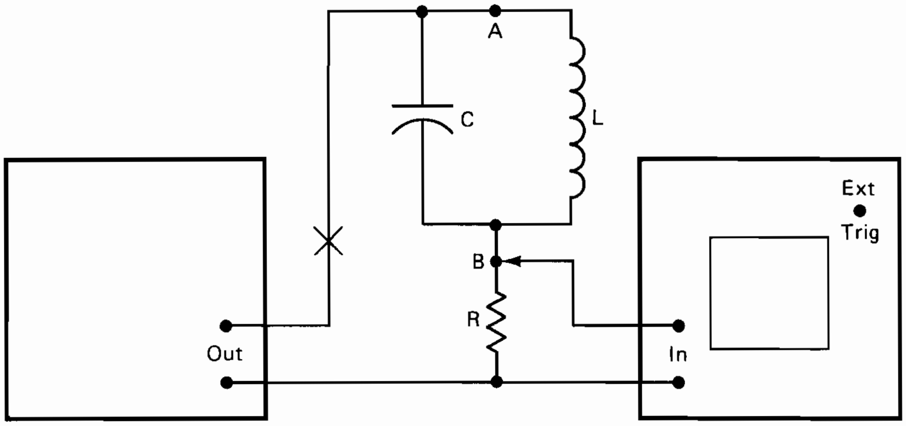


Fig. 38-1

2. Turn on the CRO and function generator and obtain a stable display of the waveform. The number of cycles seen is not important. However, the entire waveform should be visible so that voltage measurements can be made with the VOLTS/DIV control in the calibrated position.
3. Change the frequency setting of the function generator and observe the effect on the displayed waveform amplitude. Adjust the frequency so that the peak-to-peak amplitude of the displayed waveform is minimum. Measure this frequency using the CRO and enter it in Table 38-1, second line.
4. Temporarily disconnect the function generator from the circuits. Replace R with a short circuit. Place R in series with the line at point X. Reconnect the function generator and move the oscilloscope lead to point A. Measure the voltage across the parallel combination and enter the applied voltage in Table 38-1 as V_A in the second line.
5. Remove the capacitor and readjust the function generator output amplitude to the value V_A already recorded.
6. Again temporarily disconnect the function generator from the circuit. Move R and reconstruct the circuit of Fig. 38-1 without the capacitor. Using the CRO, measure the voltage across R. Divide this voltage by the value of R and enter the current so obtained in Table 38-1.
7. Modify steps 5 and 6 so that the current can be measured with the inductor out of the circuit and with V_A appearing across the capacitor. Enter the measured current in Table 38-1.
8. Modify steps 5 and 6 so that the total current can be determined with both the capacitor and inductor in parallel between points A and B. Note that the same V_A must appear across the parallel combination while measuring the voltage across R using the CRO. Enter I_T into Table 38-1 (second line). You will now obtain the data from which the bandwidth can be found. The procedure requires that two particular frequencies be discovered. One will be less than the frequency already entered in Table 38-1 and one will be greater. At these frequencies the impedance of the LC parallel combination must be 0.707 (70.7%) of the value at the frequency noted in Table 38-1. Begin by finding that impedance,

$$Z = \frac{V_A}{I_T} \tag{38-1}$$

Enter Z in the table.

Table 38-1

f	V_A	I_L	I_C	I_T	Z
		☒	☒		
		☒	☒		

In order that the new impedances be 70.7% of the first, the current at the two new frequencies must be

$$\frac{I_T}{0.707} = 1.414 I_T \qquad (38\text{-}2)$$

where I_T is the value already recorded and V_A is the same applied voltage already recorded.

10. Recheck the circuit to ensure that the configuration is the same as shown in Fig. 38-1. Leave the voltage amplitude setting as it was in step 8.
11. Reduce the frequency until the voltage is

$$V_R = 1.414 I_T R \qquad (38\text{-}3)$$

It will now be necessary to ensure that V_A is the same as before. To do this, disconnect the function generator from the circuit. Now move R to point X and follow the procedure of step 4. It may be necessary to make a slight adjustment of the function generator output amplitude control before recording V_A in Table 38-1 (top line).

12. Reconfigure the circuit as is shown in Fig. 38-1 while taking the precautions against damaging equipment and components. Again measure the voltage across R. If it does not have the value specified in Eq. (38-3), change the frequency slightly until it does. Calculate I_T and enter both I_T and f in Table 38-1. Also calculate Z and enter that value in the table.
13. Repeat steps 11 and 12 except that you will be increasing, not decreasing, the frequency.
14. Construct a new circuit according to Fig. 38-2. $L = 30$ mH, $C = 0.01\ \mu$F, $R = 100\ \Omega$, and $R_P = 6800\ \Omega$.
15. Repeat steps 2, 3, and 4. Measured quantities are to be entered in Table 38-2. Again disconnect the function generator and reconstruct the circuit of Fig. 38-2. With the function generator again connected measure the voltage across R using the CRO. Divide this voltage to obtain I_T. Record I_T in the table.
16. Leave the amplitude control of the function as it was and begin the procedure for bandwidth measurement starting with step 11. You will be using Fig. 38-2 and Table 38-2. Complete steps 12 and 13.

