# Transmission Systems

API RECOMMENDED PRACTICE 552
FIRST EDITION, OCTOBER 1994

REAFFIRMED, FEBRUARY 2007

energy API

AMERICAN PETROLEUM INSTITUTE

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**Manufacturing, Distribution and Marketing Department**

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# FOREWORD

This publication reflects the current practices in the transmission of instrument measurement and control signals in a refinery.

Throughout this publication, soft-conversion (calculated) units are provided in parentheses following actual units. Soft-conversion units are provided for the user's reference only.



Suggested revisions are invited and should be submitted to the director of the Manufacturing, Distribution, and Marketing Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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# Transmission Systems

## 1 Scope

This document reviews the recommended practices for the installation of electronic and pneumatic measurement and control-signal transmission systems. It does not discuss leased wire, radio, and telemetering transmission. The methods described are generally used throughout the United States. These methods are based on the assumption that the field devices, such as measuring transmitters, transducers, valve positioners, control valves, and other devices are properly installed. It is also assumed that the wiring, piping, and tubing at the control panel or Distributed Control System are properly installed. See the other appropriate API Recommended Practices and standards as needed.

## 2 References

The following publications are cited in this recommended practice:

API

- RP 500 *Classification of Areas for Electrical Installations at Petroleum Facilties*
- RP 540 *Electrical Installations in Petroleum Processing Plants*

ASTM[1]

- A 123 *Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*
- A 525 *Specification for General Requirements for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process*

ISA[2]

- RP 12.6 *Installation of Intrinsically Safe Systems for Hazardous (Classified) Locations* (ANSI[3]/ISA RP 12.6)
- S7.4 *Air Pressures for Pneumatic Controllers, Transmitters, and Transmission Systems* (ANSI/ISA S7.4)
- S7.7 *Recommended Practice for Producing Quality Instrument Air* (ANSI/ISA S7.7)
- S12.4 *Instrument Purging for Reduction of Hazardous Area Classification*
- S50.1 *Compatibility of Analog Signals for Electronic Industrial Process Instruments* (ANSI/ISA S50.1)

NEMA[4]

- 250 *Enclosures for Electrical Equipment* (ANSI/NEMA 250)

NFPA[5]

- 70 *National Electric Code (NEC)* (ANSI/NFPA 70)
- 78 *Lightening Protection Code* (ANSI/NFPA 78)
- 493 *Intrinsically Safe Apparatus in Division I Hazardous Locations*
- 496 *Purged and Pressurized Enclosures for Electrical Equipment* (ANSI/NFPA 496)

## 3 General

### 3.1 ADVANTAGES OF TRANSMITTED SIGNALS

Transmission systems permit operation of one or more large or small process units from a remote control center.

### 3.2 DESIGN CONSIDERATIONS FOR TRANSMISSION SYSTEMS

The following major factors should be considered in the design of transmission systems:

a. The relationship of time constants among process, transmission, and control lines, since this relationship may influence a control loop's actual performance. This problem is primarily associated with pneumatic transmission.
b. The reliability of air and electric power supplies.
c. The routing and installation of tubing, wiring, and piping to maintain circuit integrity; to reduce the possibility of damage from fire, overheating from hot process lines or equipment, and mechanical abuse; and to ensure immunity from electrical and radio-frequency interference.
d. The resistance of material and construction to corrosion caused by chemicals in the atmosphere or splatter from new construction or maintenance.
e. Provisions for manual control, testing, and ready access to instruments for maintenance.
f. Safety requirements and the effect of federal, state, and local regulations and of national and local codes.

### 3.3 ELECTRONIC

The preferred signal transmission today is electronic. Electronic methods and needs are discussed in depth in this document, starting with Section 4.

### 3.4 PNEUMATIC

Pneumatic signals are used today primarily in older plants and where there is a special advantage to pneumatics. The

[1]American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.
[2]Instrument Society of America, P.O. Box 12277, Research Triangle Park, NC 27709.
[3]American National Standards Institute, 11 West 42nd Street, New York, NY 10036.
[4]National Electrical Manufacturers Association, 2101 L Street, N.W., Washington, DC 20032.
[5]National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269.

advantages, needs, and recommended methods are discussed in this document, starting with Section 21.

### 3.5 FIBER OPTICS

*Fiber optics* is the phrase applied to the use of transparent glass or plastic fibers to carry light signals between devices. Fiber optics is a maturing technology and will find more use in the future. At present, use is usually limited to dedicated cables between portions of control systems, and for some special applications. Cables, connectors, and matching electronics are available. The user is cautioned to verify that the cable selected is appropriate for the application in strength and mechanical makeup, and that the electronics are appropriate. If the signal power is limited to Light Emitting Diode (LED), sources, rather than a Laser source, there is little concern of ignition of hazardous vapors. If the cable has no metal components which could carry electrical currents, then fiber optics provides complete electrical, *galvanic*, isolation between the connected devices, thus eliminating concerns of ground currents.

### 3.6 DIGITAL FIELD BUS

Several proprietary digital communications schemes are available today for field instruments, and standards are under development to permit convenient interconnection. Digital communications between microcomputer-based devices can utilize the intelligence of the devices to improve accuracy, to improve utility, to reduce check-out costs, and to facilutate further advances in control and control systems. These techniques also allow multiple devices to share one wire pair to reduce wiring costs. Where metallic wiring is used, the usual concerns of grounding, electrical surge, and electrical safety all apply.

## 4 General Information On Electronic Systems

### 4.1 GENERAL

This section includes practices for classified and non-classified areas. The discussion of electric signal transmission necessarily includes signals, analog or digital, that are used in measurement and control systems. The instruments include sensing elements, transmitters, analyzers, controllers, and display devices.

The installation of signal wiring requires practices that will prevent excessive distortion of the signal. Signal wiring is only part of an electronic signal transmission system. The design and installation of the wiring, transmitter, and receiver must result in a system that is suitably accurate for the application. Factors that must be considered include regulatory codes, requirements of a specific set of equipment, and electrical characteristics of the environment through which the wiring passes. This document describes frequently encountered instruments and associated equip-

Table 1—Specific Applications with Wiring Requirements, Wire Type, and Environment

| Application | Normal | Strong Magnetic Field | Strong Electrostatic Field | Reduce Noise over 10 Hertz | Remarks |
|---|---|---|---|---|---|
| IP controls, maDC, signal (see 6.1) | I, IV[a] | II, IV | III, V, VI | No need | Constant current source; maximum resistance load is limited |
| Low energy low voltage sensors (see 6.6) | III, VI | III, VI | III, VI | | Type V for short runs; RTDs may require triads |
| Turbine meter (see 6.7) | III | III | III | | Manufacturer's suggestions |
| Magnetic flow transmitter (see 6.8) | Note[b] | | | | Manufacturer's suggestions |
| IP controls, voltage signal (see 6.2) | I, IV[a] | II, IV | III, V, VI | No need | Constant voltage source; receiver impedance 100 times source impedance |
| IP controls distributed control system (see 6.1.1) | I, IV[a] | II, IV[a] | III, V, VI[a] | No need | Verify wiring needs with manufacturer |

Note: IP = Industrial Process; for wire types, see Table 4.
[a]Acceptable, but not recommended; it is not possible to guarantee no electric fields.
[b]Special Type III between magnetic flowmeter body and 4-20 maDC transmitter, as above for 4-20 maDC.

ment, along with the reasons for using them. Table 1 lists the types of wire suggested for use in the various measurement and control systems. Table 1 also cites sections of the text that contain more detailed information about each application. The specifications for equipment, enclosures, wiring, and installation methods should fully conform to the regulations of all authorities with jurisdiction at the job site.

### 4.2 STANDARD ELECTRONIC SIGNAL RANGES

The wide variety of applications makes standardization of signal ranges difficult. Although the signal range of 4–20 milliamperes DC (maDC) has become the standard for process instruments, not all makes of electronic instruments with the same signal range can be intermixed. Electronic instruments designed to use the same input or output signal may not be compatible because of differences in signal voltages, load impedances, wiring techniques required, intrinsic safety, or other characteristics. ANSI/ISA S50.1, *Compatibility of Analog Signals for Electronic Industrial Process Instruments,* can be referenced for details on compatibility.

### 4.3 REGULATORY CODES AND RECOMMENDED PRACTICES

It is essential that those responsible for electrical design and installation in processing plants be thoroughly familiar with the current edition of ANSI/NFPA 70 *National Electrical Code (NEC);* the ISA S12 series of standards; API Recommended Practice 500, *Classification of Areas for Electrical Installations at Petroleum Facilities*; and API Recommended Practice 540, *Electrical Installations in Petroleum Processing Plants.*

#### 4.3.1 Classified Areas and Listed Equipment

The presence of flammable liquids or vapors in an area necessitates classification of that area for the purpose of installing electrical equipment. API Recommended Practice 500 is a guide for determining classification. The three common classifications in a Refinery are as follows : Class I, Division 1; Class I, Division 2; and Unclassified. The criterion for a Division 1 area is that a flammable gas or vapor is likely to exist under normal operating conditions. The criterion for a Division 2 area is that a flammable gas or vapor is likely to exist only during an abnormal operating condition, such as failure or rupture of equipment. Locations that are not classified as Division 1 or 2 are unclassified. Unclassified areas are frequently referred to as nonhazardous areas.

Electrical equipment for a Division 1 location is normally designed to be explosion proof. This term means that the equipment enclosure is strong enough to withstand an internal explosion, and the enclosure joints are wide enough and clearances small enough so that flame will be quenched and will not propagate from the interior of the equipment to the surrounding atmosphere.The NEC specifically accepts pressurization in lieu of an explosion-proof enclosure. For guidance on how to provide approved purged and pressurized enclosures see ANSI/NFPA 496 “Purged and Pressurized Enclosures for Electrical Equipment” and ISA-S12.4 “Instrument Purging for Reduction of Hazardous Area Classification.”

Another alternative to explosion proof equipment is Intrinsically Safe electrical equipment and wiring. Intrinsically Safe equipment is incapable of releasing sufficient energy, under normal or abnormal conditions, to cause ignition of a specific explosive atmosphere. The NEC also specifically mentions that Intrinsically Safe equipment and wiring can be installed in any hazardous location for which they are approved without regard to the NEC requirements for hazardous locations. For guidance in using Intrinsically Safe equipment, see NFPA 493, “Intrinsically Safe Apparatus in Division 1 Hazardous Locations” and ANSI/ISA-RP12.6 “Installation of Intrinsically Safe Systems for Hazardous (Classified) Locations.”

Equipment designed for Division 2 areas has no installed sparking contacts or parts hot enough to be a hazard, or has sparking contacts immersed in oil or contained in hermetically sealed chambers. When such equipment is not available, nonincendive or explosion-proof equipment is generally used.

For Class I Division 2 areas, “Non-Incendive” practices are acceptable. See ANSI/ISA S12.12 “Electrical Equipment for Use in Class I, Division 2 Hazardous (Classified) Locations.”

#### 4.3.2 Grounding of Equipment Cases and Circuits

Grounding practices in instrumentation are of two types: those concerned with personnel safety and those concerned with signal accuracy and dependability. Both types must conform to the NEC and the regulations of any local governing bodies. Details of grounding installations are discussed in Section 20.

## 5 Reducing Electrical Interference In Electronic Systems

Electrical interference is any spurious voltage or current from external sources that appears in the signal transmission circuit. When these voltages are excessive, signals are changed or cannot be detected.

### 5.1 SOURCES OF ELECTRICAL INTERFERENCE

Unwanted voltages enter an electronic signal transmission system by the following means:

a. Inductive pickup from alternating-current (AC) fields and/or radio-frequency (RF) interference.
b. Electrostatic or capacitive coupling with other circuits.
c. Direct coupling with other circuits by means of leakage current paths, ground current loops, or a common return lead for more than one circuit.

## 5.2 MINIMIZING UNWANTED VOLTAGES IN SIGNAL TRANSMISSION CIRCUITS

### 5.2.1 Electromagnetic Coupling

Spurious signals from inductive pickup may be eliminated by five methods:

a. Using twisted pair wires. See the wire specifications.
b. Routing signal wires away from strong AC field (see Section 5.2.6).
c. Eliminating or reducing the source. One way to do this is by reducing the interference from power wiring by transposing or twisting the power conductors to cancel out or reduce the AC field that is normally produced by parallel power wires.
d. Installing signal wiring in steel conduit or covered trays.
e. Shielding the power line if this is known to be the source of interference or by installing the power line in steel conduit.

### 5.2.2 Electrostatic or Capacitive Coupling

The most effective way of reducing voltages from capacitive coupling is to break the coupling between the external voltage source and the transmission circuit. The coupling is broken by putting a grounded and electrically conductive shield around the signal wires. With a grounded shield around the wires, the external voltage couples strongly with the shield and only weakly with the wires. Only one ground should be established. Multiple grounds on shields will create ground loop interference problems.

Crosstalk can affect the performance of digital field instruments, but can be minimized by the following:

a. Eliminating resistances common to multiple circuits, such as common return leads, power supply output fuses, and diodes used to switch between redundant power supplies. In some cases these elements can be effectively bypassed with the use of appropriate capacitors.
b. Using Type III or Type VI cable.
c. Using individually isolated (floating) circuits when Type IV or Type V cable is used. If intrinsically safe barriers are used, avoid the type which connects one side of the circuit directly to the ground.

### 5.2.3 Direct Coupling by Leakage Paths

Spurious signals from current leaking from one circuit to another are commonly caused by moisture and may be reduced or eliminated by using properly insulated wire, terminal strips, and dry air purges. High quality insulation should be used in all circuits.

### 5.2.4 Direct Coupling by Ground Current Loop

Unwanted voltages from ground current flowing through a transmission circuit may be eliminated by removing multiple grounds from the circuits. Only one ground should be established. Multiple grounds on shields can create similar interference problems.

### 5.2.5 Direct Coupling by Common Return Lead

Use of a single wire as a return lead for several signal circuits to conduct currents for each circuit is not recommended because each current causes a resistive voltage drop

Table 2—Power Level Classification

| Level 1 (Low Level Signals) | Level 2 (Medium Level Signals) | Level 3 (High Level Signals) | Level 4 (Power) | Level 5 (High Power) |
|---|---|---|---|---|
| Thermocouple | Analog signal, DC electronic instruments | DC switching circuits with voltages greater than 28 | AC and DC buses with voltages of 0–800 and amperages of 20–800 | AC and DC buses with voltages above 800 or amperages above 800 |
| Pulse signals | Resistance temperature devices | AC circuits with amperages less than 28 (lighting circuits, convenience outlets, back-of-panel lights) | | |
| Strain gauge bridge outputs | Lighting and switching circuits with DC voltages of 28 or less | DC control buses with voltages of 250 or less | | |
| | Circuits to lights and relay input buffers with DC voltages of 28 or less | DC relay and contactor coils with voltages of 250 or less | | |
| . | | Ground detection circuits | | |

that appears in all the other circuits as an unwanted voltage. These unwanted voltages may be eliminated by providing a separate pair of wires for each signal generator. It is especially important to eliminate these unwanted voltages when digital signals are used.

### 5.2.6 Separation of Instrument and Power Circuits

Power circuits of different power levels should be installed with proper spacing to avoid interference and to ensure proper operation. (see Section 9). Table 2 describes the five classes of power levels. The minimum separation for circuits in each level class is shown in Table 3.

## 5.3 INSTRUMENTS TO BE INTERCONNECTED

When an electronic signal transmission system is designed, the level and type of signal and the kinds of signal generators and receivers must be considered. The instruments can be the following:

a. Process control instruments.
b. Sensors with electrical outputs.
c. Digital Data Transmission.

For wiring purposes, the difference between the first two groups is the frequency response of the equipment. Process control equipment usually has a cut-off frequency on or near 5 Hertz, while computer input circuits may respond to much higher frequencies.

The signals involved are the following:

a. Process analog, conventional, 4–20 maDC.
b. Special and low energy/voltage, eg. sensors.
c. Switches and solenoid valves, other discrete, 120AC, 24VDC or VAC with inductive loads.
d. Digital data.

Table 3—Wire Separation

Power and signal run in separate steel conduit; signal: individual shielded twisted pairs with overall cable shield, (API Type III and VI)[a]

| Power Cable(s) | Low Level (millivolts) | maDC (4-20 or 10-50) |
|---|---|---|
| Up to 125V @20A | 4” | None Req’d |
| 125V to 500V @200A | 12” | 6” |
| Over 500V | 36” | 18” |

Power and signal run in separate steel conduit; signal: twisted pair (API II and V)[b]

| Power Cable(s) | Low Level (millivolts) | maDC (4-20 or 10-50) |
|---|---|---|
| Up to 125V @20A | 8” | 4” |
| 125V to 500V @200A | 15” | 8” |
| Over 500V | 48” | 24” |

Power and signal in tray; signal: shielded twisted pair (API III and VI)
OR
Power and signal in tray with metallic barrier; signal twisted pair (API II and V[c])

| Power Cable(s) | Low Level (millivolts) | maDC (4-20 or 10-50) |
|---|---|---|
| Up to 125V @20A | 30” | 15” |
| 125V to 500V @200A | 60” | 30” |
| Over 500V | 180” | 96” |

Power: steel conduit; signal: tray shielded twisted pair (API III and VI)
OR
Power in tray; signal in steel conduit, shielded twisted pairs (API III and VI)[d]

| Power Cable(s) | Low Level (millivolts) | maDC (4-20 or 10-50) |
|---|---|---|
| Up to 125V @20A | 30” | 15” |
| 125V to 500V @200A | 30” | 15” |
| Over 500V | 60” | 30” |

Notes: mA = milliampere ; DC = direct current; A = ampere.
[a]The above tables are for parallel runs up to 500 feet long; for longer runs increase spacing proportionately to the parallel length.
[b]120-volt instrument circuits for alarms, solenoids, and similar circuits should be treated as power circuits in the above tables.
[c]Group wiring by type and level: low level signals to the farthest from power, next maDC circuits, next alarms; next 120V alarms; closest are 120 V solenoid valves and limit switches.
[d]This information is based partly on data and partly on accepted and proven experience.

# 6 Engineering Factors In Selection Of Wire Types For Electronic Systems

This section describes wiring practices for signal transmission systems for instruments commonly used. For each typical application, one type of wire or signal conductor is suggested. The wire types are identified with Roman Numerals and are defined in Table 4.

Table 4—Types of Wire or Cable for Signal Transmission

| Type | Description |
|---|---|
| I | Untwisted copper wire |
| II | Single, unshielded twisted-pair copper wire |
| III | Single, shielded twisted-pair copper wire |
| IV | Multipair cable of Type II wire |
| V | Multipair, overall shielded cable of Type II wire |
| VI | Multipair, overall shielded cable of Type III wire |

Note: In the above, replace the word *pair* with *triple* or *triad* for wiring certain items such as some resistance bulb sensors (RTD), or strain gauges, and others like these.

## 6.1 PROCESS CONTROLS WITH MILLIAMPERE SIGNALS

Most process control instruments use DC milliampere current signals in wiring that goes from a transmitter to a display station, or a control system, a controller, and/or other receivers, and from the controller to a final control element. The standard signal is 4–20 milliampere DC.

### 6.1.1 Wire Type

Although a pair of untwisted, unshielded, stranded copper wires (Type I) may be used to interconnect most industrial process control equipment, such use is not recommended. For installations where the possibility of magnetic-field interference exists, single, unshielded twisted-pair wires (Type II) can be used. In runs of three or more pairs, multipair cable (Type IV) should be considered for economic reasons. Where excessive interference is due to electrostatic coupling, shielded (Type III, V, or VI) should be used. Type VI is more expensive and might not be justified.

These wires or cables can be enclosed in conduits or laid in trays, but DC signal wiring should not be mixed with AC signal wiring or power wires.

### 6.1.2 Mixing Signals

It is considered poor practice to mix wiring of significantly different signal levels. In other words, wiring with low energy/voltage should not be mixed with wiring carrying AC signals, DC pulses, or any power. Wiring with 4–20 maDC signals should separated from 120 VAC to solenoids, 120 VAC alarms and power wiring, and power signals. See Table 5.

Table 5—Guidelines for Grouping Wires Bearing Signals of the Same Magnitude

| Type of Signal | Suggested Range |
|---|---|
| DC Voltage | |
| Low | 0 millivolts < Signal < 100 millivolts |
| Medium | 100 millivolts < Signal < 5 volts |
| High | 5 volts < Signal < 75 volts |
| AC Voltage | |
| Low | 0 millivolts < Signal < 100 millivolts |
| Medium | 100 millivolts < Signal < 5 volts |
| High | 5 volts < Signal < 75 volts |
| DC Current | 0 milliamperes < Signal < 50 milliamperes |

### 6.1.3 Resistive Loading

Instrument manufacturers publish limits on the resistive load that can be put on each signal generator for specified supply voltages.

Installations should be in accordance with the manufacturers' recommendations. The maximum transmission distance for a loop can be determined by using data from Table 6, the input resistance of the various receivers, power supply voltage, and the maximum resistive loading. This is rarely a problem except for Intrinsically Safe applications.

Table 6—Resistance of Copper Wire-Per Conductor

| AWG | Diameter, inches | Ohm/1000 ft | Ohm/mile |
|---|---|---|---|
| 10 | 0.1019 | 0.9989 | 1.588 |
| 12 | 0.08081 | 1.588 | 8.384 |
| 14 | 0.06408 | 2.525 | 13.33 |
| 16 | 0.05082 | 4.016 | 21.20 |
| 18 | 0.04030 | 6.385 | 33.71 |
| 19 | 0.03589 | 8.051 | 42.50 |
| 20 | 0.03196 | 10.15 | 53.59 |
| 22 | 0.02535 | 16.14 | 85.21 |
| 24 | 0.02010 | 25.67 | 135.5 |

Note: ft = feet; AWG = American Wire Gauge.

### 6.1.4 Grounding

Noise from ground loops can be avoided by limiting grounds to only one ground point per circuit (see also Section 20).

## 6.2 PROCESS CONTROLS WITH VOLTAGE SIGNALS

Voltage signals are seldom used for long-distance transmission because of voltage-drop considerations. One exception is vibration monitoring systems.

When a voltage signal is used, precautions must be taken to ensure that the transmission system does not degrade the measurement signal.

### 6.3 DIGITAL COMMUNICATIONS SIGNALS

Digital Communications Signals (DCS) are normally interconnected with data-highway cables. The control system manufacturer specifies the cable and recommends the installation details.

### 6.4 PROCESS CONTROL LOW ENERGY/ VOLTAGE SENSORS

Low energy/voltage sensors include thermocouples. Resistance temperature detectors (RTDs) and strain gauges generate low DC voltages when energized with a DC power supply.

#### 6.4.1 Grounding

Circuits that contain resistance temperature detectors and strain gauges should not be grounded at more than one point. The preferred location is near the source of power and on the lower voltage wire. Grounded thermocouples should have no other grounded point than that in the primary sensor. Sneak circuits can easily occur because the extent of isolation and grounding within instruments varies with their function and make. The selection of grounded-junction or ungrounded-junction is beyond the scope of this standards (also see Section 20).

#### 6.4.2 Thermocouple Burnout Circuit

Frequently the electronics used with a thermocouple will include provision for *upscale (downscale) burnout*. This provision is typically accomplished by imposing a small circulating current on the thermocouple circuit. If the thermocouple or the connecting wiring is broken, the output signal is driven to the maximun (minimum). It is necessary to consider this current in any special thermocouple circuits which would put electronic devices in parallel, since the burnout circuits may interfere with each other.

### 6.5 PROCESS CONTROL WITH PULSE OUTPUT METERS

Pulse output meters are usually connected to devices that have a relatively high input impedance.

The recommendations of the manufacturer concerning the preamplifier and the wiring should be carefully considered.

Power wires and other types of signal wires should not be mixed with pulse signal wiring. The wire type and the grounding of the signal circuit should follow the manufacturer's recommendations.

### 6.6 LOW-IMPEDANCE SENSORS TO COMPUTERS

Low-impedance sensors to computers are the same as those listed in 6.4.

Shielded twisted pair wires (Types III and VI) should be used . A multipair cable with only an overall shield (Type V) can normally be used if the distance is less than 100 feet (30 meters ) and common-mode interference is small. Individual shielding (Type III or VI) may not be needed, depending on the design of the receiver. For thermocouples, the extension lead wire should consist of shielded, twisted pairs. This wire should comply with ANSI MC96.1

### 6.7 TURBINE METERS

The suggestions of the manufacturer concerning the preamplifier and the wiring should be carefully considered.

Most turbine meters are supplied with integral converters to amplify the pulses or to convert for transmission of 4–20 milliamperes DC. Wiring for integral or field converters may require more than two wires (see 6.5).

### 6.8 MAGNETIC-FLOW TRANSMITTERS

The electric signal from magnetic flow electrodes is generally less than 50 millivolts. The low signal level requires that the electrical interference be minimized. Minimizing is done by using a two-conductor, shielded, twisted-pair cable whose length is limited by the manufacturer's recommendations. The recommended cable length is a function of the measured fluid's conductivity and the grade of the cable.

The recommendations of the manufacturer should be followed. The transmitter, cable, and receiving instrument are designed and sold as a unit. The spacing requirements given in Table 3 should be followed. Alternatively, an integral amplifier/converter may be used.

## 7 Specifications For Wires And Cables In Electronic Systems

General wiring requirements, such as those for twisted-pair, shielded, and other types of wire, are given in Section 6. The frequently used wires can be classified into one of the six types that are described in Table 4.

### 7.1 WIRE SIZE

The smallest wire size that will not cause an excessive voltage drop and that has sufficient strength and workability should be selected. Normally, the size used for single conductor wire is 14 gauge, that for single twisted-pair wire is 16 gauge, and that for multipair cable is 20 gauge. Other wire gauges may be selected for reasons of economy, space, or application.

### 7.2 STRANDED WIRE

Stranded wire is preferred because of its flexibility and resistance to breakage by bending. Where great flexibility is needed, wire with 19 strands is suggested; otherwise, seven-strand wire should be used.

In areas of high corrosion, solid conductors may be preferred. Thermocouple wires and 20-gauge multipair cables are normally solid conductors. Consider using tinned stranded wire for additional protection in high corrosion areas.

### 7.3 INSULATION

The insulation of signal wire should be adequate for the operating voltage and current. Most electric signals are less than 95 volts to ground and lower than 5 watts. Wire insulated for 300 volts is satisfactory for signals of this low operating level. To meet NEC requirements, wires in the same raceway must have insulation adequate for the highest voltage on any of the wires.

### 7.4 TEMPERATURE RATING

The wire or cable should have a temperature rating high enough for the anticipated environment. It is suggested that 75˚C be specified as a minimum temperature requirement. In very cold localities, the lowest temperature at which the wire or cable is rated is also of interest. High temperature insulation should be used in areas of expected high temperatures, such as furnace areas. When protection from flash fires is required, an arrangement of thermal barriers and/or fire retardants can be provided. Some users prefer to purchase fire-rated cable; it is possible to retain control for a reasonable time, 15-20 minutes of exposure to fire. An alternative is to bury the conductors underground. See also 13.2.6.

### 7.5 OVERALL JACKET

The overall jacket material should be moisture resistant, abrasion resistant, flame retardant, and compatible with the environment.

### 7.6 SHIELDING

The preferred shielding is aluminized polyester film with an overall spiral wrap that has 25-percent overlap. The shield should be electrically in contact with a copper drain wire that is as long as the pair of signal wires. The shield should be electrically insulated both inside and outside. For multipair cables, overall shielding should have the same specifications and should also be insulated both inside and outside.

### 7.7 NUMBER OF CROSSOVERS

Twisted wire should have a minimum of six crossovers per foot (2 inch lay)(20 crossovers per meter). Eight crossovers per foot (26 crossovers per meter) is a typical specification.

### 7.8 WIRE AND PAIR IDENTIFICATION

Either number coding or color coding is required in multipair wiring.

### 7.9 COMMUNICATION WIRES

Inclusion of communication wires in any multiple-pair cable is recommended to assist in the checkout of wiring and maintenance using sound-powered headphones.

### 7.10 LIGHTNING PROTECTION

Refer to Section 16 for information on lightning protection.

## 8 Typical Applications of Wire Types Used in Electronic Systems

Six common types of wire and cable are described in Table 4. Table 1 provides a quick guide for selecting the minimum type of wire that can be used for a given application. Generally, the following rules of thumb can be applied with good results:

Wiring from a field mounted electronic instrument to a field mounted junction box or multiplexer box should be Type III.

Wiring from the field junction box to the control building or “rack room” can be multi-pair Type V cable for signal levels one volt or greater; but should be Type VI for signal levels less than 1 volt and for thermocouples.

## 9 Guidelines for Separation of Wires in Electronic Systems

Most industrial plants will require signal transmitting systems of several different types. Guidelines for separating the various systems from each other and from power wiring and equipment are presented below (see also 6.3).

### 9.1 SIMILAR SIGNAL LEVELS

All the signals in one cable or conduit should be of similar magnitude. Whenever it is necessary to combine different signal levels in a single cable or conduit, each pair should be individually shielded and grounded at a single point. Floating (balanced) wiring is used and minimizes intereference in many systems; however, it may be difficult to maintain.

Wiring from some types of sensor should be completely separated from other circuits. Magnetic flow meters, turbine meters, pH electrode wiring, chromatograph detector wiring, and AC-powered bridge circuits are just a few examples. Thermocouple wiring should not be mixed with milliampere signal wiring. Wiring for circuits in which sharp voltage pulses are transmitted (such as relay contact closures, relay coils, and solenoids) should also be segregated from other wiring.

A practical exception to the preceding is the situation of one conduit to a control valve with the wiring for the 4–20 maDC signal for the valve, the 24 VDC for an associated solenoid valve, plus the wiring for the limit switches.

### 9.2 SIGNAL AND POWER WIRING

Where signal wiring is run along a parallel route with AC power circuits, separation of conduits, cable, and trays should comply with Table 3. This table applies to instrument signal circuits for analog signals, high and low speed digital pulses, and high, medium, and low noise level circuits.

If groups of cable trays are stacked vertically, the signal wiring should be in the top tray, and high-voltage feeders should be in the bottom-most tray. With this arrangement, the signal wiring is not in the electric field that exists between all voltage lines and ground

The circuits. might be arranged top to bottom as follows:

a. Signal wiring.
b. Light-capacity power circuits.
c. Medium voltage AC and DC feeders.
d. High-voltage feeders.

### 9.3 PROXIMITY TO AC FIELDS

Although direct routing is desirable for all types of wiring, the sensitivity of signal wiring to electrical magnetic interferences may call for special routing precautions. Magnetic field interference occurs when signal wires pass through strong AC fields which are present near large motors, generators, electric furnaces, and transformers. As a general rule, a minimum of 5 feet (1.5 meters) of clearance should be allowed between the noise generating equipment and signal carrying wires. If steel conduit is used, clearances can be reduced by half.

Signal leads should, if possible, enter or exit AC power equipment at right angles to the equipment's magnetic field. When power and signal wiring cross in close proximity to each other, the crossover should be made at right angles and no closer than 12 inches (0.3 meters).

## 10 Effect of Transmission Distance on Electronic Signal Installations

The design of an installation is largely governed by economics: for example, more expensive signal multiplexing equipment using fewer wires or fiber optic systems may be justified for long distances, but less expensive direct connected wiring may be more economical for short distances. The economics of various types of transmission systems should be evaluated on an individual project basis.

The length of the transmission line also affects the magnitude of electrical interferences. Generally, the longer the distance the greater the possibility of noise. Lightning also creates problems in longer lengths of cable. The spare conductors in a multiconductor cable should be grounded at one point so that they do not induce large voltage surges on signal circuits when lightning strikes nearby.

AC powered solenoid valves connected to wire runs of 1000 feet (3000 meters) or more may fail to switch on the opening of the control contacts due to electrostatic coupling to AC lines. DC is recommended with adequate wire size.

## 11 High Temperature Areas

When wire is run next to fired heaters or other heat radiating equipment (as occasionally is required with thermocouples), every effort should be made to keep the wire in areas where temperatures are not excessive. If this condition is not practical, wire with a moisture resistant, high temperature insulation should be used. A common junction box should be provided in a safe area, away from the heat source, to allow connection to regular wire which can be run the remaining distance.

## 12 General Information On Installation Methods For Electronic Systems

Although signal wires may be installed and protected from physical damage by methods that are similar to those for power wiring, such methods are not always sufficient for good signal transmission. Information on methods and hardware that result in a good signal transmission system is given in Sections 13 through 20. Routing of redundant data highway cables requires consideration of the need to maintain redundancy by avoiding exposure to common hazards.

## 13 Installation Of Trays For Electronic Systems

### 13.1 LOCATIONS AND ADVANTAGES

Cable trays may be used advantageously to support a large number of cables between two points if their use is permitted by the NEC and other applicable codes for the application in question. Tray use is generally limited to Division 2 and nonclassified areas unless Intrinsically Safe wiring is used. The primary advantage of trays over conduit is their lower initial cost. Power Limited Tray Cable (PLTC) is normally required.

### 13.2 DESCRIPTION

The different types of trays are discussed in the following

#### 13.2.1 Applications and Limitations

Many varieties of metal trays are available for either horizontal or vertical mounting. Prefabricated trays are usually purchased, but some users prefer to have trays made in their own shops or by local steel fabricators. The general types of prefabricated trays for horizontal mounting are ladder, trough, and channel. A ladder tray is a prefabricated metal structure consisting of two longitudinal side rails connected by individual transverse members (rungs). A trough tray is a prefabricated metal structure greater than 4 inches (100 millimeters) in width with a continuous bottom, either ventilated or solid, contained within integral or separate longitudinal side rails. A channel tray is a prefabricated metal structure consisting of ventilated channel sections not exceeding 4 inches (100 millimeters) in width. These trays are normally used at the processing unit and are not run to control centers.

The selection of the proper horizontal tray design will vary with the size of tubing loads and with environmental conditions.

Although protective covers are not necessarily required, their use on horizontal trays should be considered. Continuous solid covers for horizontal trays are advisable to protect the plastic tubing or bundle sheath in plant areas.

### 13.2.2 Horizontal Trays

The proper design of a horizontal tray system will vary according to the weight of the cables, environmental conditions, and the need for additional electrical shielding. In general, where cables of small size are to be installed, ventilated, or solid bottom trays are preferred over the ladder type. Although protective covers are not necessarily required, their use on horizontal trays should be considered. Continuous solid covers are advisable for protecting cables in areas where damage from falling objects, sunlight, ice, snow, rain, etc. may result. Temporary plywood covers may be used during construction for protection.

### 13.2.3 Vertical Trays

Some users prefer vertical trays to horizontal trays. Figures 1 and 2 show methods of mounting vertical trays. The primary advantage of vertical trays is that they require much less pipe rack space. Other advantages include the following:

a. The upper surface of the tray is available for mounting an additional tray.
b. Support design is simpler because of the tray rigidity.
c. Peaked tray covers minimize problems from falling objects and debris.

The assembly and support of vertical trays utilize the same hardware used for horizontal trays. However, additional labor is required for installing the wiring.

### 13.2.4 Selection of Materials

Environmental conditions should be considered when tray materials are selected. Steel trays should be used where the best electrical shielding is desired; aluminum or any other nonferrous material is not effective in reducing electromagnetic noise. Each installation has unique requirements, and each material and coating should be thoroughly investigated. Fiberglass trays may be used in more corrosive environments.

Prefabricated trays are commonly made of steel or aluminum. Steel trays can be galvanized or coated with epoxy or polyvinylchloride (PVC). A popular material selection for process plants is galvanized steel in accordance with ASTM A123. This type requires hot-dip galvanizing after all fabrication and welding operations are completed. ASTM A525 is not recommended because it specifies that the metal is to be galvanized before fabrication and welding are completed. In certain environments, aluminum has proved to be a more economical choice. Several aluminum material specifications can be used. Copper-free aluminum is often recommended.

The structural design of tray systems is similar to that of other structures in that dead loads (cables, trays) and live loads (ice, snow, wind, earthquakes, and installation pulling-in forces) are necessarily considered. However, there are substantial differences in the structural design of trays as contrasted with other structures. These differences are discussed in detail in 13.2.5.

*CAUTION:* Trays are not designed as walkways or hoisting beams, and employees should be advised not to use them as such.

### 13.2.5 Structural Design

One should refer to tray vendors' catalogs of structural design for information and should apply good judgment. One should also consider spacing of horizontal supports to prevent sagging of the trays.

To ensure the safety of all personnel who come in contact with tray installations, specifications should require that all fabricated pieces be free from burrs and sharp edges.

### 13.2.6 Routing

The successful installation of 12-inch-and-over cable trays requires layout studies and detailed drawings. This effort should not be left to the judgment of field erection crews, especially at the entrance and inside of buildings. Tray runs should be made as straight as possible, but should avoid exposure of the cables to excessive heat, moisture, strong electrical interference, and mechanical damage.

Tray runs should follow routes that contain a minimum number of fire hazards. Placing trays near hot piping should be avoided, since this can cause deterioration of the cable insulation over a period of time. One should also avoid areas where hydrocarbons or corrosive or washdown fluids are likely to fall on or flow into the trays.

Also avoid placing cable runs or trays over mechanical equipment or over air coolers or any location that may interfere with maintenance or rigging operations on nearby equipment.

One good location for tray runs is above pipe racks. Trays may also be installed under pipeways. A discussion of the procedures for arranging trays for various services is given in Section 9.2.

### 13.2.7 Fireproofing

Specialty designers of fireproofing systems may be consulted for assistance in designing fireproofing for trays in areas containing fire hazards. Materials that can be used to fireproof trays and their structural support include lightweight industrial insulating and fireproofing blankets and intumescent mastics or paints. Intumescent paints should be applied in the field according to the manufacturer's recommendations, normally on the tray covers. A material with a fire resistance rating of 1 hour for structural steel should not be expected to give signal wire with its plastic insulation integrity for more than a few minutes. A time of 10 minutes for fire protection is suggested. The use of high-temperature wire insulations should be considered.

## 14 Installation Of Raceways In Electronic Systems

### 14.1 GENERAL

The general term *raceways* includes rigid conduit, electrical metallic tubing (EMT), flexible metal conduit, surface metal raceways, under-floor raceways, busways, wireways, and auxiliary gutters. Process plant raceways for control signals are, for the most part, rigid conduit. Surface metal raceways, under-floor raceways, and auxiliary gutters are usually limited in application to control center installations. Flexible conduit is frequently used to connect a field-located instrument to the raceway, and is sometimes used to isolate selected signal cables inside pull and terminal boxes. Raceway sizing is covered in the NEC.

The guidelines for selecting a tray size for control and signal cables are different from those for selecting a tray size for power cables. Power cables are normally placed in a single layer, with a ventilation space maintained between the cables to allow for heat dissipation and free air rating. Control and signal cables in trays may touch each other and may be in one or more layers. Metal barriers approximately twice the height of the largest cable have been used to separate different types of signal cables, and for separating Intrinsically Safe (IS) wiring from non-IS wiring (see 4.3.1).

The sizing of cable trays for control circuits depends only on the space required to accommodate the cables at various locations in the system. This space requirement also indirectly determines the tray capacity. Enough space should be provided so that at least 20 percent more cables can be installed in the future.

### 14.2 ABOVEGROUND INSTALLATIONS

#### 14.2.1 Applications

Aboveground conduit runs are used for individual instrument wiring to junction boxes and are often used for handling wires and cables from junction boxes to the control centers when cable tray is not appropriate.

#### 14.2.2 Materials

The conduit material should be suitable for the environmental conditions and should possess the required electrical shielding properties. Galvanized steel is the most commonly used material. Aluminum and steel conduits coated with polyethylene or PVC are also used. Nonmetallic conduit is seldom used aboveground in process plants and is not recommended for instrument wiring, since nonmetallic conduit provides no electrical shielding.

#### 14.2.3 Installation

Recommendations for the support and arrangement of conduit systems are as follows:

a. Do not use piping to support conduit.
b. Provide for thermal expansion and other equipment movement.
c. Fasten conduit to support with pipe clamps or bolts.
d. Install conduit runs with a minimum number of bends and offsets.
e. Provide conduit drains at low points.
f. Provide fireproofing where fire damage is possible, similar to fireproofing for trays (see 13.2.6). Protecting conduit with suitable pipe insulation, such as calcium silicate, fiberglass, and similar materials, will help to protect against flame. Stub-ups from underground conduit may be enclosed in concrete for fire protection. Fireproofing should be designed to provide protection from fire for 10 minutes circuit integrity or more.
g. Provide junction boxes, considering ease of pulling the cables, places where the type of wire or insulation changes, or places where single pairs change to multipair.
h. Provide solid connection between the conduit and tray for electrical ground continuity.