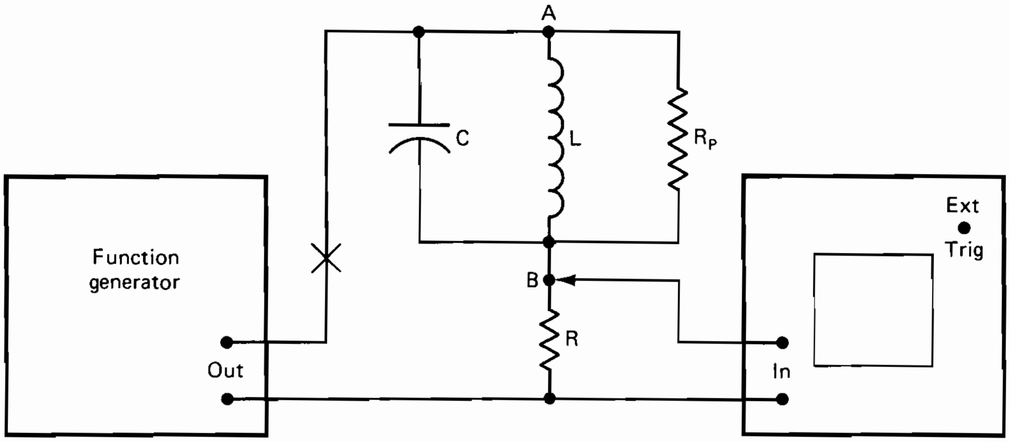


Fig. 38-2

Table 38-2

f	V_A	I_T	Z

QUESTIONS

1. What is the name for the frequency measured in step 3 of this experiment?
2. Referring to Table 38-1, why is not $I_T = I_L + I_C$?
3. Compare I_L and I_C in Table 38-1. Are they equal? Why?
4. Using the data in Table 38-1, find the bandwidth.
5. Assuming that Z is resistive at the resonant frequency, find Z using the data of Table 38-1.
6. Using the data of Table 38-2, find the Q of the circuit in Fig. 38-2.
7. What is the bandwidth of the circuit in Fig. 38-2?
8. Why is the current minimum at the resonant frequency for a parallel LC circuit?
9. In Fig. 38-2, the value of R_P is 6800 Ω. Compare Z in Tables 38-1 and 38-2. Why is the Z value in Table 38-2 not 6800 Ω?
10. How much capacitance is required to cause parallel resonance with an 8-H choke at 60 Hz?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 39

Transformers

READING ASSIGNMENT

Modern Electronics: A First Course, pages 577–589

Topic: Transformers

OBJECTIVES OF EXPERIMENT

1. To measure the output voltages and primary inductive reactance under no-load conditions
2. To compare the performance of a transformer connected to step down the voltage and to step up the voltage levels under no-load and loaded conditions
3. To observe the ability of a transformer to convert impedance levels

COMPONENTS AND EQUIPMENT REQUIRED

1. Meters: two ac current; two EVMs or DMMs
2. Filament transformers: 115 V to 6.3 V or 12.6 V or 25.2 V (preferred) with current rating of at least 250 mA
3. Access to resistors capable of dissipating 2 W or more; resistance values depend on the transformer being used (see steps 7 and 8)
4. Isolation transformer and variable autotransformer

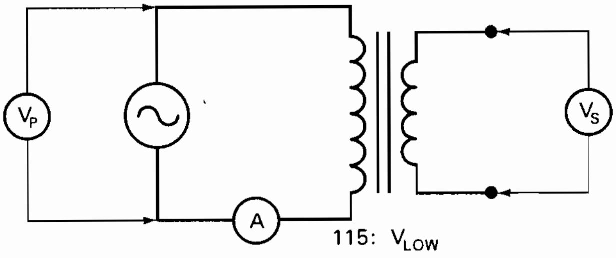


Fig. 39-1

PROCEDURE

1. Connect the circuit shown in Fig. 39-1. The ac voltage source consists of an isolation transformer plugged into the ac line followed by a variable autotransformer set for minimum output. Two voltmeters are used. One is used to measure the applied primary voltage. The other measures the open-circuited secondary voltage. A current meter is placed in series with the primary winding. The circuit is normal for this transformer in that the higher voltage is applied to the primary winding. The transformer has been designed to be a step-down transformer and this is the manner in which it has been connected. However, there is no load on the secondary.
2. Adjust the primary voltage levels to the values given in Table 39-1. For each level read V_P, I_P, and V_S. Record the readings in the table.
3. Assuming that the impedance of the transformer primary is inductive reactance, calculate X (Calculated) for each set of readings in Table 39-1.

Table 39-1

V_P	I_P	V_S	X (Calculated)
20			
40			
60			
80			
100			
120			

4. Reduce the autotransformer output to the lowest value and, with the power off, construct the circuit of Fig. 39-2. Compare the circuits of Figs. 39-1 and 39-2. The only difference between them is that the low-voltage winding is serving as the primary in Fig. 39-2. In Fig. 39-1 the winding with the larger number of turns is the primary. In Fig. 39-2 the winding with the smaller number of turns is the primary. The transformer in Fig. 39-2 is a step-up transformer.

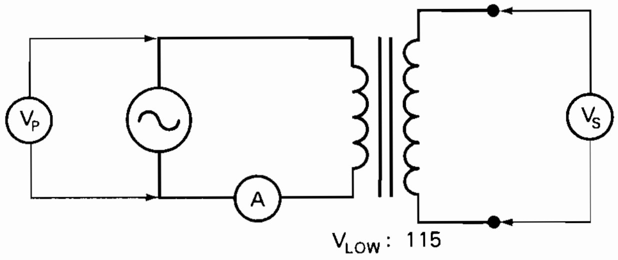


Fig. 39-2

Table 39-2

V_P	I_P	V_S	X *(Calculated)*

5. Subdivide the original lower voltage rating of the transformer into approximately six whole-number parts. For example, if the rating is 6.3 V, use 1, 2, 3, 4, 5, 6 V. Enter these values into the V_P column of Table 39-2. Set V_P to each of these values in turn, read the instruments, and complete the I_P and V_S columns of the table. Before turning on the power for the isolation transformer/variable autotransformer combination, be sure that the adjustment is for minimum output voltage.
6. Assume that the primary current recorded in Table 39-2 is limited solely by the reactance of the primary winding self-inductance. Calculate X for each row and enter the calculated values into Table 39-2.
7. Turn off the ac power and construct the circuit of Fig. 39-3. The load resistor values are to be initially calculated using the low-voltage winding (the normal, step-down transformer secondary) rating and the current rating. Since the current rating will not appear on the least expensive filament transformers, the instructor or the stockroom clerk should supply this information. As a last resort, assume that $I_S = 1$ A and monitor carefully for overloading as the experiment is performed. Use the following formulas:

$$R = \frac{V_S}{I_S} \tag{39-1}$$

$$R_{\text{STD}} > R \tag{39-2}$$

$$P = \frac{V_S^2}{R_{\text{STD}}} \tag{39-3}$$

Equation (39-1) provides the resistance needed for rated current I_S and V_S, the secondary voltage rating of the transformer. Equation (39-2) is a shorthand way of saying that R_{STD} is to be greater than R. Select R_{STD} to be the next larger value of a parallel combination of standard resistors having identical resistance and power ratings. In anticipation of future steps in this experiment, the number of parallel resistors should be four, eight, or any other reasonable multiple of four. The combined power rating of all resistors should be at least that found by applying Eq. (39-3). For example, if $I_S = 1$ A and four 27-Ω, 2-W 10% composition resistors are available, the calculations are as follows

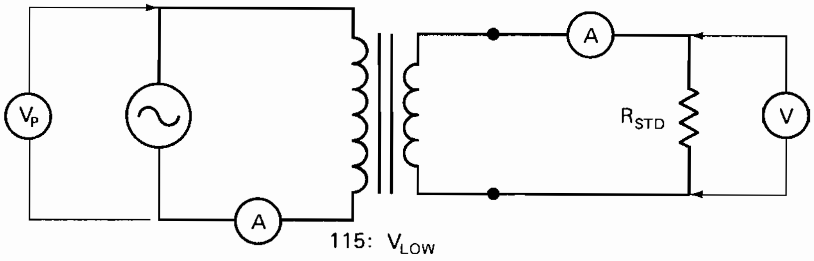


Fig. 39-3

$$R = \frac{6.3}{1} = 6.3\ \Omega \qquad (39\text{-}1)$$

$$R_{STD} = \frac{27}{4} = 6.75\ \Omega > 6.3\ \Omega \qquad (39\text{-}2)$$

$$P = \frac{6.3^2}{6.75} = 5.88\ \text{W} \qquad (39\text{-}3)$$

Table 39-3

R	R_{STD}	P	V_P	I_P	V_S	I_S

Since 5.88 W is less than the 8 W combined rating of all four resistors, the arrangement is satisfactory. Enter R, R_{STD}, and P in the last line of Table 39-3.

8. Repeat the applications of Eqs. (39-1) through (39-3) using 25% of rated I for the first line, 50% for the second line, and 75% for the third line. (*Hint:* Use one-fourth, one-half, and three-fourths of the resistors already selected.) Complete the first three columns of Table 39-3.
9. Complete the connections for each load of Table 39-3, set the same V_P for each row, make the measurements and record the data.
10. After reading *all* the directions for this procedural step, repeat steps 7 through 9 for the circuit of Fig. 39-4 and for Table 39-4. In comparing Fig. 39-4 to Fig. 39-3 it is seen that the windings have been interchanged. In Fig. 39-4, the low-voltage winding is the primary since the current rating of the transformer is that for the low-voltage winding. The current rating of the 115 V winding is different. Use

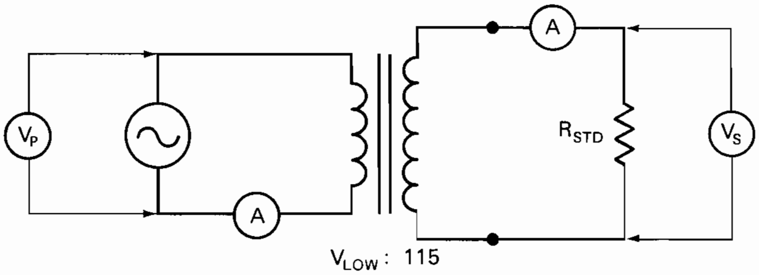


Fig. 39-4

Table 39-4

R	R_{STD}	P	V_P	I_P	V_S	I_S

the following equation to find the current rating for the 115-V winding:

$$I_{115} = I_{\text{LOW}} \times \frac{V_{\text{LOW}}}{115} \qquad (39\text{-}4)$$

Be particularly careful in connecting the circuit so that the isolation transformer/variable autotransformer *source is set to the minimum level before turning on the power.* You are dealing with a step-up transformer with the possibility of producing high voltages. Do not be concerned if you are unable to set the primary voltage to the exact low-voltage rating of the transformer. Set it as close as possible and record the exact voltage reading in Table 39-4. *Do not apply a voltage more than 10% above the rated voltage,* as this may cause the magnetic core to saturate, the inductive reactance to decrease, and the fuse to blow.

11. Refer to Table 39-3 containing data for the step-down transformer. Transfer the several values for load resistance (R_{STD}) from Table 39-3 to the first column of Table 39-5.
12. In the center column of Table 39-5, place the predicted value of the resistance looking into the primary winding. This is the load resistance multiplied by the square of the turns ratio.
13. In the third column of Table 39-5, place the actual resistance looking into the primary winding. This is the ratio of V_P to I_P with values obtained from Table 39-3.
14. Repeat steps 11, 12, and 13 using the circuit of Fig. 39-4 and the data from Table 39-4. The results should be entered in Table 39-6.

Table 39-5

R_{STD}	R_P (*Predicted*)	V_P/I_P

Table 39-6

R_{STD}	R_P (*Predicted*)	V_P/I_P

QUESTIONS

1. Compare the calculated values of reactances in Table 39-1. Name two possible reasons different values appear.
2. Compare the calculated values of reactances in Table 39-2 with those in Table 39-1. Remember, there is no load in the secondary circuit. Therefore, only the impedance in the primary circuit affects the current flow when a given voltage is applied. Name one reason that one set of reactances is much larger than the other.
3. Using the V_P and V_S data from Table 39-1, plot V_S in the vertical direction and V_P in the horizontal direction. It will be necessary to select a convenient scale for V_S in Fig. 39-5. Pick whole numbers for ease in interpolations for the scale. When the points have been marked on the figure, draw a smooth continuous curve through the points. What simple curve most nearly describes the graph?
4. Compare the predicted and measured values in Table 39-5. For which loads do the values check most closely?
5. Compare the predicted and measured values in Table 39-6. For which loads do the values check most closely?
6. Judging from the information in Tables 39-5 and 39-6, what feature of the transformer is most likely to make the difference between the predicted and measured values?