### 14.3 UNDERGROUND INSTALLATIONS

#### 14.3.1 Conduit Materials and Installation

The most widely used underground installation is galvanized steel or plastic conduit arranged in banks that have a protective red-dyed concrete cover envelope. Aluminum conduit is not recommended for underground use. Refer to the NEC requirements for duct bank installation details.

Where underground conduit routes cross beneath roadways, railroads, or other areas subject to heavy loading, or where required by soil conditions, conduit banks should be adequately supported or the envelope should be reinforced to prevent shearing, crushing, or other damage from uneven settlement.

Aboveground pull boxes are preferred; underground pull boxes should be avoided. If an underground pull box is required, it should be made of reinforced concrete and have a removable cover designed to adequately support loads from maintenance vehicles. Pull box covers should be labeled with their load limit. Conduit runs for signal cables should slope and drain toward the pull box. Adequate space must be provided in the pull box for pulling the cable. The pull box should have a drain or a sump suitable for use with a portable sump pump.

Cable splices shall be avoided in underground sections. When future requirements are not known, it is suggested that underground conduit banks entering control centers include spares no less than 20 percent of the conduits initially required, and 50 percent is recommended.

Nonmetallic conduit may be substituted for galvanized steel. When it is used, stub-ups should be galvanized steel. A grounding conductor should be installed in each conduit, bonding the metallic conduit extensions together at each end. The grounding wire should be considered in calculating the percentage of conduit fill. The grounding wire is sometimes laid outside the conduit to reduce the installation cost. Vitrified-clay ducts may be used with the same provisions as for nonmetallic conduits.

#### 14.3.2 Direct Burial

Direct burial control cables are sometimes used in plant processing areas. The high cost of cable replacement and the associated plant downtime have been the major deterrents to this practice. European refineries make broad use of direct-burial cables. The cable jacket should be of a material that is compatible with the soil, and no underground splices should exist. Cables are typically laid in a sand bed 2 inches (50 millimeters) deep, covered with an inch (25 millimeters) of sand and then protected with a red-colored precast slab of concrete or tile usually about 2 inches (50 millimeters) thick. Stub-ups are made in the same way as underground nonmetallic conduit. The permissible bending radii of armored cables are necessarily longer than those of unarmored cables. The manufacturer's recommendations should be followed.

#### 14.3.3 Identification of Locations

The locations of all underground wireways in a process plant should be clearly marked and identified as electrical cable runs. This identification is customarily accomplished with pointer-and-service identification signs mounted on posts or fixed in the plant pavement at each turn of the raceway and at straight-run distances of not more than 100 feet (30 meters)

### 14.4 ROUTING

Layout drawings are required for any raceway installation. Runs should be made with a minimum number of bends and offsets. Underground installations require early job definition so that raceways can be installed at the same time as other subsurface installations, such as gravity drains. Aboveground raceways are subject to the same obstruction and hazard considerations as are any tray installations. The preferred location for overhead conduit runs is above overhead pipelines, but they are also installed underneath or outside of pipeways.

## 15 Messenger Cable

In applications where adequate structures such as pipe racks or buildings are not available for supporting trays or where long spans must be bridged for a limited number of transmission circuits, transmission cables may be supported by messenger cable. Messenger cable is a high-strength, stranded aerial cable that is supported at intervals by poles or posts.

The magnetic shielding effect of the tray is not present with messenger cable, and the cable may be installed remote from metal structures, possibly on the same poles that support power wiring. Messenger cable should be grounded for fault and lightning protection. Messenger cable cannot be depended on for lightning protection because of its close proximity to the signal cable (see Section 16). The avoidance of ground loops is important, particularly for long lines that must be grounded at intervals on the poles. Power lines should be as far as possible from the transmission cable and should be transposed where possible.

The NEC, state and local codes, and vendor data should be consulted for spacing requirements and other considerations.

## 16 Surge Protection For Cables In Electronic Systems

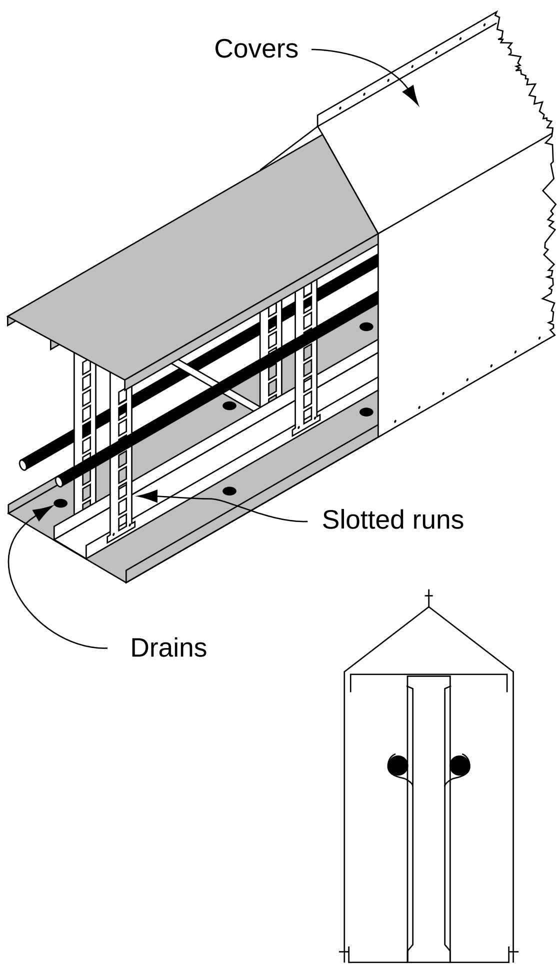
### 16.1 GENERAL

Instrument signal cables may be exposed to high voltages caused by lightning, atmospheric electrostatic phenomena, power-line transients, or power lines falling on the cables. Ordinarily, no protection is required if transmission cables are enclosed in grounded raceways or surrounded by grounded metal structures considerably higher than the cable. However, cables are sometimes exposed to electrical transients on long runs to tank farms, loading docks, or remote equipment. Fiber optics provide the most obvious immunity to any electrical surges, and should be the first choice for long lightning-(and other surge)-susceptible transmission signal carriers to remote locations. If fiber optics is not an available option, and if the cables cannot be protected by routing along metallic shielding such as steel pipe, structures, or conduit, consideration should be given to installing protective devices. The NEC provides for such devices, with personnel safety in mind, (see Figures 3 and 4). In addition, protection of instrumentation, especially designs that employ solid-state components, is desirable to prevent plant downtime.

This section deals only with the protection of equipment from physical damage caused by high-voltage surges on signal transmission lines. Protection against surges that can be experienced from the power source or on AC or DC lines supplying power to the devices is not considered here. Neither is an attempt made to cover preservation of signal integrity during the period of the high-voltage transient.

## 16.2 TYPES OF ELECTRICAL SURGES

There are several sources of high-voltage electrical surges. Lightning can strike the cable directly, but high-voltage disturbances are more commonly the result of a nearby lightning strike that is capacitively or magnetically coupled to the transmission line. Manmade surges can occur as a result of switching transients or faults in nearby power lines. Induced surges on signal transmission lines are characterized by a rapid rise to a high intensity of short duration. In contrast, a sustained surge can be encountered when power lines fall across signal lines. Each installation should be evaluated to determine potential surge sources and durations.




Note: Covers are often omitted when tubing bundles are used.

Figure 1—Vertical Tray

## 16.3 TYPES OF PROTECTIVE DEVICES

The following protective devices are applicable to instrument transmission lines where surges represent a major concern and where fiber optics or metallic shielding is not possible. All of the named options have advantages and disadvantages with respect to current carrying capability, voltage limiting, and the effects on the normal operation of the protected circuits:

a. Shield wires (not to be confused with a shielding wrap on the cables).
b. Air, carbon, and carbon-air gap arresters.
c. Hermetically sealed, gas-filled gap arresters.
d. Solid-state devices.
e. Fuses.
f. Inductive and resistive limiters.
g. Hybrid devices.

### 16.3.1 Shield Wires

The effect of lightning striking a transmission cable can be minimized by the use of a grounded shield wire located above the cable. The shield wire provides a triangular wedge of protection. This triangular area has a base that is twice its altitude; that is, if the shield wire is located one foot above the cable, the cable is protected for one foot on either side of its center line.

A one-to-one wedge, or a triangle that has the same dimension for its altitude as for its base, is sometimes used in order to assure an additional degree of protection. Two wires located above and on either side of the cable to be protected will provide more protection than will a single cable.

ANSI/NFPA 78, *Lightning Protection Code*, recommends a distance of at least 6 feet (1.8 meters) between the shield wire and the transmission cable it is protecting, to prevent any side flashes. If practical, the grounding conductor for the shield wire should be the same minimum distance from the transmission cable. The maximum separation is limited only by the cost of installation.

The protective shield wire may be aluminum, copper, or galvanized steel and should be attached at intervals to a low-resistance ground (see 19.2). Copper ground and shield wires should be at least American Wire Gauge (AWG) #6; aluminum ground and shield wires should be at least AWG #4; and galvanized steel ground and shield wires should be at least 5⁄16 inch (7.9 millimeters) in diameter and guy wire stranded.

Power wires installed above the transmission cable may be considered as shielding protection for the signal transmission cable, and a shield wire is not required in such a situation.

### 16.3.2 Air, Carbon, And Carbon-Air Gap Arresters

Unlike resistors, all types of surge arresters provide a threshold voltage below which no current flows. This threshold prevents interference with normal circuit operation. Once the transient voltage appears, the surge current begins. The result is a surge-developed voltage that is built up across the arrestor, and thus across the circuit in parallel.

An air gap arrester (as distinguished from a hermetically sealed, gas-filled gap arrester) is the older form of spark-gap protection used to protect electrical equipment and personnel from lightning or other surge damage (see Figure 4). Usually, carbon electrodes located in atmospheric air are used to transmit the arc-over voltages to ground. These type devices are inexpensive and carry large surge currents, but have a wide tolerance of arc-over voltage and generally allow too much voltage to protect instrument circuits adequately.

The normal gap of 0.003 inch (0.076 millimeter) will have an arc-over voltage of between 350 and 700 volts root mean square (RMS), depending on the ambient conditions existing in the air gap. The air gap is enclosed to protect it from dirt and fouling. On a signal transmission system, one air gap arrester is required at each end of a transmission wire; this requirement translates to four arresters per signal-cable pair.

### 16.3.3 Hermetically Sealed, Gas-Filled Gap Arresters

Hermetically sealed, gas-filled gap arresters are essentially improved air gap arresters. The arc-over voltage can be varied by design and will remain constant for the life of the unit. At normal line operating voltages, gas-filled arresters present an extremely high resistance to ground (thus no leakage current to complicate operating circuits). These arresters are made in a wide variety of forms and breakdown voltages, depending on gas pressure, type of gas, electrode spacing, material, and shape. Some available designs operate with a surge rise time on the order of a few micro-seconds and are capable of handling momentary currents as high as 40,000 amperes. In addition to a two-element design for individual line-to-ground protection, a three-element design using a common gas chamber is available that provides simultaneous line-to-line and line-to-ground protection (see Figure 5).

Arc discharge devices have the highest surge current capacities of all arrestors, but the volt-characteristics are more complex than the solid state devices. In the fired state, clamping voltage is essentially independent of current magnitude. However, unlike diodes and varistors, spark gaps require a large over-voltage to fire, and require current limiting to return to the non-firing state. The time lag to fire, although in the micro-second range, usually leads to over-voltages too great to protect solid state circuits. Breakdown voltages are typically from 90 Volts DC to thousands of volts, with current peaks from several hundred to thousands of amperes. These devices have the least capacitance and are therefore good protection for high frequency applications, given the other weaknesses.

In short, arc-discharge devices, whether carbon blocks or gas-filled, should be used alone only where over-voltage can be tolerated for a short time, where the transient energies are too great to be handled by varistors or semiconductor devices. However, arc-discharge devices can be combined with solid state devices into the hybrid devices mentioned in the following.

### 16.3.4 Solid-State Devices

DC voltages do not cross zero volts every cycle as do AC voltages. Consequently, DC voltages are a major application problem for spark gap protectors. Where the DC voltage is higher than 20–30 volts, the spark-gap arrestors will not extinguish following their firing. It is for this reason that

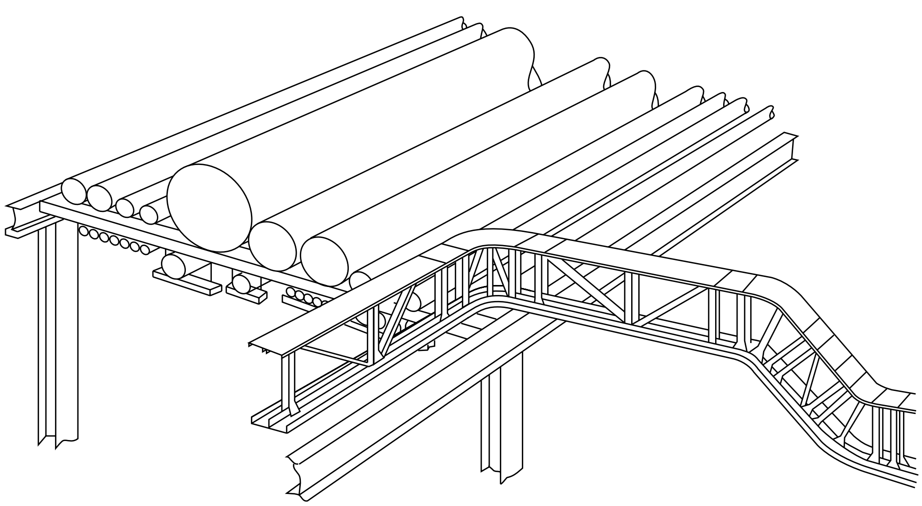


Figure 2—Vertically Mounted Long Span Tray

solid state devices are most commonly used to protect DC circuits.

Diodes are widely used on telecommunication lines to protect the solid-state transmitters and receivers from damage by excessive normal-mode voltages (line-to-line voltages). In general, diodes provide a conductive shunt at a surge voltage low enough to protect the transmission equipment. Semiconductors provide a quicker response to fast rising voltage transients and limit voltages to a far lower magnitude. However, semi-conductors cannot absorb the high energy surges that gap arrestors can.

Various diodes include the Zener diode plus members of the thyristor family. Rectifier diodes can protect signal circuits in the mV range, and can be stacked in series to increase the breakdown voltage. However, when the normal circuit operational voltage reaches beyond this scheme, a Zener or avalanche diode must be used. Zener diodes have a wide range of breakdown voltages to choose from. The small surge current capacities of diode devices generally require that several be used in parallel, or that they be combined with gap arrestors in a hybrid device. Thyristors such as the SCR (silicon-controlled rectifier) and TRIAC

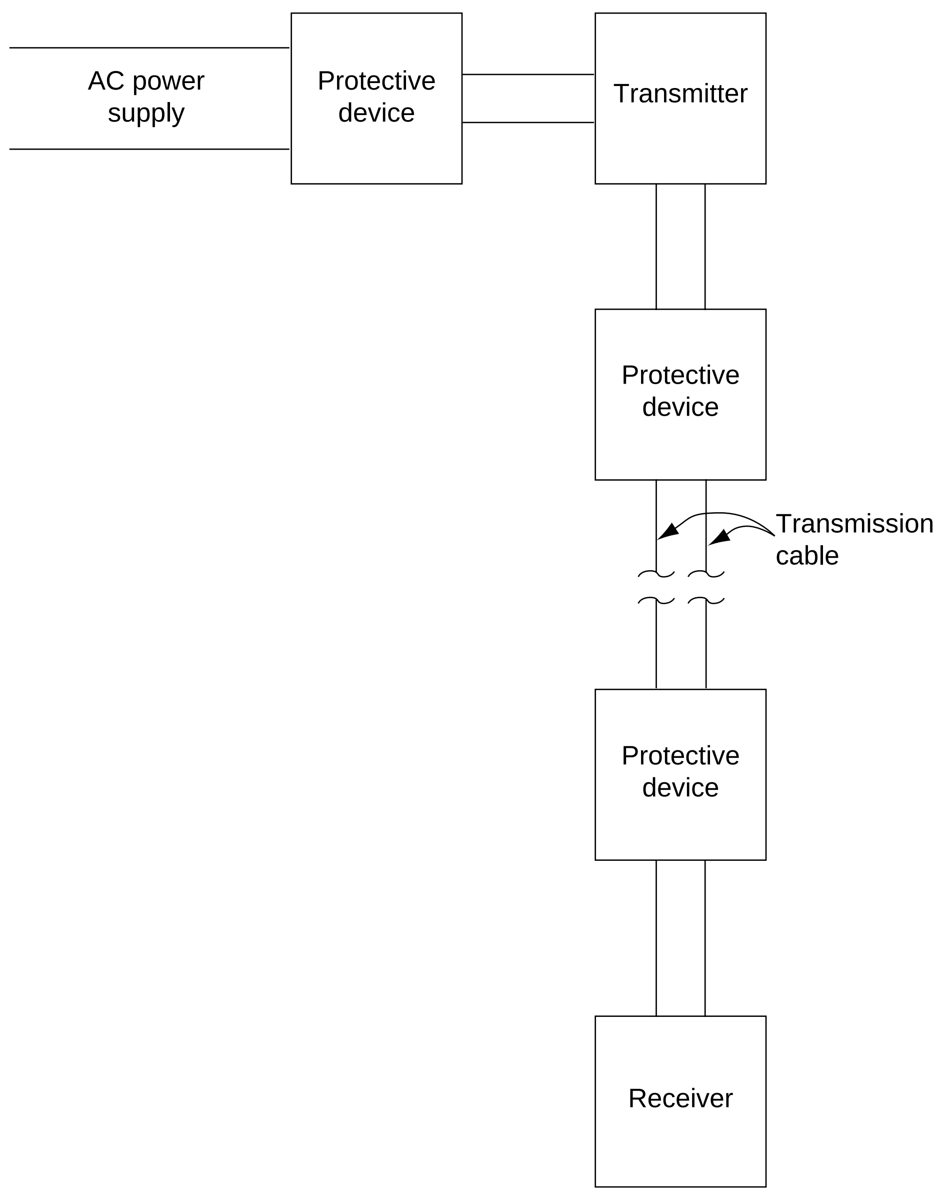



Figure 3—Typical Application and Location of Lightning Protective Devices

(bi-direction triode thyristor) may be used for higher current surge protection.

Varistors are variable resistor devices (resistance varies with voltage) that are bi-directional for transient protection. The silicon-carbide varistor excels in surge current capacity (some can carry 100,000 amps). The zinc-oxide varistor gives the best voltage-limiting ability for limited surge current applications. Varistors are available for protection as low as 30 volts, capable of 250 joules for 50 ms. However, leakage current at 29 volts could be 30 mA.

Solid-state devices are not normally used alone. They require protection from current and voltage overloads. Hence, these components are normally used in conjunction with other forms of protection devices, such as gap arresters, resistors, and inductive devices (see Figures 5 and 6).

### 16.3.5 Fuses

The NEC, Article 800, requires the use of fuses, particularly where signal transmission cables may come in contact with falling overhead power lines. Fuses are used in conjunction with gap arresters because fuses by themselves are not fast enough to completely protect personnel from a lightning-induced surge (see Figure 4).

Fuses do not blow quickly enough to protect solid-state equipment from voltage surges, but it is desirable to have them in the system, since the solid-state protective device can start to fail with continued steady voltage and current still flowing through it. Under such conditions, the fuse will blow before the instruments are damaged. A blown fuse will interrupt service. But this disruption is normally preferable to damaging the equipment.

### 16.3.6 Inductive And Resistive Limiters

Impedance, both resistive and inductive, is widely used to limit the peak current associated with line surges to prevent the destruction of such protective devices as diode shunts.

### 16.3.7 Hybrid Devices

Semiconductor devices are often used in conjunction with arc-discharge devices for limiting very low transient voltages as well as very high surge currents. Combinations of arc-discharge (spark-gap) devices with fuses or relays which extinguish the arc are sometimes used to protect DC circuits.