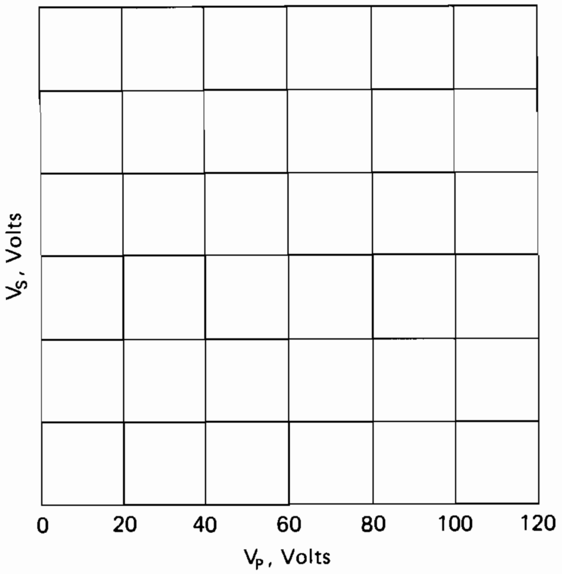


Fig. 39-5

7. Referring to Tables 39-3 and 39-4, when the load is increased (I_S gets larger), what happens to V_S?
8. The temperature of a working transformer body will be higher than that of the surrounding air. Why?
9. Name at least two specific causes for the power losses in a transformer.
10. If a certain transformer has a 10 : 1 step-down ratio, the output voltage will be 11 V (rms) if the primary voltage is 110 V (rms). What will be the output voltage if the primary voltage is 110 V (peak)?

CONCLUSION

Describe in your own words what you have learned from this experiment.

Experiment 40

Mutually Coupled Circuits

READING ASSIGNMENT

Modern Electronics: A First Course, pages 459–467, 589–599

Topics: Self-Inductance; Mutual Inductance; Magnetically Coupled Circuits

OBJECTIVES OF EXPERIMENT

1. To measure the impedance of each inductor and resolve the impedance into the resistance and reactance components
2. To measure the mutual inductive reactance of two inductors
3. To measure the total impedance of two inductors with mutual inductance connected in series
4. To find the coefficient of coupling for two inductors

COMPONENTS AND EQUIPMENT REQUIRED

1. Triggered-sweep CRO
2. Meters: ac current; two EVMs or DMMs
3. Two 30-mH inductors

PROCEDURE

1. Prepare two inductor coils for the experiment by mounting them together. The directions for doing this and for conducting the experiment assume the use of 30-mH inductors which are found in many intro-

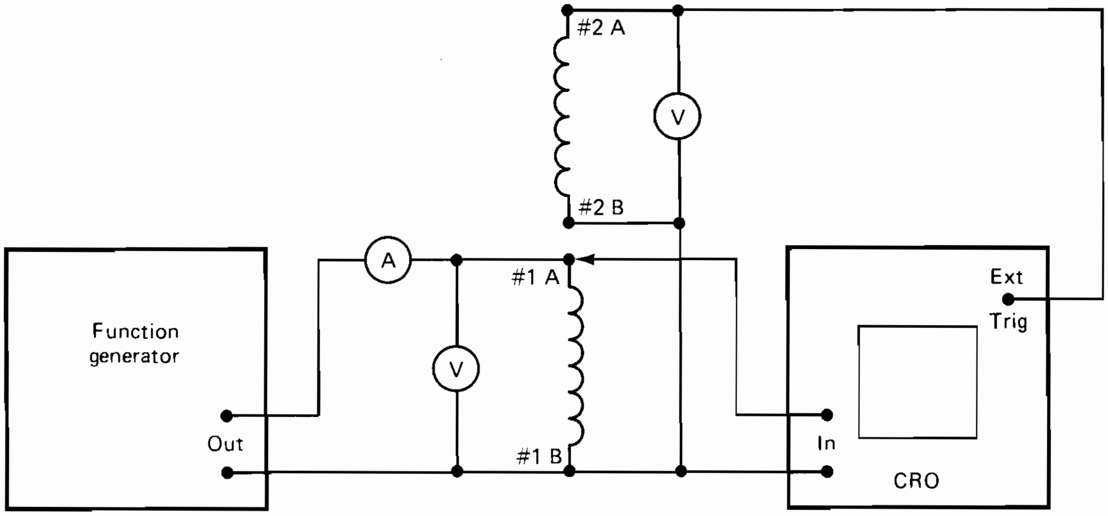


Fig. 40-1

ductory electronics laboratories. Other inductor values can be used through slight modifications of the procedures.

First align the inductors so that the axes lie along the same line. The purpose is to make the mutual inductance the largest possible. Both leads for each inductor should remain clear for future connections. Mechanically attach the inductors together using string, rubber bands, clamps, and so on. If the inductors are to be used for the same experiments at another time and can be dedicated for this purpose, glue is recommended.

If a nonpermanent method for attaching the inductors is adopted, precautions must be taken to ensure that no relative motion of the two takes place after the experiments are started. Leads should be connected to the four terminals of the two inductors and left in place. This will allow the different circuit configurations to be wired without touching the inductor pair. Designate the inductors as 1 and 2 and the leads as 1A, 1B, 2A, and 2B, respectively. Small strips of masking tape are useful for labeling the leads.

2. Connect the circuit of Fig. 40-1. Set the function generator to deliver a 10-V (as measured by the voltmeter) sine wave at 10 kHz. If the instruments are not accurate at this frequency, adopt a lower frequency, as the specific frequency is not important. Adjust the CRO so that one cycle is visible covering 10 horizontal divisions with the waveform exactly centered after temporarily moving the CRO INPUT lead from point 1A to 2A. Note that the CRO TRIGGER MODE control should be set to EXTERNAL.
3. Move the CRO INPUT from point 2A to 1A so that the waveform of the primary voltage can be seen. If the resistance in the primary winding is small compared with the inductive reactance, the sine wave will either be approximately in phase with that seen in step 2 or will be approximately 180° out of phase. If it appears to be almost 180° out of phase, reverse connections 2A and 2B and redesignate the two leads; that is, trade the markings on the leads as made in step 1. Actually, the voltage waveform seen will appear to lag that of step 2 by a small angle when the markings are correct.
4. Repeat steps 2 and 3 but sketch and label the waveforms in Fig. 40-2.
5. Calculate the impedance angle for the primary circuit. It is 90° less the phase difference between the waveforms of Fig. 40-2:

$$\text{impedance angle} = 90^\circ - \frac{n}{10} \times 360^\circ \tag{40-1}$$

In Eq. (40-1), n is the number of divisions separating the zero crossings for the two waveforms in Fig. 40-2. The impedance angle calculated is ________°. Enter the impedance angle in Table 40-1 in the column marked ϕ_1.

6. Read V_1, I_1 and V_2 using the meters in Fig. 40-1. Enter the measured values in Table 40-1. Perform the following calculations and enter the calculated values in Table 40-1.

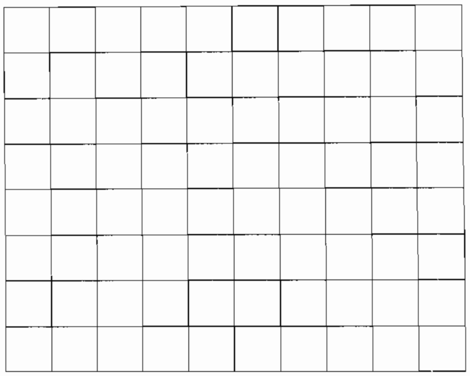


Fig. 40-2

Table 40-1

V_1	I_1	Z_1	ϕ_1	R_1	X_1	V_2	X_M

$$Z_1 = \frac{V_1}{I_1} \tag{40-2}$$

$$R_1 = Z_1 \cos \phi_1 \tag{40-3}$$

$$X_1 = Z_1 \sin \phi_1 \tag{40-4}$$

$$XM = \frac{V_2}{I_1} \tag{40-5}$$

7. The next steps in the procedure are intended to find R_2 and X_2 for the second inductor. Another measurement of X_M will also be made. Start by constructing the circuit of Fig. 40-3. Note that the positions of the two inductors have been reversed from those of Fig. 40-1. This suggests that steps 2 through 6 apply for filling Table 40-2. There is one difference required in following those steps in the procedure. That difference is to substitute "2" for "1" and "1" for "2" in applying the instructions. This should be done. The waveforms are to be sketched in Fig. 40-4.

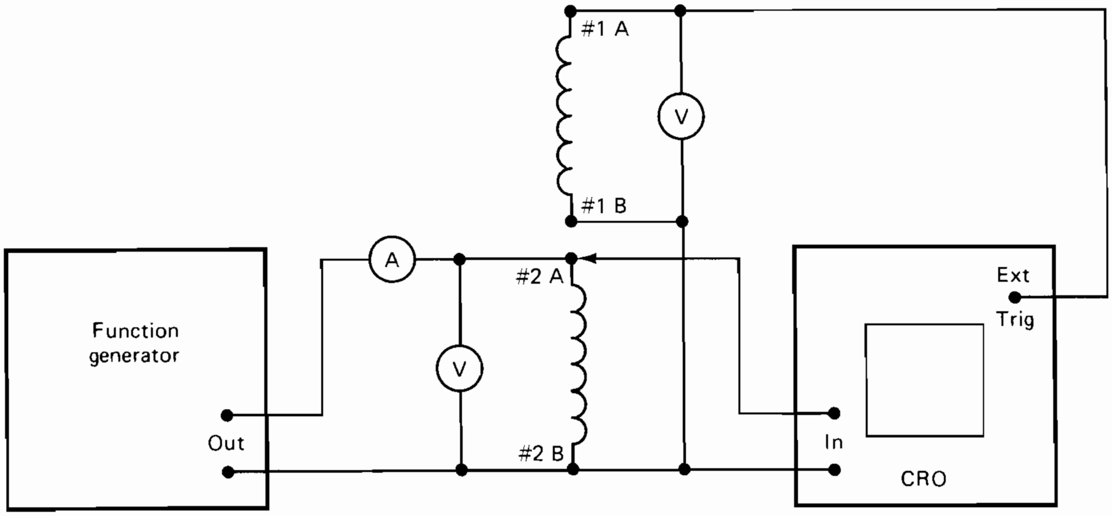


Fig. 40-3

Table 40-2

V_2	I_2	Z_2	ϕ_2	R_2	X_2	V_1	X_M

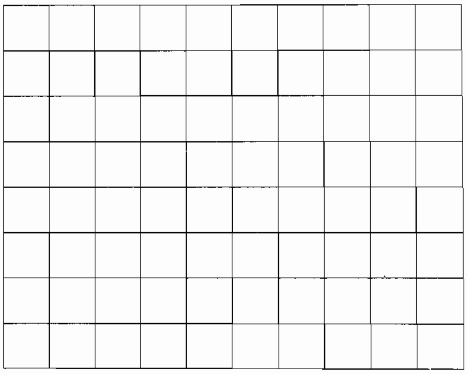


Fig. 40-4

8. If the X_M in Table 40-2 differs greatly from that in Table 40-1, some error may have been made. It is now better to check all recorded values starting with step 2 and to make necessary corrections in the recorded values.
9. Construct the circuit of Fig. 40-5, which consists of the two inductors connected in series across the terminals of the function generator.