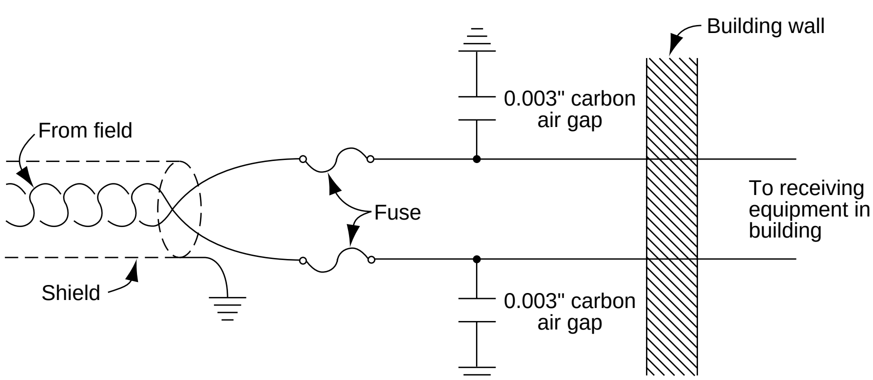
Two of the most common combinations are the following:

a. Arc-discharge devices and varistors.
b. Arc-discharge devices with diodes.

For example, an arc-discharge device in series with a varistor works as follows: the current through the varistor is blocked until a transient over-voltage fires the arc-discharge device. This process places the varistor across the line, which limits the voltage to the lower values. The varistor also helps extinguish the arc. Several of these pairs can be placed in parallel for added protection. Arc-discharge devices can also be used with diodes, such as a spark-gap in parallel with a Zener diode, with a resistor between the two.

## 16.4 SELECTION AND INSTALLATION OF SURGE PROTECTION DEVICES

Signal operating voltage and current of the protected circuit vary, and anticipated surges vary in current, wave shape, and rise times. In addition, the level and duration of voltages and currents that will cause damage vary with the equipment design and with the method of installation. For this reason, no




Note: Carbon gap arc-over voltage can vary between 300–700 volts; hence, normal mode voltage momentarily seen by receiving equipment can be as high as 350 volts.

Figure 4—Typical Installation of Lightning Protective Device for Personnel Safety at One End of a Signal Pair

one package of devices will fit every case. Each signal line that requires surge protection should be individually examined in order to select the correct array of devices that will provide the desired protection without sacrificing signal fidelity.

Surges usually enter on an AC power line, which may be protected by surge protection at that point. Thus, the actual surge on the DC line contains less energy, requiring less protection. Analysis must be made of the anticipated surges at the protection point to choose the device with the correct parameters.

Vendors who specialize in the design and manufacture of electronic surge protection equipment should be consulted. For the vendor to be responsive, however, he must have a thorough knowledge of each component in the transmission loop, as well as the component's tolerances. In a telecommunication installation, this requirement would probably mean meeting with only one vendor. In contrast, a digital process control system installation would require consultation with several different vendors.

Since no constructive generalization can be presented, the discussion below provides guidelines by which individual situations can be evaluated and understood as they are encountered.

### 16.4.1 Protection Of Personnel

The NEC, Article 800, is very specific in its requirements for personnel protection devices. A typical installation is shown in Figure 4. Note that each signal line must have its own fuse and air gap arrester. The transmission system should be designed so that the signal accuracy is not impaired by the addition of the fuses. If shielded pairs or a cable shield is required for the integrity of the transmission signal, then the shield should be solidly connected to ground as shown. A hermetically sealed, gas-filled gap arrester can be substituted for the air gap arrester shown in Figure 4.

As shown in Figure 4, the receiving equipment should be capable of withstanding a common-mode voltage of 700 volts and a normal-mode voltage of 350 volts. Using a gas-filled gap arrester of a specific design, for example, the line-to-ground value could be 175 volts +/- 15 percent, and the line-to-line value could be 200–400 volts (resulting in a common mode of 175 volts +/- 15 percent and a normal mode of 52.5 volts maximum).

Such high normal-mode voltages are damaging to modern-day solid-state electronics. The fuse provides no protection, since the solid-state electronics are critically damaged before the fuse can blow. Additional devices, such as a diode shunt (see Figure 5 and 6), are required to provide the desired equipment protection.

### 16.4.2 Protection Of Process Controls With Milliampere Signals

A typical processing plant could have hundreds of analog 4-20 mA and discrete 24VDC signal transmission loops, either

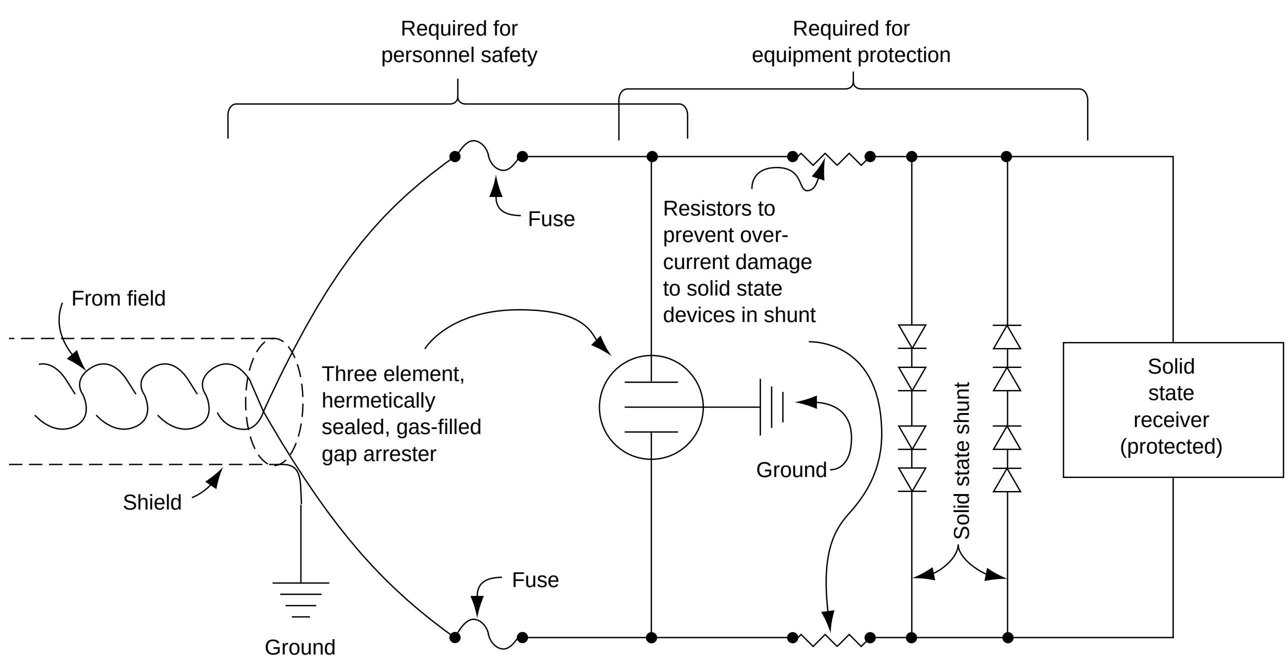



Figure 5—Typical Three-Terminal Gas-Filled Gap Arrester and Diode Shunt Lightning Protector

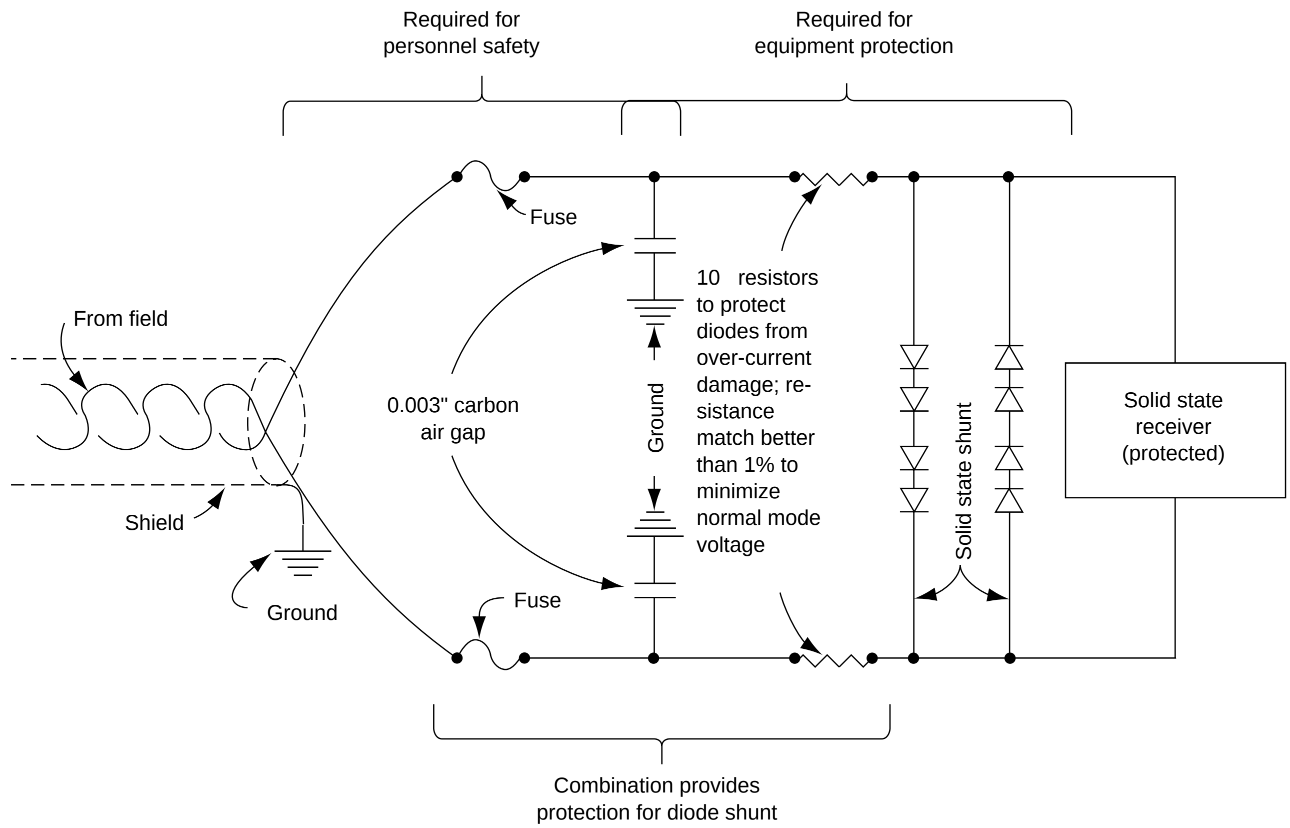



Figure 6—Typical Carbon Air Gap and Diode Shunt on A-C Signal Transmission

from single loop electronic controllers or from a Distributed Control System. Not all loops may have the same power-supply and transmitter designs, so different performance characteristics and surge limits would exist between loops, requiring a design variation in the surge protection devices.

It is apparent that an approach other than the design and installation of surge protection devices for individual lines is warranted. The economics of process plant design and installation dictate the protection of the signal transmission cable from transient surges only where there is a real threat of surges, such as in long runs to remote areas. The most obvious choices for protection are fiber optics or metallic shielding. In these instances, many signal transmission cables can be grouped together and protected in a common run. All spare conductors in a cable should be grounded at one point so that they do not act as antennas and impose high voltages on the signal circuits when lightning strikes nearby.

### 16.4.3 Protection Of AC Transmission Signals

Refer to Figures 5 and 6 and assume that the solid-state receiver is not damaged by a sustained common-mode voltage of 400 volts or a sustained normal-mode voltage of 5 volts, and that the pulsed, phase-modulated, or frequency-modulated transmitted signal is to be +/- 2 volts. This example could be considered typical for a telecommunication installation. For such an installation, silicon diodes can be used to shunt to ground the potentially damaging normal-mode voltage (5 volts). This proceses is done by shunting to ground through the first gap arrester activated.

The diodes, installed as shown in the figures, have a low shunt conductivity for the 2-volt signal level but become highly conductive when 0.9 volts per diode is exceeded (four diodes in series would become conductive at 3.6 volts). The break-over voltage must be higher than the operating signal voltage so that the signal pulses will not be clipped.

The diodes selected normally have a peak current rating of 50–80 amperes and require protection from surge damage. For this reason, limiting resistors or some other devices that increase impedance are installed ahead of them. These impedance-increasing devices should be matched so that they do not induce unwanted normal-mode voltages on the signal lines.

Care must be exercised to ensure that the capacitance introduced by the diodes as well as the resistance added by the resistors and fuses do not impair the accuracy of the transmission signal.

If the maximum common-mode voltage of the receiver is limited to 250 volts, a carbon-air gap arrester cannot be used.

A specially designed three-element, hermetically sealed, gas-filled gap arrester with a break-over voltage of less than 250 volts is required, as illustrated in Figure 5.

In the case of communication systems, conductors are usually small and cannot transmit large transient currents. Thus the protectors can be smaller with lighter-duty requirements. However, operation is usually at higher frequencies where protector insertion losses could be significant. Overvoltages must be limited to a much lower level than with power systems, since the protected circuitry contains integrated circuits, etc. Protection of audio frequency systems is best done with varistors or Zener diodes; whereas, protection of radio frequency systems (VHF and higher frequencies) is best done with a spark gap device, due to the unacceptable capacitances of varistors and semiconductor devices.

# 17 Wiring For Field Mounted Process Instruments

## 17.1 LEAKAGE OF PROCESS FLUID

Electronic components shall be located in that part of the instrument which is isolated from the process. This isolation will prevent damage to the electronic components, and eliminate the potential for process fluids to enter the wiring system.

Type MI (Mineral-Insulated) cable from the instrument to the wiring system is one method used successfully to effectively block process flow .

## 17.2 MOISTURE

Moisture may affect instrument performance and may cause corrosion of the electrical components.

Type MI (Mineral-Insulated) cable has been used for this purpose.

## 17.3 TEMPERATURE

The manufacturer's specifications for high and low environmental temperature limits should be consulted, particularly for instruments that require heat tracing. Instruments and connecting wiring must be suitably designed and located to withstand abnormal temperatures. Thermocouple wiring around furnaces should be given special consideration if it will be exposed to high temperatures.

## 17.4 TYPICAL WIRING PRACTICE

Article 501 of the National Electrical Code (NEC) gives specific electrical requirements for the installation of field wired electrical instruments in Class I hazardous (classified) locations.

It is not the intent of this section to repeat the detailed requirements of the NEC.

## 17.5 FACTORY SEALED ENCLOSURES

NEC 501-5(c)(5) allows assemblies with the arc, spark, or high temperature element located in a "factory sealed" compartment separate from the compartment containing the splices or taps to be approved for Class I installations without an external conduit seal.

Note: Special attention should be given to NEC 501-5(f)(3),which requires that instruments which depend only on a "single compression seal, diaphragm, or tube to prevent flammable or combustible fluids from entering the electrical conduit system" must have an additional approved seal, barrier or other means "to prevent the flammable or combustible fluid from entering the conduit system beyond the additional devices or means, if the primary seal fails." A conduit seal does not meet this requirement.

## 17.6 NON-INCENDIVE DESIGN (DIVISION 2), INTRINSICALLY SAFE DESIGN (DIVISION 1), PURGED ENCLOSURES, AND MI CABLE INSTALLATIONS

Non-Incendive Design (Division 2), Intrinsically Sage Design ( Division 1), Purged Enclosures, and MI Cable Installations are various methods which in general allow the relaxation of explosion-proof or sealing requirements for the various hazardous areas in which they are approved. Specifically, Intrinsically Safe installations allow wiring methods suitable for unclassified locations. Refer to the NEC, ISA, and NFPA standards for specific requirements concerning these installations.

## 17.7 DRAINAGE REQUIREMENTS

NEC 501-5(f) requires that if an enclosure is likely to trap liquid or condensed vapor, an approved means must be provided for periodic draining. Combination drain/breathers should be considered.

## 17.8 OTHER SEAL REQUIREMENTS

In addition to the seals mentioned above adjacent to instrument enclosures, the NEC should be consulted concerning additional seals required when entering termination boxes, when conduit passes between different hazardous area classifications, etc.

# 18 Junction Boxes

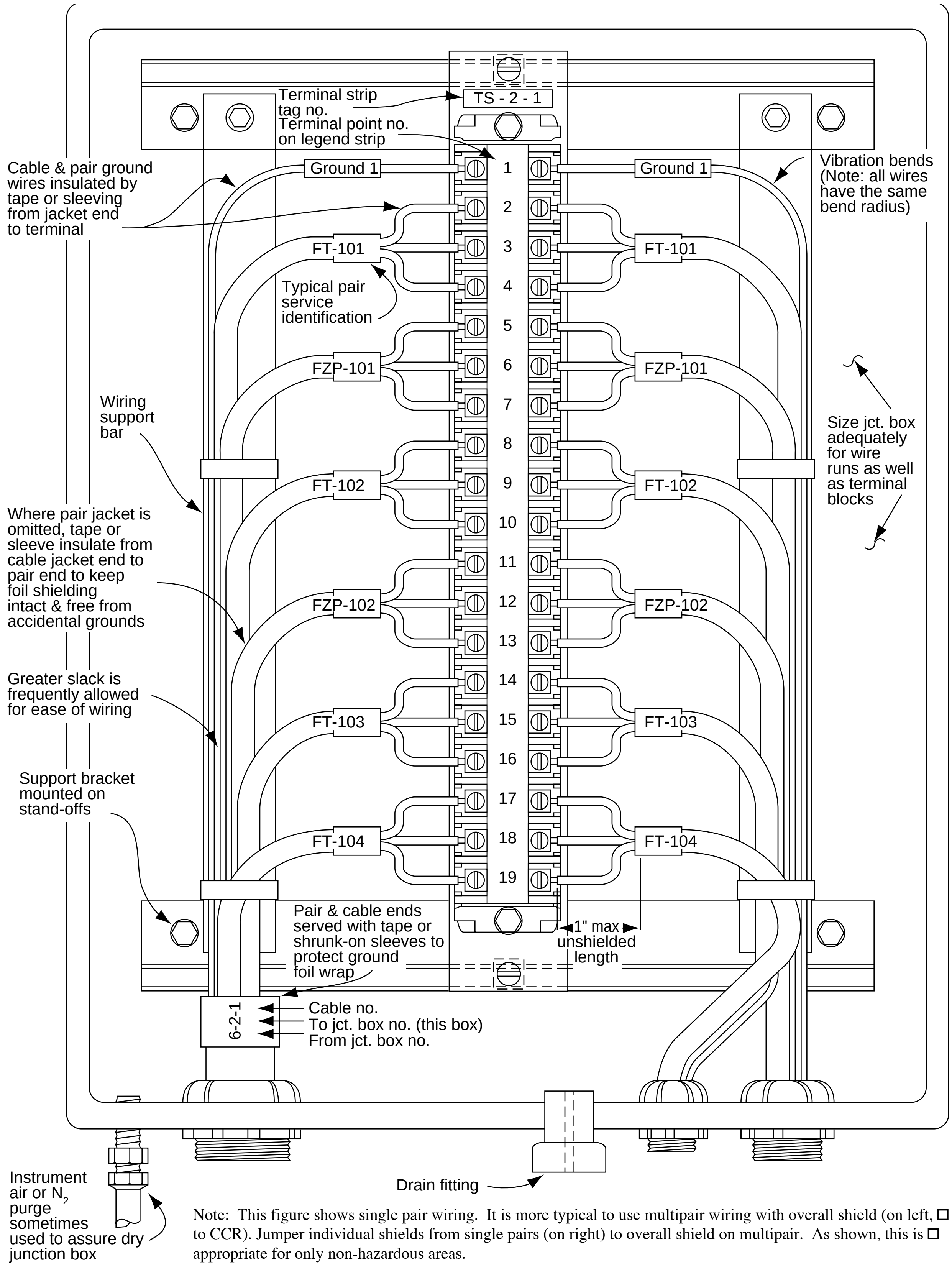
## 18.1 USE OF BOXES

Junction boxes (see Figure 7), should be used to provide a convenient location in which to connect instrument wiring. These junction boxes should be used to identify wires, to join wires in an orderly arrangement, to enable reasonable lengths of cable to be purchased and installed, to break out into smaller cables or wires, and to do the testing and repairing associated with instrument circuits and wiring. Wire splices should not be used.

Normal practice is to run a single-pair wire from the field instrument to the junction box, and multipair cable from the junction box to the control room.