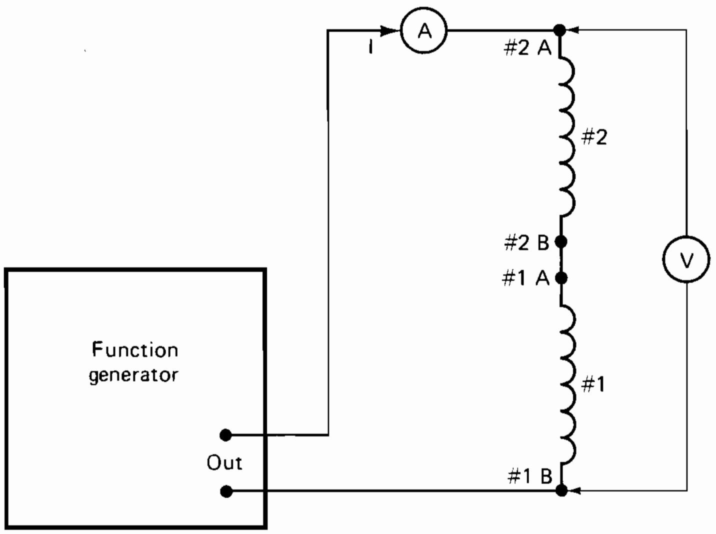


Fig. 40-5

10. Set the function generator sine-wave output to a level not less than 10 V which will give a convenient accurate current reading. Read V and I and enter in Table 40-3. Also determine Z using Ohm's law and put it in the table.
11. Reverse one inductor as shown in Fig. 40-6. Repeat step 10.
12. Apply the following formulas to find the Z for the series circuits of Figs. 40-5 and 40-6. Enter the calculated values in the table for each circuit.

Table 40-3

Circuit	*V*	*I*	*Z*	*Z* (*Calculated*)
Fig. 40-5				
Fig. 40-6				

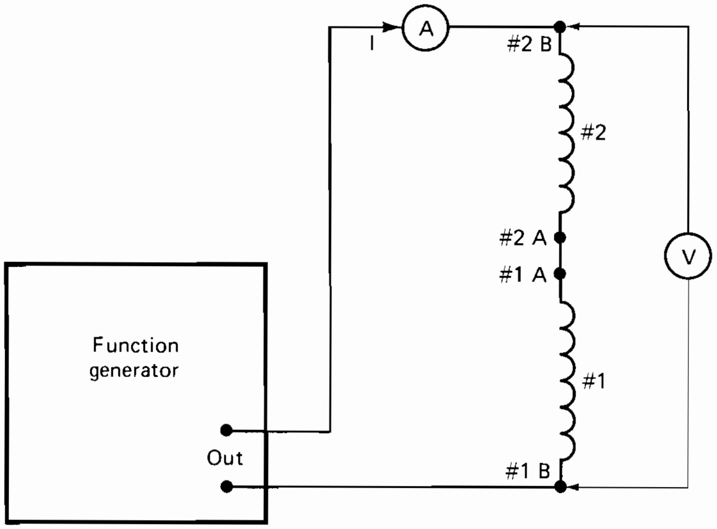


Fig. 40-6

$$Z = \sqrt{(R_1 + R_2)^2 + (X_1 + X_2 + 2X_M)^2} \qquad (40\text{-}6)$$

$$Z = \sqrt{(R_1 + R_2)^2 + (X_1 + X_2 - 2X_M)^2} \qquad (40\text{-}7)$$

In applying the formulas, use an average value for X_M.

QUESTIONS

1. In Fig. 40-1, inductor 2 is not electrically connected to inductor 1. Name the form of coupling between them.
2. Is the X_M supposed to be the same for the circuits of Figs. 40-1 and 40-3?
3. What is the Q for inductor 1?
4. What is the Q for inductor 2?
5. What is the Q for the series combination for which the total impedance is greatest?
6. What is the Q for the series combination for which the total impedance is the least?
7. Calculate L_1 and compare with the rated value for the inductor.
8. Calculate L_2 and compare with the rated value for the inductor.
9. Calculate mutual inductance M using data from Tables 40-1 and 40-2. Also calculate the corresponding coefficients of coupling k.
10. Compare the series combination impedances calculated using Eqs. (40-6) and (40-7) with those obtained by measurement.

CONCLUSION

Describe in your own words what you have learned from this experiment.

Appendix

Safety and First Aid

INTRODUCTION

The precautions stated herein are intended to reduce the possibility of injury in the typical first-course electronics laboratory. The coverage is sufficiently broad so as to be of value for subsequent electronics and other laboratory courses. It is recommended that the student become familiar with all aspects of safety in the several categories. The instructor may then wish to emphasize and elaborate on those of particular importance for a laboratory course.

The student should be made aware that additional hazards, precautions, and safety rules exist in the work environment. Accidents do not just happen. They are caused by a lack of appreciation of the dangers, inadequate precautions, fatigue, and a variety of other reasons. The cautious student, like the cautious employee, will understand the hazards and develop procedural habits to minimize the possibility of injury. It is never too late to improve your safety habits.

The subject of first aid has received relatively less attention here. The reasons are twofold:

1. Prevention of injury is the primary goal.
2. The treatment of injuries is best left to medical personnel resident at the site. Whatever immediate medical attention is required is the responsibility of the instructor.

GENERAL

1. Become thoroughly familiar with the school's fire signals, fire drill procedures, and fire exits. In case of a fire alarm, walk quietly to the nearest exit and follow your instructor's directions.
2. Keep all rags containing oil, gasoline, paint, solvents, or any other combustibles in covered metal containers; otherwise, fire could result from spontaneous combustion.
3. Never use gasoline near flames, potential sparks, or radiators.
4. Do not throw or leave scrap materials, screws, nails, and so on, on the floor because of possible slips and falls.