## 18.2 FACTORS IN BOX SELECTION

Junction boxes for instrument wiring should be suitable for the service required. Although this principle is elemen-




Note: This figure shows single pair wiring. It is more typical to use multipair wiring with overall shield (on left, to CCR). Jumper individual shields from single pairs (on right) to overall shield on multipair. As shown, this is appropriate for only non-hazardous areas.

Figure 7—Typical Junction Box

tary, it is often overlooked. The following factors are involved in box selection and design:

a. Indoor versus outdoor location.
b. The electrical area classification.
c. Intrinsically Safe versus non-Intrinsically Safe installation.
d. The presence of a corrosive atmosphere or dripping liquids.
e. The need to exclude nest-building insects, rodents, and other wildlife.
f. The materials of construction for the box, which may be painted, galvanized, or aluminized carbon steel; painted, galvanized, or aluminized cast iron; aluminum; stainless steel; or fiberglass or plastic resin. Some caution is suggested in the use of fiberglass or plastic resin boxes: limited life has been experienced in some cases, due to ultraviolet damage.
g. The material of construction for the hardware (hinges, fasteners, and similar items), which may be the same material or one superior to that used for the rest of the box.
h. Security requirements (key locks or other deterrents).
i. The size of the box, based on the number of terminal strips involved; the wire space between, behind, above, and below the terminal strips; and the side or bottom area required for the entry or exit of cables, ducts, or conduits.
j. The need for access to the box, and the number and type of doors or cover plates.
k. The need for fire and blast protection.
l. The minimum cost that is consistent with the service requirements.
m. Allowance of adequate terminals for the shields.

## 18.3 BOX DESIGN

A single box design cannot meet all possible requirements. NEMA Type 12 design, is appropriate for indoor use. NEMA 4 is used outdoors and NEMA 4X is appropriate for corrosive areas. Under very corrosive conditions, boxes made entirely of stainless steel, fiberglass, cast iron, epoxy-coated steel, or aluminum have been used, together with dry-air or nitrogen purges to protect wiring within the box. Although sheet metal is the usual material of construction, heavy steel plate has been used for blast protection where critical services have to be maintained. This protections allows correct and orderly shutdown after a blast has affected the area. Light sheet metal offers notoriously poor blast resistance and should not be used if blast damage is critical. Some users have indicated a preference for NEMA Type 4 construction (see ANSI/NEMA 250) because these

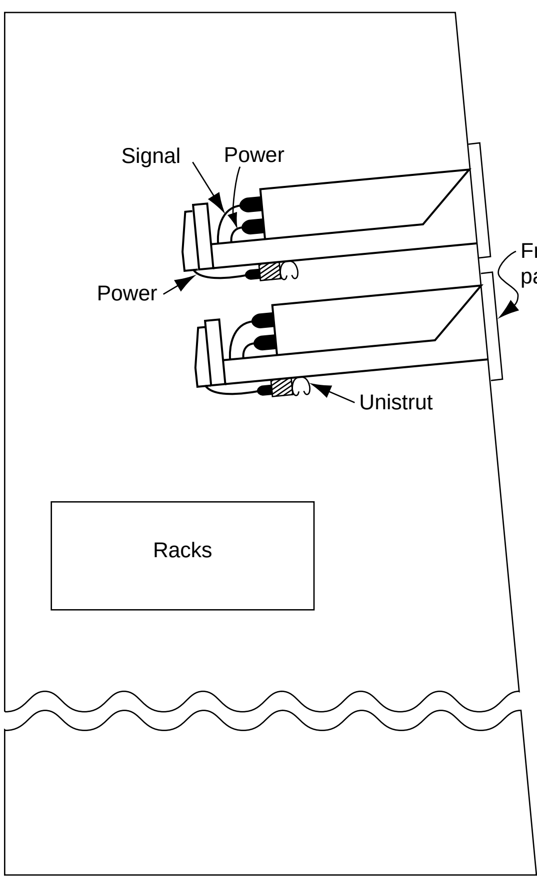



Figure 8—Panelboard Wiring Terminating Field Wiring at Instruments

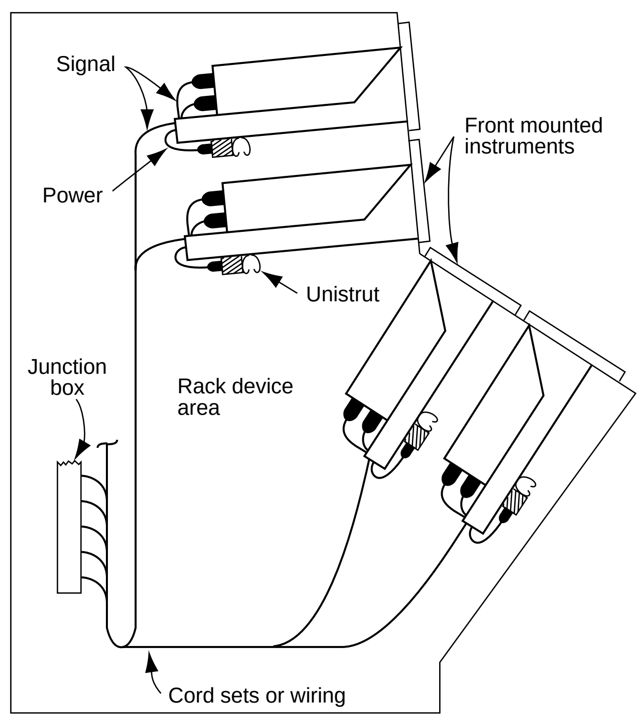



Figure 9—Panelboard Wiring Terminating Field Wiring at Panel-Mounted Junction Box

boxes remain watertight during washdowns. Where Type 4 boxes are used, oil-resistant gasketing should be specified, since NEMA does not require Type 4 boxes to have such gasketing. NEMA 4X is used where corrosion is severe (see Figure 9).

## 18.4 INTERIOR COLOR

The interior of junction boxes should be white to improve visibility.

## 18.5 MOUNTING OF BOXES

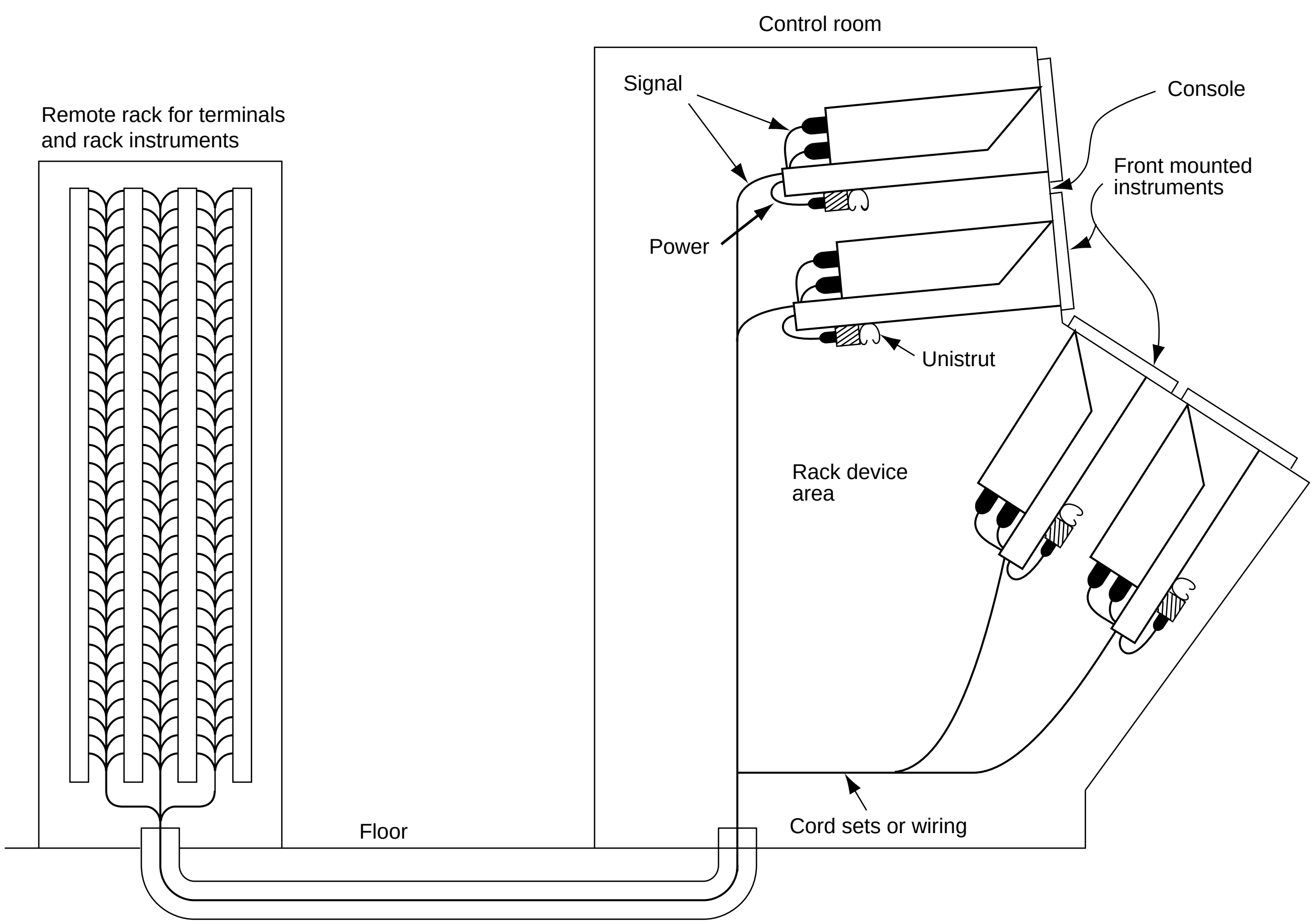
Practices for mounting junction boxes vary widely.

Where cables runs are underground, junction boxes should be mounted at an easily accessible height. Mount the top of the junction box about 6 feet (1.8 meters) above grade and encase all conduit from grade to the box in concrete or another fire-resistant material. This design minimizes cable repair after a fire. The protected wire below the box will probably survive a fire, but wire in and above the box will probably be damaged beyond use. If such damage occurs, the protective material is removed and a junction box is mounted closer to grade; the underground wire runs are long enough to tie into the new terminals in the lower box.

Boxes are usually mounted on columns, pipe supports, or other vertical supports, when these are available. Separate footings and support steel are provided if needed.

Conduit and cable entry through the top of the box is to be discouraged due to the loss in water-tight integrity.

Bottom entry is preferred for wiring simplicity. Side entry is permissible. Bottom drains, possibly with screens to discourage insect nests, will reduce the accumulation of water. The cables entering the box may also be sealed to reduce the entry of water.




Note: Wire may be as shown or overhead. The conduit as shown ☐ may be below the floor but is above grade.

Figure 10—Panelboard Wiring Terminating Field Wiring at Separate Junction Box

### 18.6 MOUNTING OF TERMINAL STRIPS

Terminal strips should be mounted on sub plates for convenience, improving access for construction and maintenance and maintaining better watertight integrity.

### 18.7 GROUND CONTINUITY FOR SHIELDS

To comply with the requirement for grounding shields at only one point, use a terminal point to carry each shield through the terminal box. Insulate both the shield end and the shield drain wire between the end of the cable jacket and the terminal strip (see Figure 7). Since only one end of a shield is grounded, each cable has an ungrounded end. This cable end is finished with no ground, and insulation is applied over the trimmed cable end to avoid accidental grounds on any exposed shield or the shield drain wire.

## 19 Control Room Wiring

### 19.1 GENERAL

The available space within a control room is usually limited, and care must be taken to prevent the space limitations from resulting in poor wiring practices.

The guidelines for junction boxes in Section 18 apply to large boxes in control rooms, but the size of control room boxes presents unique problems. Sometimes entire rooms are set aside for use as junction boxes. Although the room itself is, in effect, a large junction box, boxes are still desirable to prevent dust from collecting on terminals and to provide shielding to isolate one type of wiring from another.

### 19.2 FIELD WIRING TERMINATIONS

Field wiring may be terminated at any of two locations:

a. The connections in a panel instrument (Figure 8).
b. Terminal strips mounted in separate junction boxes.

Terminating the power and field wiring, including shields and shield drain wires, at the instrument connections is best suited for high-density instrument systems, since the instrument terminal blocks are closely grouped. This method has the advantage of reducing the number of connections, thus reducing panel cost and simplifying instrument checkout. However, this method can have the disadvantage of increasing wiring time if the instruments are not closely grouped (see Figure 9).

When the field wiring is terminated at terminal strips mounted in separate junction boxes, prefabricated cables are used to connect the junction boxes to the panelboard or DCS, Figure 10. Shield drain wires are often tied to a ground bus in the junction box. With this method, the previously mentioned practices of insulating shield ends and drain wires should be followed to avoid accidental grounding at more than one point. Terminal strips on the panelboard itself may or may not be used. In addition, rack-mounted equipment can be mounted near the terminal space where rear panel space is limited or its use is undesirable.

Marshalling panels or cabinets are used to accomplish the following:

a. Provide for "Scramble" wiring; the arrangement of wires from the field are re-arranged to match the needs of the control system.
b. Provide a location for IS or surge barriers.
c. Allow pre-wiring from the field before the control system is available.

### 19.3 OTHER CONTROL WIRING

Wiring between the control system racks and other areas may be located overhead or under the floor and may be in conduit, ducts, trays, trenches, or other raceways. Guidelines for installation are given in Sections 13 and 14.

On a large job, the use of the two methods, both overhead and under the floor, can minimize congestion and aid in system segregation. One method is to use elevated flooring, or Computer Floors, to provide space for wireways (see Figure 11).

### 19.4 PRECAUTIONS FOR POWER SUPPLY WIRING

Wiring for AC or DC power should be separated from signal wiring to reduce electrical interference (see Table 3, Section 6, and 9.2).

Interference can be picked up by DC power-supply wires and fed back through the power supply to other instruments.

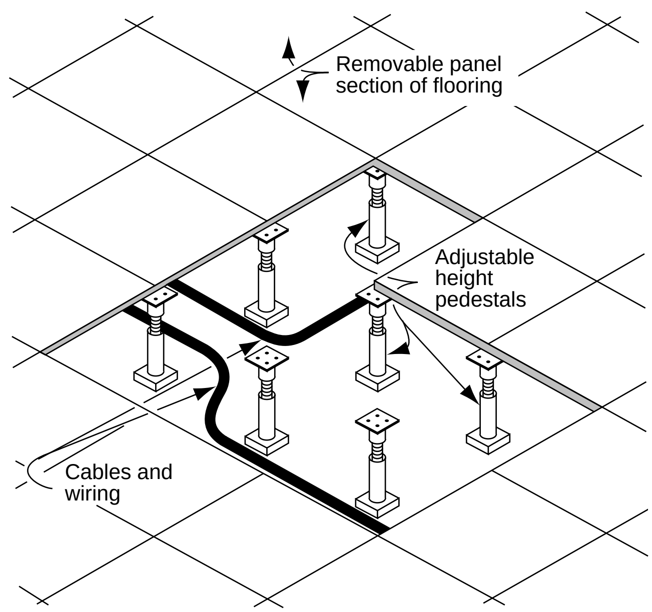



Figure 11—"Computer" Floors

This interference can be minimized by completely enclosing the power-supply wiring in a steel wireway up to the instrument case, by using short lengths of twisted-pair cord where plug-in cords are used, and by designing the instrument case so that signal wires enter at a point some distance from where the power-supply wires enter.

# 20 Installation Of Grounding For Electronic Systems

## 20.1 GENERAL

Most of the details of grounding practices were developed based on the power aspects of electrical work. Protection of personnel and equipment from lightning and fault currents has been the primary consideration in this development. Signal transmission circuits, however, are sensitive to electrical interference that is induced along the wiring. One of the methods for minimizing interference is the judicious use of grounds (see Sections 5.2 and 6). The power industry's practice of grounding various circuits to any convenient earth ground is not recommended for circuits that transmit electronic signals. The future will see fiber optics used to eliminate concerns of ground voltage differences. The chief reason for not using more than one earth ground is that differences in potential exist between earth grounds at different points within a given area. These differences result from the following conditions:

a. Ground-return paths of electrical equipment.
b. Natural soil differences and "battery action" of the soil, which may create a difference in voltage between one ground point and another. Differences in this case are usually less than a few tenths of a volt.
c. Cathodic protection currents impressed on steel in contact with the soil (see Section 20.11).
d. Induced currents caused by artificially induced magnetic fields; electrical machinery and distribution systems; electromagnetic activity from, for example, radio stations and radar (both commercial and military); and other sources of interference.
e. Ground faults of electrical systems.
f. Lightning and other atmospherically induced static charges.
g. A trend toward remotely mounted and powered I/O systems interfacing with the field, i.e. DES (Digital Electronic Systems) racks, without fiber optic or full isolation from those remote grounds.

Such differences in potential can cause false signals, or noise, in instrument circuits and often cause current flow in wireways, trays, and shields. These false signals can in turn induce noise in circuits within such enclosures. To avoid these problems, all signal systems should have only one high-quality earth ground.

## 20.2 DEFINITION OF TERMS

Note the following definitions of terms[6]:

**20.2.1 digital electronics systems (DES):** computer equipment (mainframe, mini-,and microcomputers; multi- and single-loop controllers; programmable controllers; man/ machine interfaces; personal computers; input/output interfaces; and peripherals that are connected via communication networks and that enable information interchange necessary for safe and effective implementation of the application.

**20.2.2 single-point ground (SPG):** a method used to ground the set of enclosures, frames, power supplies, and devices of a given electronic entity, requiring only one grounding connection from the given entity to a planned ground reference. The ground reference must be connected to the safety ground system of the building housing the electronic entity. Because this entity does not have more than one connection (planned or incidental) to ground, it is often referred to as an *isolated ground* or i*solated ground plane*. Note that the single point ground (isolated ground) must not be disconnected from the building safety ground (see Figure 12).

**20.2.3 total single-point ground (TSPG):** the TSPG scheme is utilized with DESs having close electrical coupling between logic and equipment grounds (certain minicomputer-based systems). The TSPG eliminates the problem of noise from the "noisy" equipment ground to the logic bus. This is accomplished by single-point grounding of the equipment as well as the logic system (see Figure 13).

**20.2.4 signal reference grid (SRG):** a matrix of conductors bonded at their interconnection in a manner that allows the grid to serve as a signal reference plane of constant potential over a very broad band of frequencies. The grid provides multiple grounding paths so that if one path is a high-impedance path, because of full or partial resonance, other paths of different lengths will be available to provide a lower impedance path.

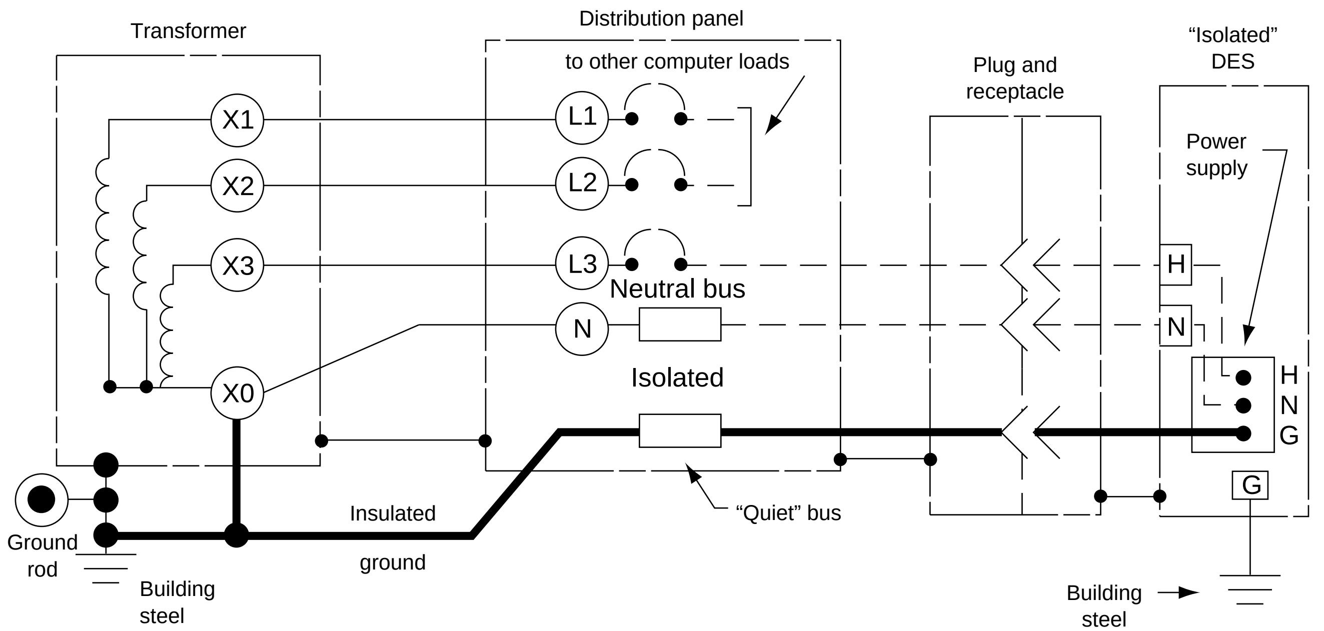
**20.2.5 logic ground:** the DC common return path found in most computer systems.

**20.2.6 ground grid plane:** an electrode, equipment, building, group of buildings, or area having the same earth resistivity.

## 20.3 QUALITY OF INSTRUMENT-CIRCUIT GROUND SYSTEMS

The consensus regarding instrument-circuit grounds is that they **will be only as good as the connection to the signal reference grid (SRG) ground.**

[6]V. J. Maggioli, "Impact of Fiberoptics on Grounding of Distributed Electronics," *IEEE Transactions, Industrial Applications*, May/June 1989 Volume 25, Number 3.




Note: DES, Digital Electronic System, includes PLC, DCS, etc.

Figure 12—Single-Point Ground Scheme

For most plant applications, power grounds are typically specified as having a maximum resistance of 3–5 ohms to true earth ground. However, a reasonable effort should be made to lower instrument grounds to less than 1 ohm using NEC recommendations.

For ordinary situations instrument-circuit (logic) grounds may be connected to the same earth-electrode beds used for power grounding. However, this must be done in such a way that all instrument grounds are at the same potential (see Figure 14). It is expected that this single reference ground will be the plant ground grid. In referring to instrument-circuit grounds, a distinction must be made between circuit (logic) and case grounds (see 20.9).

Under conditions that make it difficult to make good contact with earth (such as in high resistant soils, or in sandy, rocky, or dry areas; where the instruments or computers are sensitive to high-frequency noise; or where interference conditions are severe), specially designed grounding is a requirement. This special design will require a thorough study of all grounding to assure that instrument and computer signal grounding do not have a ground source with lower ground resistance than the single reference ground. With the plant grid as the ultimate single ground reference, all faults or currents flow to that ground.

## 20.4 TESTING OF GROUNDS

A ground system should be tested by individuals familiar with accurate measurement of grounds utilizing a four point method. This testing should be done upon completion or, in the case of modernizations, when the DES system is installed to verify that it is adequate. Records of these tests shall be recorded for future reference. Thereafter, the testing should be repeated periodically to verify that the ground system is still adequate. Attention must be given to the latest *National Electric Code (NEC)* as to frequency of testing requirements.

## 20.5 GROUND ELECTRODES

The design of ground electrodes is considered beyond the scope of this section, but reference to the following literature is recommended.

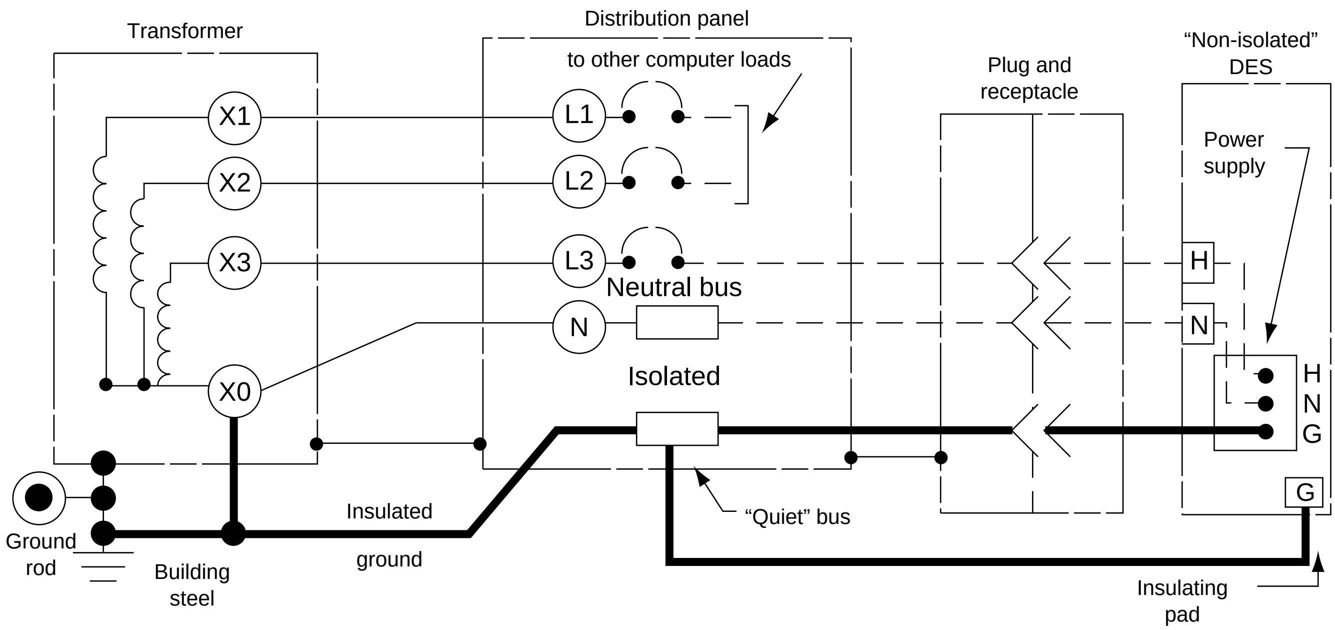



Figure 13—Total Single-Point Ground

*Getting Down-To-Earth. A Manual of Earth-Resistance Testing,* 2nd ed., James G. Biddle Company, Plymouth Meeting, Pennsylvania, March 1967.

*Grounding of Industrial Power System,* Paper No. 953, American Institute of Electrical Engineers (Now Institute of Electrical and Electronics Engineer, 345 East 47th Street, New York, New York), 1956.

"Grounding Principles and Practices" (Reprint S-2), *Electrical Engineering,* June 1945.

"Equipment Grounding," *Industrial Power Systems Data Book—Equipment Grounding*, Section 33, General Electric Company, Schenectady, New York.

ANSI/NFPA 70 *National Electrical Code*, National Fire Protection Association, Quincy, Massachusetts, 1984.

## 20.6 GROUNDING OF TRANSMISSION CIRCUITS

The need for grounded transmission circuits varies somewhat with the type of instrument or sensor in the circuit. The requirements for different instrument types are given in Section 6.

All spare conductors in a multiconductor cable should be grounded so that they do not induce large voltage surges on signal circuits when lightning strikes nearby, as discussed in Section 6.

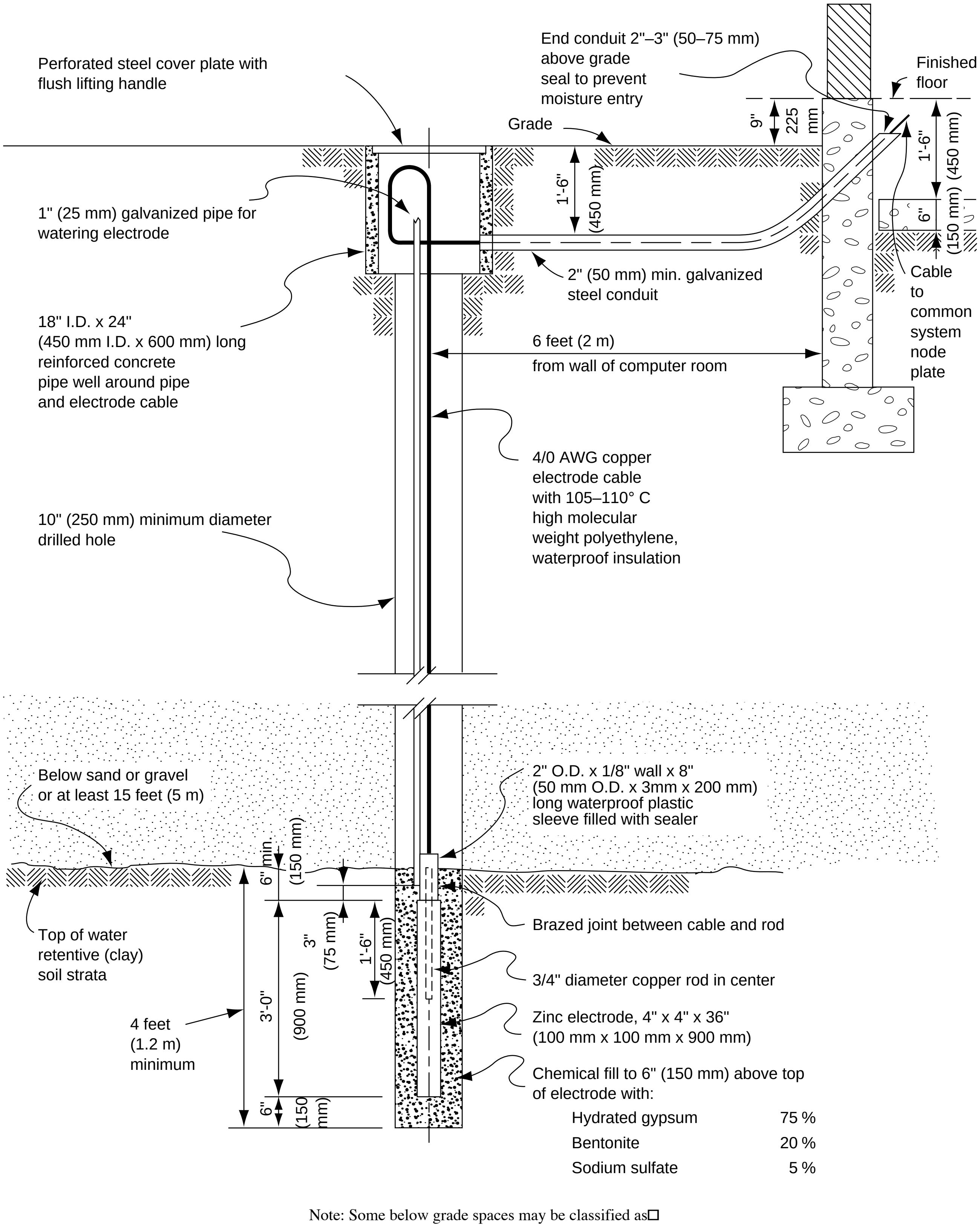
Grounded thermocouples present a special problem. If the thermocouple is located on cathodically protected equipment, the thermocouple should not be grounded. If a grounded thermocouple is used, the cathodic return path will be through the shield and/or couple lead to the ground grid causing the noise to be removed. Where grounded thermocouples are used, an additional resistor between the circuit and ground at the thermocouple head is desirable to maintain the circuit ground if the junction ground should fail. Since the ground at the junction block is a second junction ground, and high ground loop currents could therefore flow, a resistor is used to minimize such ground loop currents. When grounded thermocouples are used on cathodically protected equipment, their shields and wiring should utilize separated terminal blocks and cable to better isolate the undesirable ground. This process is not recommended unless other means of isolation is provided through multiplexing and/or fiber optics for the communications back to any other ground.

## 20.7 GROUNDING OF CABLE SHIELDS

Shields on signal wires should never be:

a. Left unconnected
b. Grounded indiscriminately
c. Connected to their signal pair
d. Connected at two or more points
e. Tied to other signal leads.

For analog process instruments using DC current systems, the shield grounds are usually terminated at a ground bus on the termination panel.




Note: Some below grade spaces may be classified as
Div 1 if flammable gasses and vapors can accumulate

Figure 14—Ground Electrode for One Low-Conductivity Soil Condition

Where shielded thermocouple wire is used, it is considered desirable to ground the shield near the point at which the circuit is grounded. For grounded-junction thermocouples, this ground point is at the thermocouple head. For ungrounded-junction thermocouples, this ground point is at the DES equipment in the termination room. Extreme care must be taken on cathodically protected equipment to tape back the shield at the termination room end to assure it does not contact metal. Multiple thermocouple pairs may have an overall shield. The same care should be used as above.

### 20.8 GROUNDING OF DES TERMINATION ROOM AND CONTROL PANELBOARDS

The control panel is usually grounded through a ground bus attached to the panel. Though the principle reason for the bus is to ground the instrument circuits, the bus will also ground the panel if the two are properly connected. The isolated ground bus for panelboards is to have provisions for connection to the same permanent plant ground grid plane through a dedicated properly sized ground wire.

### 20.9 DES AND PANELBOARD GROUND BUSES

The panelboard should have at least one ground bus. Some users use two—one for AC instrument grounds and the other for DC grounds. If the bus is adequately sized, grounded at only one point, has a correctly sized ground conductor, and has extremely low resistance to earth potential, one bus is usually considered adequate. Where all of these factors are not present, separate buses for AC and DC offer a reasonable safeguard against feedback through the ground system from one instrument to another. When separate buses are used they must connect to ground at the same point. Such buses are typically ¼ inch (6 millimeters) thick and 1 to 1½ inches (25–38 millimeters) wide and are constructed of copper. Each panel section should have its own bus, with the center of the bus connected to a ground point that is common to all panel section grounds and from which an adequately sized conductor leads to the earth connection (see Figure 15).

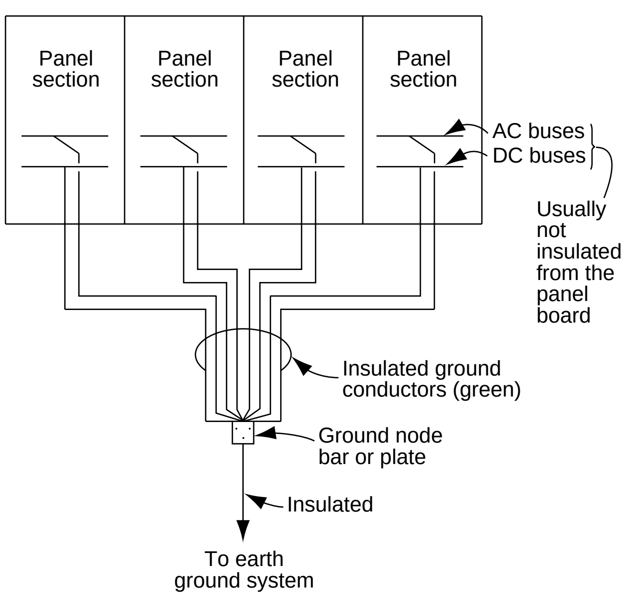



Figure 15—Panelboard Grounding

DES installations normally have an isolated ground run beneath the computer floor to gather all DC commons; this also ties to the single point ground system.

### 20.10 GROUNDING OF INSTRUMENT CASES

The cases of instruments supplied with electric power must be grounded to protect personnel from electric shock. The NEC requires some cases (normally, those of equipment operating at 115 volts AC and above) to be connected to ground. The grounding of cases should not be confused with the grounding of circuits, which usually requires other procedures.

### 20.11 GROUNDING OF CONDUITS AND WIREWAYS

Cable tray and wireways should be intentionally grounded along their length, using a ground wire in the tray or wireway attached to each section and grounded to the plant ground grid. Conduit should use clamps and brackets attached to structural steel and grounded to plant ground grid. Care shall be given to assure that cathodic protected equipment be given isolation and a bond resistance at the point of contact to conduit and tray.

Some users elect to ground conduits by deliberately grounding field terminal boxes and then using taper-threaded joints with a suitable joint compound that will ensure electrical continuity between the box and the conduit.

### 20.12 GROUNDING CONSIDERATIONS WHERE CATHODIC PROTECTION IS USED

Both sacrificial anodes and rectification sources of DC energy are used to protect certain process equipment from loss of metal due to stray currents flowing in the metal of that equipment.

Controlled points of contact for shields and guards on wiring require detailed engineering evaluation in a cathodically protected plant. Cathodic protection applied to process units through which wiring is routed and terminated may be at several different DC potential levels. Failure to identify these sources of energy can render a well designed grounding system ineffective or worse, unsafe in a very short time. This problem happens when very high DC currents flow along shields, guards, and circuit wiring through the electronic control systems to a single point ground. This flow will usually damage the shields, guards, ground conductor, and finally the single point ground. Multiple grounds only complicate the issue. The solution is found in rigorous attention and control to assure nothing is grounded to the cathodic protected equipment unless necessary isolation and fiber optics are used to provide all needed communication of information from and to the protected area. In all cases, isolation allows grounding to stay in the protected unit where the system can be monitored to detect unwanted grounding.

## 21 General Information on Pneumatic Systems

### 21.1 SCOPE

This section presents common practices for the installation of instrument air supply systems and the transmission of pneumatic signals

### 21.2 AIR SUPPLY SYSTEMS

For proper instrument operation, instrument air shall be oil and dust free, sufficiently dry to prevent condensation of water, and at a minimum pressure of approximately 100 pounds per square inch gauge (700 kilopascals) at the inlet to the instrument air header.

For additional information, see ISA Recommended Practice ISA-RP7.7, *Recommended Practice for Producing Quality Instrument Air*.

#### 21.2.1 Compressor

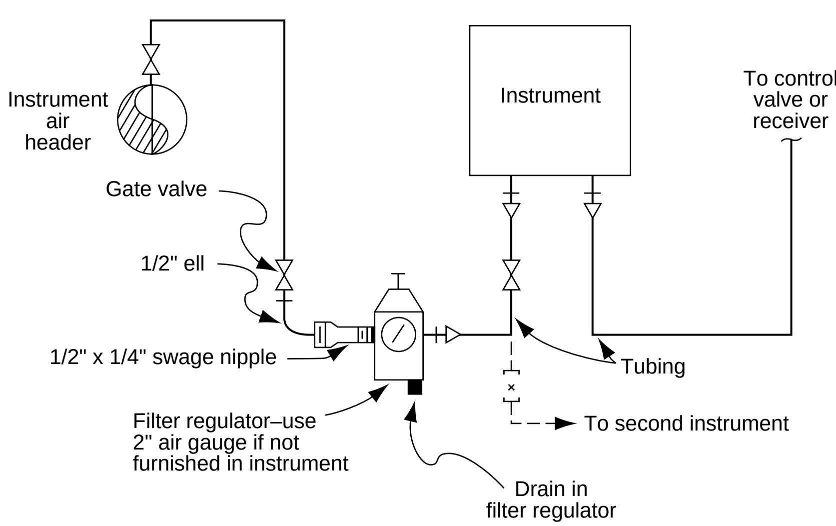
Compressors in instrument air systems may be either reciprocating, centrifugal, or rotary, depending on size, economics, and user preference. Compressors that use no oil in the parts exposed to the compressed air are required. Compressors shall be capable of continuous operation and should be sized for 200 percent of the total estimated instrument air requirement.

Control systems for instrument air compressors generally are furnished by the compressor manufacturer. Several types of systems are available. Reciprocating and rotary compressors are available with automatic start-stop, constant speed (automatic unloading), and combination control systems. Centrifugal compressors are available with either throttling or total-closure control systems. The type of system chosen depends on vendor selection and user preference. The quality of the hardware and installation of furnished instrumentation should be commensurate with the rest of the plant.

For additional information, see API Standard 672, *Packaged, Integrally Geared Centrifugal Air Compressors for General Refinery Service* and API Standard 618, *Reciprocating Compressors for General Refinery Services*.