5. Keep the floor, aisles, and passageways clear of stock, materials, scraps, tools, and equipment. Place all scrap material or cuttings in the scrap box provided for that purpose. Good housekeeping helps prevent accidents.
6. Wipe up immediately any liquids or grease spilled on the floor, in order to eliminate the dangers of fire, and to prevent slips and falls. Falls are always dangerous, particularly so when a student is carrying a heavy object.
7. Do not place articles on windowsills, stepladders, or other high places, where there is a danger of their falling and striking someone below.
8. Remember that procedures require the elimination of playing, clowning, running, and participation in nonproductive activities. Playing and scuffling, often referred to as "horseplay," is extremely dangerous. A playful push may cause a fall, resulting in injury from contact with a sharp edge of a bench or the corner of a machine or other objects.
9. Call the attention of your instructor to anyone you see violating a safety rule or good safety practice. Do not consider this as "snitching," as it may prevent serious injury to yourself or your classmates. In addition, report any defective tool and equipment or any unsafe condition.
10. Inform your instructor at once in case of an accident, however slight. Infection may result from uncared-for minor cuts and scratches.
11. Always keep your mind on your work. Inattention may result in a serious accident and years of regret.
12. Do not lift any object beyond your ability to handle it easily. Squat down in picking up heavy objects. Use the leg muscles and keep the back nearly vertical. This procedure may prevent a rupture or spinal injury.
13. Carry long pieces of material very carefully so that they will not cause injury to others. Good safety practice requires that long pieces of material (6 feet or more) must be carried by a student at each end. Shorter pieces may be carried by one student provided that he or she keeps the front end high enough to avoid striking anyone.
14. Do not move any equipment or material unless you can see your way clearly and there are no obstacles in your path.
15. Never handle hot cathode ray tubes.
16. While handling cathode ray tubes, wear gloves and face shields or goggles for protection in the event a tube should implode. Cathode ray tubes are highly evacuated and under atmospheric pressure and mishandling of the tube may cause it to break or implode, causing sharp particles of glass to be scattered with considerable force.
17. Report to the instructor immediately in the event a tube breaks and you are injured, even if the injury is very minor. All minor cuts should be washed to remove dirt and particles. Some materials used for coating the tubes are dangerous.
18. Use particular care in avoiding acid burns when handling batteries. No open flame is permitted in a battery-charging room because of the explosion hazard.

ELECTRICAL SHOCK

1. A current of 25 mA passing through the body can kill. Any equipment capable of supplying this amount of current is extremely dangerous when the natural insulating protection of the skin is penetrated.
2. Always use an isolation transformer when constructing circuits to be supplied by 120 V (or higher) 60-Hz power.
3. Never touch a person who is unconscious as a result of shock while the body is in contact with the electrical conductor(s). Assist the instructor in separating the body from the power source, after which CPR should be administered by a qualified individual.
4. Avoid working on electrical equipment with wet hands. Sweaty or wet hands provide conduction for electrical current and thereby increase the possibility of fatal shock.
5. Complete the connection to any apparatus before plugging the cord into the power outlet. Always turn off the power before changing the connections on any equipment.
6. Keep your fingers away from the live metal parts of the test leads.
7. Avoid using any cords with defective plugs or insulation.

8. When using ground wires, make certain that they are secure.
9. Avoid cutting any wires carrying electrical current.
10. Check the condition of the insulation on the wire in the high-voltage circuits. If it is necessary to change wiring, use insulated wire rated for the voltage to be applied.
11. Determine with a voltmeter or a test device which side of the line receptacle is at ground potential. Always use polarized plugs on test equipment and text benches. Serious shock can result from touching the "hot side" of a line to ground.
12. Prior to working on electrical circuits, turn the power off before discharging a high-voltage capacitor.
13. Avoid bypassing any safety interlock switches. When working on equipment, see that the interlock switches are in working condition.
14. Avoid replacing resistors and condensers while voltage is applied.
15. Connect the clip leads to the high-voltage circuits before connecting equipment to the power source.
16. When working on power transformers, take special care to see that the high-tension leads are adequately insulated.
17. Avoid making any connections on transformers while the power is on.

SOLDERING

1. A student should not use acids, alkalis, organic solvents, or fluxes containing any of these without the specific direction of the instructor. Irritation and burning of the skin through contact are possible. The breathing of fumes can irritate the tissues and membranes of the respiratory tract.
2. When passing a soldering iron to another student, place it on a rest or on a surface so that he or she can pick it up conveniently.
3. Never leave a hot soldering iron easily accessible where an unsuspecting student may touch it. Always return it to its proper place.
4. Do not permit the hot tip of the soldering iron to come into contact with the power cord. If the insulation burns through, the metal body of the soldering iron will present an electrical shock hazard.

HAND TOOLS

1. Always hand tools or material to another student. Eyes, hands, or bodies can easily be injured by thrown articles.
2. Do not leave tools or materials protruding from a vise or workbench where another student may stumble against them.
3. Keep the handles of tools free of oil or grease to prevent them from slipping from your grasp and injuring other students or damaging equipment.
4. Avoid using wrenches with cracked, sprung, or worn jaws. A wrench that slips usually causes a painful hand injury.
5. Do not carry sharp-edged tools in your pockets. Your hand may be cut if you should thrust your hand into your pocket, or you may be injured should you slip or fall.
6. Keep all tools sharp. A dull tool is more dangerous than a sharp one because it will slip over and away from the work. A dull tool requires more pressure and is difficult to control, increasing the danger of slips which may result in cuts on your hands, arms, or body.
7. Cut away from your body when using sharp-edged tools. If the tool should slip while you are cutting toward yourself it may cut your hand, arm, or body.
8. Do not hold small articles in the palm of the hand while tightening screws with a screwdriver. A slip may cause a painful hand injury.
9. Avoid using files without handles. The tang or pointed end of the file is sharp and, if not protected by a handle, may puncture your hand. A puncture is one of the most dangerous kinds of wound because it is difficult to clean thoroughly.
10. Grind off the mushroomed heads on chisels, hammers, punches, and similar tools before using them. Sharp pieces from a mushroomed tool head may break off and cause injury.

11. When using a chisel or gauge, always hold the tool in both hands unless using a mallet. Cut away from yourself, and be sure that no one is standing in front of you.
12. Don't be the victim of hand or finger laceration by careless handling of sharpened tools or by sliding your hands over the edges of sheet metal. Sheet metal has razor edges, burrs, and fish hooks.
13. When cutting, drilling, or punching chassis or panels or doing any kind of mechanical work, be sure the work is securely fastened to the bench or clamped in a vise so that it cannot slip. Always center-punch all holes to be drilled.
14. Use a file to remove burrs on the heads of screws or around the edges of holes or chassis. Using your fingers will cause painful cuts.
15. Do not use plastic-handled screwdrivers near an open flame or near a hot soldering iron. Plastic is inflammable.

POWER TOOLS

1. You are permitted to work on machines only after you have been given safety instructions. Every machine is dangerous if operated incorrectly. You must first be instructed in safe operation.
2. You are not permitted to work on any machine before, during, or after class hours unless you have received permission and there is an instructor in the shop. Should you be injured, a qualified instructor will be near to assist you immediately.
3. Never remove guards or safety devices from any machine, as they must always be used. If, for any reason, a safety guard is removed, or if the machine is defective in any way, the machine must not be used until corrections are made by the proper authorities. Tag the defective machine to warn another student against using it.
4. Secure the permission of your instructor before starting any job or operating any power equipment. He or she may make suggestions that will prevent an accident.
5. Make certain that all other students are clear of the machines or equipment. Pick up loose tools before turning on the power.
6. Clean, oil, or adjust machinery only when it has stopped; otherwise, some part of your body, clothes, or equipment may be caught by the moving parts, causing injury to yourself or others.
7. Remember that only you, as the operator, may start and stop the machine. Once the machine starts, one person must assume control of it and decide exactly what is to be done.
8. Do not crowd around a machine. Only the operator and the instructor are permitted within the defined safety zone around any machine. Crowding around a machine distracts the operator's attention and may cause the person to be injured.
9. Do not distract the attention of any student operating a machine. In the event anyone wishes to speak with you, discontinue your work and stop the machine while you are talking. Safe operation of a machine requires concentration.
10. Remove all tools and other objects from the machine and check adjustments before turning on the power. Unless all adjustments on the machine are securely locked in place before it is started, the vibration may cause them to slip or change position. Vibration may also cause tools or other loose objects to be drawn into the moving parts, causing personal injury and damaged equipment.
11. Start your machine and stay with it until you have turned it off and it has come to a dead stop. This will prevent another student from approaching the unattended machine in operation.
12. Stop any machine before wiping it with rags or waste, in order to prevent these items from being caught in the moving parts.
13. Never stand in the direct line with the "throw" of any machine. If a saw should break or a machine become overloaded, if the stock is not held securely, or if a knot or large sliver should come loose, these objects would be thrown out with terrific force.
14. If you are engaged in any activity where eye hazards of flying particles, corrosive substance, or blinding light exist, you must use suitable eye protection, such as goggles or face shields. Do not gamble with your eyesight.
15. Before starting to work, remove rings, watches, and gloves; tuck in loose clothing and dangling neckties, and use a cap for long hair. These items could be caught in the moving parts, drawing your hand or body along with them.

16. Use the drill press vise or clamp to hold the work being drilled. This procedure will prevent the drill from catching and throwing the work loose, striking you or others.
17. Grip the vise firmly while you are drilling, thereby preventing the drill from breaking or the work from revolving dangerously.
18. Ease up on the feed pressure as the drill breaks through the work. This procedure will decrease the chances of the drill catching the work and causing it to revolve dangerously.
19. Stop a drill press immediately if the drill catches in a piece of work. It is dangerous to touch the revolving work.
20. Always use a sharp drill, ground for the right material. Improperly ground drills dig into the work and, as a result, may cause breakage and injury.
21. Stop a drill press before attempting to remove the work, chips, or cuttings. Use a brush to remove the chips; otherwise, they may pierce the skin and cause deep and painful cuts.
22. Remove the chuck key from the chuck of a drill press and the drift from the spindle before turning on the power. Failure to comply with this rule may result in serious injury since either of these items could fly out.
23. Always use the correct drill press speed for the size of the drill and the kind of stock being drilled. If too much speed is used, or if the drill is forced too rapidly into the material, the hole cannot be cleaned out fast enough to avoid burning or possibly breaking the drill.
24. Keep your face away from the work being drilled. Your eyes or face would be endangered if the drill should break. In addition, hot oil and sharp chips may strike you.
25. When using a power grinder, keep the tool rest as close to the grinding wheel as possible. The gap should not exceed $\frac{1}{64}$ inch. Tools or materials may become jammed between tool and rest, causing breakage of grinding wheel and flying particles of abrasives or steel if the gap is too wide.
26. Take particular caution when grinding work that is held in your hands in order to prevent the work from slipping, causing injury to your fingers.
27. Grinding on one side of the grinding wheel is dangerous, as the wheel may break from the tension. Doing so also undercuts the stone and it may explode from centrifugal force.
28. Never hold the tool down between the tool and the rest when using a grinder. Dangerous jamming of the tool and wheel may result in injury.
29. Stand to one side when the grinder wheel is being faced or started up for the first time, as there is a possibility of the wheel breaking or particles flying out.
30. Always wear safety glasses during any grinding or buffing operation.
31. Hold small pieces of material being ground with vise grips or a small vise to prevent the items from slipping and becoming jammed in the wheel. Never use pliers to hold the work.

LASERS

1. Wear laser safety goggles which are designed for protection against the beam of the laser being used. However, follow all other safety precautions as though goggles were not being worn.
2. Avoid looking at the primary beam when the laser is in operation.
3. When aiming the laser and during its operation, do not look at reflections of the laser beam.
4. Be careful that all persons are clear of the laser beam path before turning on the laser.
5. Be very cautious when around lasers that operate at invisible-light frequencies.
6. Remove any reflective objects, such as shiny buttons, rings, watches, and other jewelry, before entering the laser area.
7. Be careful that no reflective object or material is placed near the laser beam.
8. Report any afterimage for medical attention.