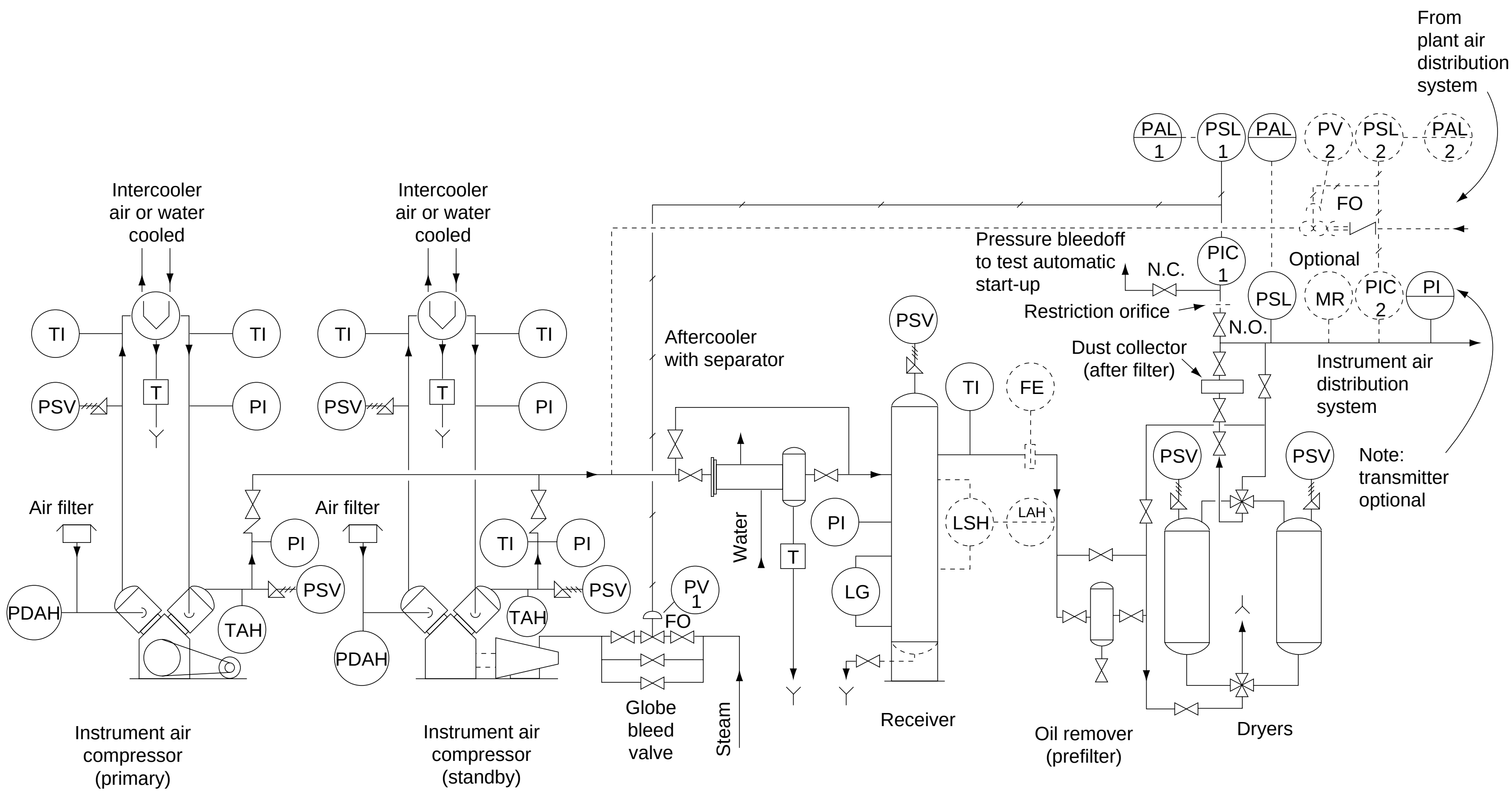
#### 21.2.2 Treatment Facilities

The compressed air should pass through an aftercooler and a separator to remove the major portion of the free water. The air should then be dried to a dew point (measured at distribution pressure) of at least 18˚F (8˚C) below the minimum local recorded ambient temperature at the plant site. The local weather bureau may be used as a source of climatic conditions. An adsorbent oil prefilter to remove any oil vapors is recommended for all installations, even those using “oil-free”compressors. A coalescent prefilter with



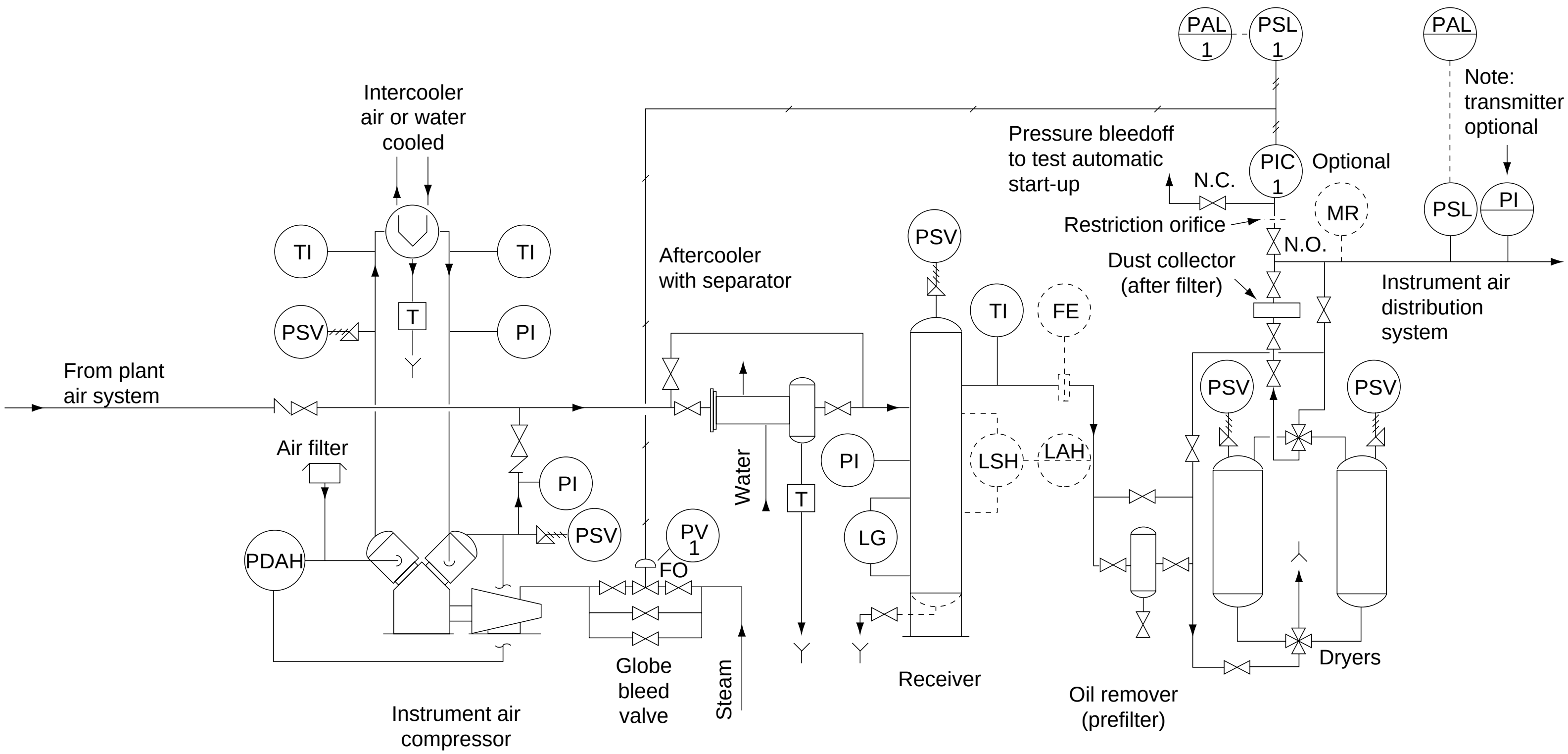

Note: Valves between regulator and instrument are required only if ☐ regulator supply valve is not within convenient reach.

Figure 16—Air Supply Piping for Field Instrument



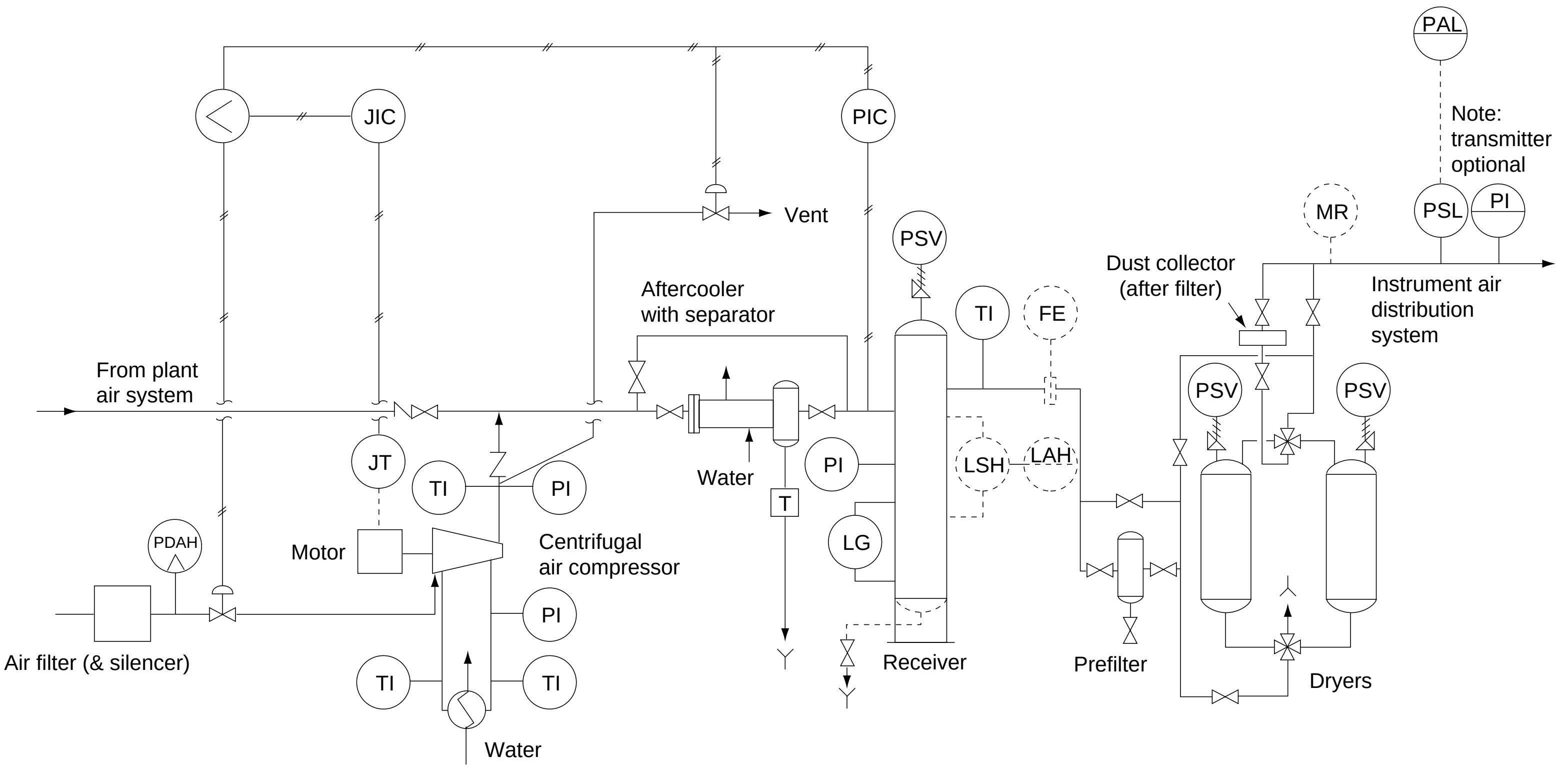

Note: Instrument symbols and identifying letters are per ANSI/ISA-S5.1 (see Appendix A).

Figure 17—Instrument Air Supply System With Standby Compressor and Optional Plant Air Backup




Note: Instrument symbols and identifying letters are per ANSI/ISA-S5.1 (see Appendix A).

Figure 18—Instrument Air Supply System From Plant Air With Instrument Air Standby as Air Backup




Note: Instrument symbols and identifying letters are per ANSI/ISA-S5.1 (see Appendix A).

Figure 19—Instrument Air Supply System Using a Centrifugal Compressor

continuous drain feature also should be considered. All desiccant dryers shall be provided with a 5-micron afterfilter to prevent dust fines from entering the distribution system. Also, the individual filter or filter-regulator shown in Figure 16 should be used between the air supply and those instruments without an integral filter or filter-regulator.

### 21.2.3 Standby Provisions

For reliability, a standby compressor powered from a different source should be provided to supply air in the event the primary source fails.

The standby compressor should be equipped to start automatically when the outlet pressure of the dryer falls below the desired value.

Additional safeguards against the loss of instrument air (such as automatic cutback of non-instrument air users and automatic cut-in of plant air) should be considered. Typical systems are shown in Figures 17, 18 and 19.

### 21.2.4 Arrangements

When a separate source of instrument air is desired, the system can be arranged as shown in Figure 17. The broken lines show an automatic makeup from oil free plant air. Figure 18 shows an instrument air system from plant air, with an instrument air compressor as backup. Figure 19 shows an instrument air system that uses a centrifugal compressor.

It should be noted that the centrifugal compressor shown in Figure 19 could be used in place of the reciprocating or rotary compressors shown in Figures 17 and 18.

### 21.2.5 Precautions

A compressor that will contaminate the air line with oil shall not be used even under temporary or emergency conditions such as construction, plant startup, or standby service. Once the air system becomes contaminated, it will continue to contaminate the clean air.

It is essential that a good filter be supplied to remove dryer adsorbent fines.

Air intakes shall be located properly to avoid picking up contaminated air, making sure to avoid building or process vents. Intake air filters shall be provided in accordance with the compressor manufacturer's recommendations.

### 21.2.6 Capacity

The capacity of an instrument air system is based on the total requirements of all connected loads, assuming all instruments operate simultaneously. Where accurate figures are not available, 1.0 standard cubic foot per minute (1.7 cubic meters per hour) shall be used for each consumer of instrument air. At least 100 percent extra capacity shall be provided for miscellaneous instrument purges and leaks in the distribution system. Instrument air is to be used for instruments and instrument purges only.

The use of instrument air for other purposes such as for pneumatically operated tools, air cleaning, or vessel purging can reduce the safety and reliability of the plant system.

### 21.2.7 Compressor Aftercooler

The compressor should have an aftercooler to remove the heat of compression. The aftercooler may be either air cooled or water cooled and should include a water separator to collect the condensibles. A temperature alarm or another suitable means of indicating loss of cooling is desirable.

### 21.2.8 Air Receiver

An air receiver should be included to damp out pressure fluctuations in the system and to provide surge time in the event of compressor failure. The receiver also functions as a liquid knockout drum to prevent entrained liquid from entering the dryer. The receiver should be sized to provide adequate surge time to allow for a safe shutdown.

### 21.2.9 Air Dryer

The dryer should be the adsorptive type to remove water vapor. Systems are designed for automatic regeneration, using a time cycle. The dryer shall be sized to match the compressor capacity.

Mis-operation of dryers will cause damage to the desiccant. Conservative users will provide spare dryers.

The air drying equipment must meet the dew point requirements of American National Standard ANSI/ISA-S7.3, *Quality Standard for Instrument Air*

### 21.2.10 Permissible Pressure Drop

The pressure drop throughout the entire drying and cleaning system (consisting of an aftercooler, water separator, receiver, prefilter, air dryer, and afterfilter) should not exceed 15 pounds per square inch (100 kilopascals).

### 21.2.11 Distribution Systems

Lines in the distribution system should be sized in such a manner that the maximum pressure drop between the dryer outlet and the most remote consumer does not exceed 5 pounds per square inch (35 kilopascals) when all consumers are taking air at maximum rates. A minimum pipe size of ½ inch NPS (12 millimeters) should be used for takeoffs to individual consumers. Where many instruments are in close proximity and are connected to one header (such as on a control panel or when a header is located at a junction box), a larger pipe size may be required. Table 7 can be used as a guide in line sizing for both main and branch headers.

Headers should be valved and plugged at the ends to allow for future expansion. All takeoffs should be from the top of the headers, and approximately 20 percent spare connections should be provided. Provisions should be made for blowing out the headers. It is recommended that when pressure testing, water should not be used. If water is used the system must be completely dried prior to commissioning.

A typical instrument air supply and sub-header piping arrangement is shown in Figure 20.

Table 7—Line Sizing Guide for Pipe Headers

| Pipe Headers | Number of Users | Nominal Pipe Size (Inches) | Nominal Pipe Size (mm) |
|---|---|---|---|
| Main | 80 | 1½ | 40 |
| | 150 | 2 | 50 |
| | 300 | 3 | 75 |
| Branch | 4 | ½ | 15 |
| | 10 | ¾ | 20 |
| | 25 | 1 | 25 |
| | 80 | 1½ | 40 |

### 21.2.12 Instrument Supply Piping

Air supply piping details for instruments should be similar to those shown in Figure 16. Carbon Steel or galvanized pipe is used upstream of the filter regulator. Brass, copper, and stainless steel downstream are commonly used materials for this service depending on the environment. $H_2S$, other sulphur bearing vapors, and other corrosives will affect copper bearing metals.

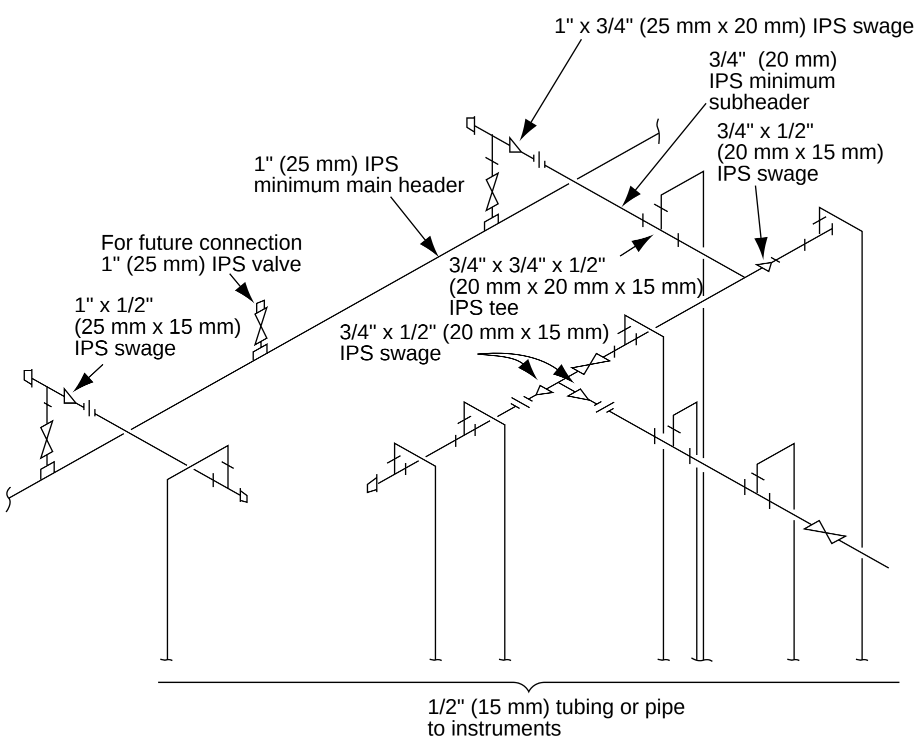
## 21.3 PNEUMATIC TRANSMISSION SYSTEMS

### 21.3.1 Standard Pneumatic Signal Ranges

For the process industries, the preferred transmission pressure range is 3–15 pounds per square inch gauge (20–100 kilopascals) as established by ISA Standard ISA-S7.4, *Air Pressures for Pneumatic Controllers, Transmitters, and Transmission Systems*.

### 21.3.2 Transmission Tubing

Tubing is normally used for pneumatic transmission lines. The preferred size is an outside diameter (OD) of ¼ inch (6 millimeters) with a typical wall thickness range of 0.030 to 0.040 inch (0.8 to 1.0 millimeter). This size gives optimum performance, based on minimum transmission time constant verses cost, for the air handling capacity of approximately 1.0 standard cubic foot per minute (1.7 cubic meters per




Note: No more than four (4) air supplies shall be taken off downstream of isolation valves.

Figure 20—Typical Instrument Air Supply and Subheader Piping

hour). Tubing with an OD of ⅜ inch (10 millimeter) and a typical wall thickness range of 0.032 to 0.062 inch (0.8 to 1.6 millimeter) is used in instances where greater air capacity and/or a shorter transmission time constant is required for good control.

### 21.3.3 Tubing And Fitting Materials

No single type of tubing material or configuration, single tube or bundled tubes, is satisfactory for all applications. The following points shall be considered:

a. Environmental factors, such as climatic temperature extremes, exposure to corrosive materials, and exposure to vibration.
b. Installation costs.
c. Material costs.

### 21.3.4 Single Metallic Tubes

The preferred material for metallic tubing in transmission installations is copper. Dead-soft annealed copper is preferred. Brass fittings are used with copper tubing. Stainless steel or special alloy tubing may be used in special cases.

Because of the presence of corrosive substances in processing plant atmospheres, copper tubing can give longer and more reliable service when the tubing is coated with plastic/PVC. Bare ends and fittings should also be protected from any corrosive atmosphere by wrapping with plastic tape or spraying with PVC.

### 21.3.5 Bundled Metallic Tubes

Bundled metallic tubing is available in a variety of materials and protective coatings. Copper tubing is furnished in parallel or spirally wrapped layers. The tube nests are wrapped with plastic tape or directly encased in a heavy extruded plastic jacket. Additional protection can be obtained by encasing the tube bundle in flexible armor. If protection from flash fires is required, an arrangement of thermal barriers and/or fire retardants can be provided.

Copper is the most popular material for bundled metallic tubing and is available in ¼-inch (6-millimeter) and ⅜-inch (10-millimeter) OD.

### 21.3.6 Single Plastic Tubes

Single plastic tubes are available but not normally used except for short protected runs.

### 21.3.7 Bundled Plastic Tubes

Bundled plastic tubing is available in a variety of materials and protective coatings. Plastic tubes are wrapped with plastic tape and encased in an extruded plastic jacket or flexible armor. If protection from flash fires is required, an arrangement of thermal barriers and/or fire retardants can be provided.

Polyethylene is the most popular material for bundled plastic tubing and is available in ¼-inch (6-millimeter) or ⅜-inch (10-millimeter) OD. Almost all plastic tubes are compounded with carbon and are black in color for resistance to aging from ultraviolet light. Black plastic tubes in a

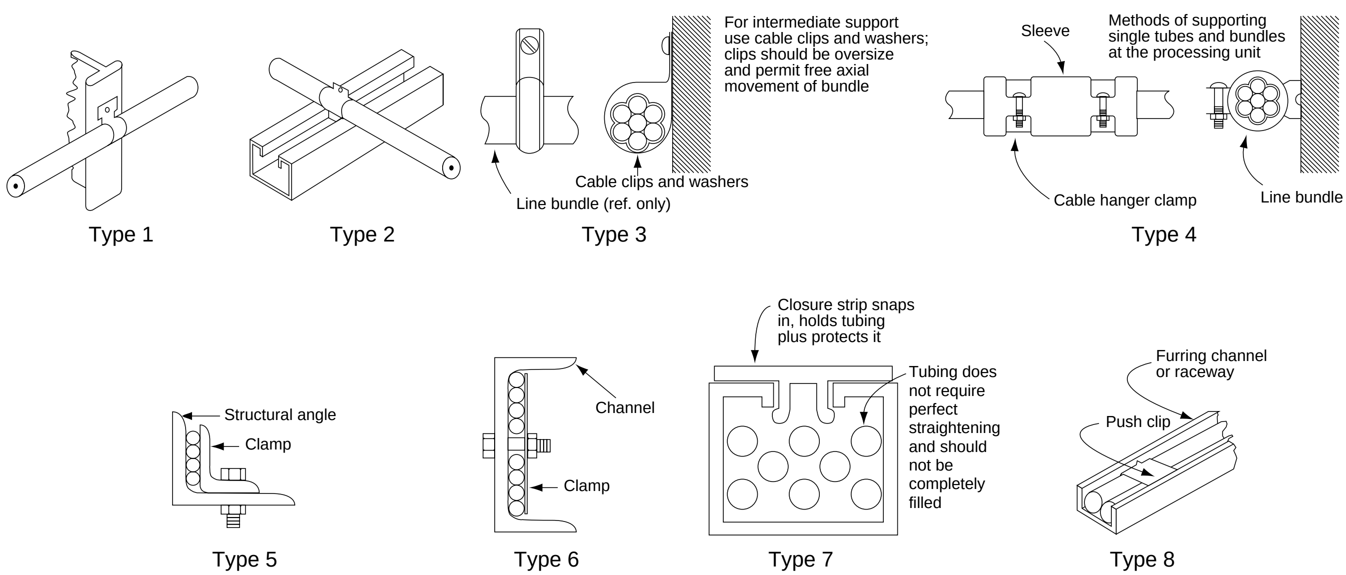
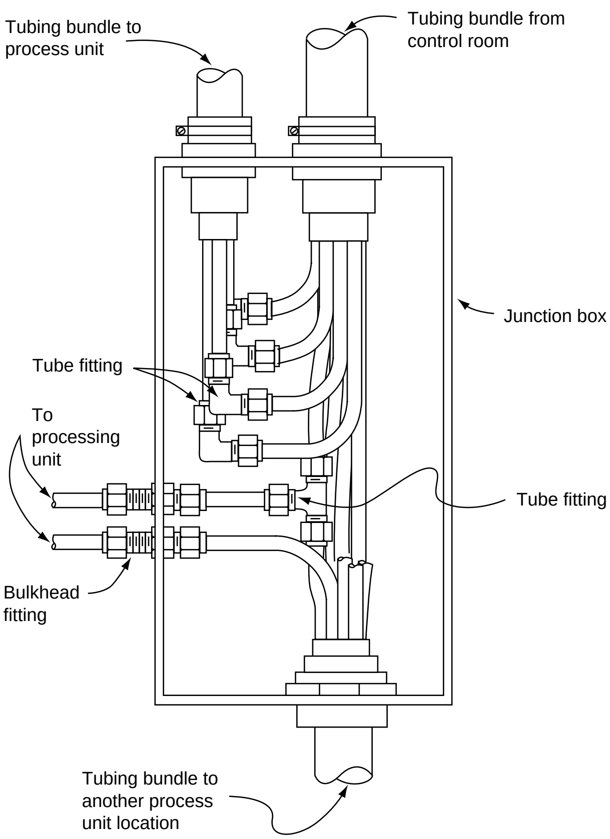
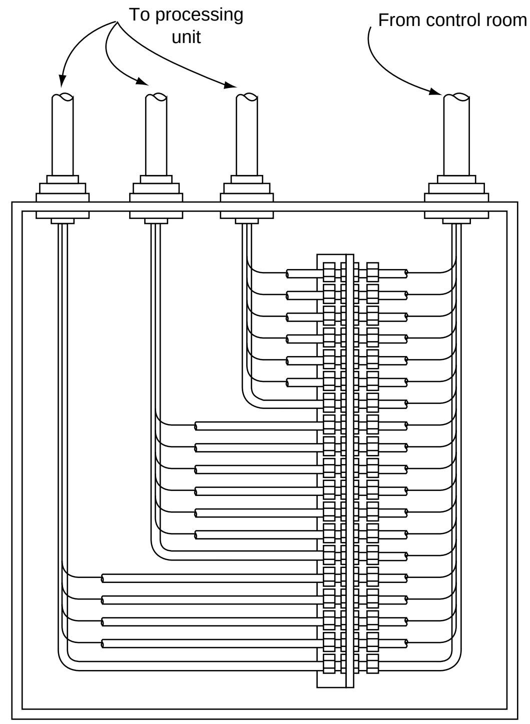


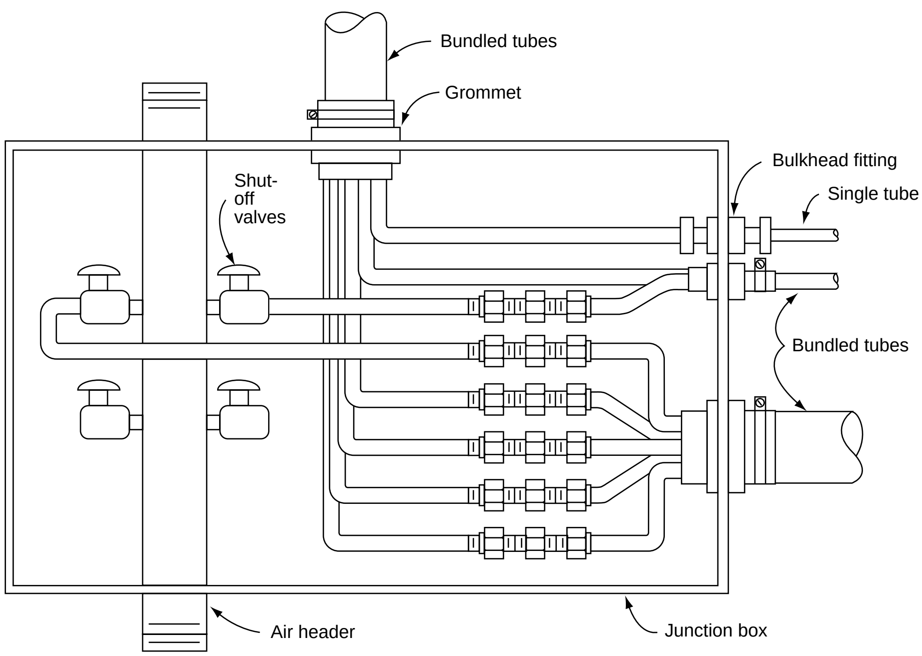

Figure 21—Methods of Supporting Single Tubes and Tubing Bundles at the Processing Unit




Detail A (see Note 1)




Detail B (see Note 2)




Detail C (see Note 3)

Notes:
1. Detail A: Junction box utilized for breakout from a large continuous bundle to a small bundle and single tubes.

2. Detail B: Junction box used to join several small tubing bundles to one large tubing bundle utilizing a terminal plate and bulkhead fitting.

3. Detail C: Junction box combining an air header and connections between a large tubing bundle and a variety of takeoffs.

Figure 22—Enclosed Junction Box Configurations

bundle are continuously numbered along their entire length to permit positive identification of each tube.

## 22 Installation Of Pneumatic Systems

### 22.1 GENERAL

This section presents common practices for installation of pneumatic systems. Installations are discussed according to distinct plant functions:

a. *Field-routed* designates tubing that is run from each field-mounted instrument to a common junction box.
b. *Junction Box* designates the location where field-routed tubes and tubing bundles meet.
c. *Transmission* designates common routing through the plant from junction box to the control room.

### 22.2 FIELD-ROUTED TUBING INSTALLATIONS

Various methods of installing tubing from a field-mounted instrument to a junction box have been used. Single or bundled tubes may be run between a field-mounted device and the junction box, but support and protection against mechanical damage or overheating must be considered. Figure 21 indicates various methods of supporting single tubes and tubing bundles.

### 22.3 JUNCTION BOX

The junction box is the location where single tubes and small tube bundles from the field devices are joined to one or more larger tube bundles for common routing to the control room. Figure 22 shows various junction box details. A junction box that will allow adequate working space should always be selected. Terminations may be easily made with standard bulkhead tube fittings.

### 22.4 TRANSMISSION TUBING INSTALLATIONS

Bundled tubing may be run overhead or underground. When installing bundled tubing overhead, one should support the tubing in cable trays or with steel messenger cable. Bundles may also be attached to building walls or structural members with pipe clamps or special fasteners. When bundles are installed underground, they may be in sand-filled trenches or in conduit embedded in concrete. See also Section 14.3.

#### 22.4.1 Routing

Routing must be planned to protect the transmission tubing from physical damage and fire. Overhead systems are commonly mounted in trays on process piping supports. Underground systems should avoid areas of potential soil movement and ground water.

#### 22.4.2 Spare Tubes And Rack Space

In bundled tube systems, one should initially provide at least 20 percent spare tubes per bundle. Spare rack or tray space shall be provided in all systems. Space for a 25 percent increase is recommended.

## 23 Cleaning And Pressure Testing Of Pneumatic Tubing

### 23.1 GENERAL

An important requirement in the installation of any pneumatic transmission system is thorough cleaning and pressure testing of each circuit.

### 23.2 CLEANING

Cleaning is accomplished by blowing each transmission tube with clean, dry, oil free air to remove all foreign matter.

### 23.3 PRESSURE AND LEAK TESTING

Pressure testing may be conducted in accordance with ISA-Recommended Practice ISA-RP7.1, *Pneumatic Control Circuit Pressure*.

### 23.4 PROCESSING PLANT INSTALLATIONS

The recommended arrangement for field tubing consists of tubes run from field-mounted devices to a collection point, which is normally a junction box. This installation concept and details of the piping are shown in Figure 16. In Figure 21, the various methods of supporting the tubing are identified as Types 1 through 8. When tubing fittings are installed, a single plastic-coated metallic tube requires special attention to preserve its corrosion resistance. The attachment of fittings requires removal of the plastic covering and exposure of the bare metallic tube. To prevent corrosion of the exposed portion of the tube, and perhaps the fittings as well, a protective covering should immediately be applied. The covering can be either a corrosion-resistant compound or a self-sealing plastic tape.

When bundled metallic tubing (two or more tubes) is connected to a field-mounted device, more bare tubing is exposed to the atmosphere than when single plastic-sheathed tubing is connected. It is recommended that the bare tubes be covered immediately with self-sealing plastic tape rather than being sprayed or painted.

### 23.5 COLLECTION POINTS

When bundled tubes are used as recommended, the collection point is the location where single tubes and small tube bundles from the processing unit are joined to one or more larger tube bundles for common routing to the control room. These collection points are also referred to as junction boxes.

Since atmospheric corrosion is generally a problem in refineries, a junction box is recommended to protect the collection point. Typical junction boxes are shown in Figure 22.

### 23.5.1 Junction Boxes

The concept of junction boxes for pneumatic transmission is similar to that for electronic transmission. In addition to providing a protective, neat installation, junction boxes can also accomplish the following:

a. Provide flash fire protection of individual plastic tubes at a breakout from a tubing bundle that has an overall protective covering. The box should have a fire-protective covering.
b. Provide corrosion protection at a collection of transition point where the protective sheath on metallic tubing must be stripped back to make a junction.
c. Prolong the legibility of information on tubing tags.
d. Provide protection of the terminated spare tubes in a bundle.

Guidelines for determining materials of construction, design, and mounting of junction boxes are given in Sections 18.1 through 18.5. Since the outside diameter, bend radius, and tool clearance space requirements for tubing connections are greater than those for electrical connections, the area required for a tubing connection is considerably greater than that required for an electrical connection. A junction box that will allow adequate working space should always be selected.

### 23.5.2 General Information On Bundled Tubing Connections At Collection Points

Because unprotected tubing junctions are so similar to junctions housed in a junction box, it is sufficient to discuss only installation of connections in an enclosed junction box.

### 23.5.3 Connections For Metallic Tube Bundles

Figure 22 illustrates various junction box configurations for use with metallic tube bundles. The bundle enters the junction box through a weather-tight grommet or fitting of proper size. A length of bundle at least 1½ times the length of the box should be inserted to ensure that the bundle will reach any location within the box. Where a corrosive atmosphere is expected, metallic fittings and bare sections of tubing can be protected either by a corrosion-resistant covering or by purging the box with air.

### 23.5.4 Connections For Plastic Tube Bundles

The installation of connections for bundled plastic tubing is very similar to that of connections for bundled metallic tubing.

All of the concerns described in 21.3.3 for connecting metallic tube bundles should be followed, and the following additional considerations should be taken into account:

a. Plastic tube bundles undergo more thermal expansion than do metallic bundles, so more slack should be allowed between the junction box grommet and the first bundle clamp.
b. Extreme care must be taken when the outer protective sheath is removed so that no nicks or cuts are made on any of the enclosed tubes. Such nicks and cuts are points of potential failure.

## 23.6 TRANSMISSION TUBING

### 23.6.1 General

Tubing in transmission areas, from collection points at the processing unit to the central control room, may be located overhead or underground.

Tray designs can differ; they may be trough or ladder types. Bundled tubing may be run overhead or underground. When run overhead, the tubing should generally be supported by trays. Messenger cable or clamps (brackets) may also be used. When run underground, the tubing may be in sand-filled trenches or in conduit embedded in concrete (see Section 14.3).

### 23.6.2 Routing

Routing must be planned to protect the transmission tubing from physical damage and fire. The shortest route may not be best because it may have potential danger spots. Where a complete plant shutdown must be avoided and hazards cannot be bypassed, it is advisable to employ more than one common junction box and route to the control room.

a. Overhead systems (trays) are commonly mounted on existing structures, such as process piping supports. The safe portions of the pipe rack can be used, although areas directly over pumps, compressors, and exchangers and under air-cooler exchangers should be avoided. The chosen route should minimize danger from falling objects, debris, welding sparks, moving cranes, and other sources of potential mechanical damage.
b. Messenger-cable installations should also avoid high-temperature areas. Lines should not run over air coolers or heaters or locations where discharge fluids from a relief valve or other exhaust gases could impinge on the lines. A messenger cable should be installed so that it is clear of trees and structures, and should be properly protected to prevent wear or damage from the effects of wind.
c. Underground routing should be planned to protect tubing from damage from soil movement and hydrocarbons or corrosive liquids. The routing should also be planned to ensure that there is no danger from fire where the bundle emerges from underground. Good layout drawings of underground installations are required before excavation at the plant site. These installations should be made simultaneously with the other subsurface work. Routing should result in a minimum number of bends. Planning of the route will permit an accurate estimate of the amount of tubing required. This planning is especially important when bundled tubing is to be used, for the following reasons:
   1. The bundled length must be ordered to size initially, so a precise measurement of length is required.

2. Tubes in the bundle must be permanently identified -
3. Spare tubes must be determined and installed initially. It is advisable to provide at least 10 percent spares, or not less than two tubes per bundle.

### 23.6.3 Tray Installations

Trays may be used advantageously when a large number of single tubes or bundled cables are run.

Installations are similar to elecrical wiring (see Section 12). The only difference is that there is no concern over heat dissipation.

Spare space is not normally a large consideration when running bundled tubing, since spare tubes are provided in each bundle. It is, however, an economically sound practice to allow space for two or three future tube bundles.

Some users prefer vertical trays to horizontal trays. The primary advantage of vertical trays is that they require much less pipe rack space. Other advantages include the following:

a. The upper surface is available for mounting an additional tray.
b. The support design is simpler because of increased rigidity.
c. Peaked tray covers minimize problems from use as temporary shelves, from falling objects, and from accumulation of debris.

The assembly and support of vertical trays use the same items as are used for horizontal trays. However, if vertical trays are used, more labor is required for installation of tubing than is required for installation of tubing in horizontal trays.

The selection of tray materials depends primarily on environmental considerations (see 23.4 Messenger-Cable Installations).

In applications where adequate structures, such as pipe racks or buildings, are not available for supporting trays or where long spans must be bridged for a limited number of tubes, bundles may be supported by messenger cable.

Messenger cable is a high-strength, stranded serial cable supported at intervals by poles, posts, or other structures. The messenger cable in turn provides the necessary support for the tubing bundle. Messenger-cable installations were originally developed for overhead support of multiconductor electrical cables. Tubing bundles externally resemble multiconductor cables, so the same installation concepts and hardware are used (see Section 14).

Some manufacturers of bundled tubing can provide an integral messenger-cable design, with 4, 7, 12, or 19 plastic tubes of ¼-inch (6-millimeter) OD and 0.040-inch (1-millimeter) wall thickness. These manufacturers can also suggest sources of mounting fittings and recommended methods of installation.

### 23.6.4 Underground Installations

The most widely used underground construction is bundled tubing pulled in galvanized steel conduit banks with a protective, red dyed identifying concrete cover slab or envelope.

Tube bundles can also be installed in reinforced cement pipe.

## APPENDIX A—ABBREVIATIONS USED IN FIGURES

AC = alternating current
AWG = American Wire Gauge
CCR = central control room
DC = direct current
DES = digital electronic system
FE = flow element
FO = flow orifice
FT & FZP = part of instrument loop number
G = ground
H = hot
I.D. = inside diameter
IPS = iron pipe size
Jct. = junction
JIC = power indicating controller
JT = power transmitter
L = power wiring phases
LAH = level alarm high
LG = level gauge
LSH = level switch high
Max. = maximum
MR = moisture recorder
N = neutral
N.C. = normally closed
N.O. = normally open
NPS = nominal pipe size
O.D. = outside diameter
PAL = pressure alarm low
PDAH = pressure difference alarm high
PI = pressure indicator
PIC = pressure indicating controller
PSL = pressure switch low
PSV = pressure safety valve
PV = pressure valve
T = trap
TAH = temperature alarm high
TI = temperature indicator
TS = terminal strip
X = transformer phases

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