FM 5-424
MCRP 3-17.7K

Theater of Operations Electrical Systems

U S ARMY ELECTRICIAN

ELECTRIFYING THE FORCE

Headquarters, Department of the Army

Distribution Restriction: Approved for public release; distribution is unlimited.

*FM 5-424

Field Manual
No. 5-424

Headquarters
Department of the Army
Washington, DC, 25 June 1997

Theater of Operations Electrical Systems

Table of Contents

*This publication supersedes TM 5-760, 23 August 1968, and FM 20-31, 9 October 1987.

List of Illustrations

Tables

Figures

Preface

Field Manual (FM) 5-424 is intended for use as a training guide and reference text for engineer personnel who are responsible for planning and executing theater of operations (TO) construction. The five parts of this manual provide practical information for military personnel in the design, layout, installation, and maintenance of exterior and interior electrical wiring and power-generation systems. Figures and tables dealing with electrical parts and equipment are contained in Appendix A; figures and tables dealing with electrical data are contained in Appendix B.

Technical Manuals (TMs) 5-301 (1-4 series), 5-302 (1-5 series), and 5-303 present the Engineer Functional Components System, which is based on the wiring techniques described in this manual. Future revision of the Engineer Functional Components System will change the wiring systems that are currently used to more modern methods of cable and conduit wiring.

The proponent of this publication is Headquarters (HQ), United States Army Engineer School (USAES). Send comments and recommendations on Department of the Army (DA) Form 2028 (Recommended Changes to Publications and Blank Forms) directly to Commandant, USAES, ATTN: ATSE-TD-D, Fort Leonard Wood, Missouri 65473-6650.

Unless this publication states otherwise, masculine nouns and pronouns do not refer exclusively to men.

Acknowledgement

This publication contains copyrighted material that is used with permission from *Basic Home Wiring*, copyright © 1987, Sunset Publishing Corporation, Menlo Park, California 94025.

Part One. Basic Electrical Techniques

CHAPTER 1

Fundamentals

This manual emphasizes the constructional aspects of electric wiring. The term *phase* is used when referring to the angular displacement between two or more like quantities, either alternating electromotive force (EMF) or alternating current (AC). It is also used for distinguishing the different types of AC generators. For example, a machine designed to generate a single EMF wave is called a *single-phase alternator*, and one designed to generate two or more EMF waves is called a *polyphase alternator*.

USAGE

Power generators produce single- or three-phase voltages that can be used for electrical power systems at generated voltages or through transformer systems. Single-phase generators are normally used only for small lighting and single-phase motor loads. If the generated voltage is 120 volts, a two-wire system is used *(see Table B-1[A], page B-1)*. In this situation, one conductor is grounded and the other is ungrounded, or hot. The generated single-phase voltage can be 240 volts. This voltage is normally used for larger single-phase motors. To provide power to lighting loads, the 240-volt phase is center-tapped to provide a three-wire, single-phase system *(see Table B-1[B])*. The center tap is the grounded neutral conductor. The voltage is 120 volts from this grounded conductor to either of the two ungrounded conductors. This is half of the total phase value. The voltage between the two ungrounded conductors is 240 volts. This system provides power for both lighting and single-phase, 240-volt motors.

The most common electrical system is the three-phase system. The generated EMFs are 120 degrees apart in phase. As shown in *Table B-1 (C, D, E)*, three-phase systems may be carried by three or four wires. If connected in a delta (Δ), the common phase voltage is 240 volts. Some systems generate 480 or 600 volts. If the delta has a grounded center-tap neutral, then a voltage equal to half the phase voltage is available. If the phases are Y-connected, then the phase voltage is equal to 1.73 times the phase-to-neutral voltage. The most common electrical system found in the military is the three-phase, four-wire, 208/120-volt system.

Single-phase, three-wire systems and three-phase, four-wire systems provide voltages for both lighting and power loads. If the load between each of the three phases or between the two ungrounded conductors and their grounded center-tap neutral are equal, a balanced circuit exists. When this occurs, no current is flowing in the neutral conductor. Because of this, two ungrounded conductors and one grounded neutral may be used to feed two circuits. Thus, three conductors may be used where four are normally required.

Electric lamps for indoor lighting in the United States (US) generally operate at 100 to 120 volts from constant-potential circuits. Two- and three-wire distribution systems, either direct current (DC) or single-phase AC, are widely used for lighting installations.

These systems of distribution are capable of handling both lamp and motor loads connected in parallel between the constant-potential lines. The three-wire system provides twice the potential difference between the outside wires as it does between either of the outside wires and the central or neutral wire. This system makes it possible to operate large motors at 240 volts, while lamps and smaller motors operate at 120 volts. When the load is unbalanced, a current in the neutral wire corresponds to the difference in current taken by the two sides. A balance of load is sought in laying out the wiring for lighting installations.

DRAWING SYMBOLS AND READING BLUEPRINTS

An electrician must be able to interpret simple blueprints, because construction orders are ordinarily in that form. He must be able to make simple engineering sketches that describe work for which he receives only verbal orders. TM 5-704 contains detailed information about engineering drawings.

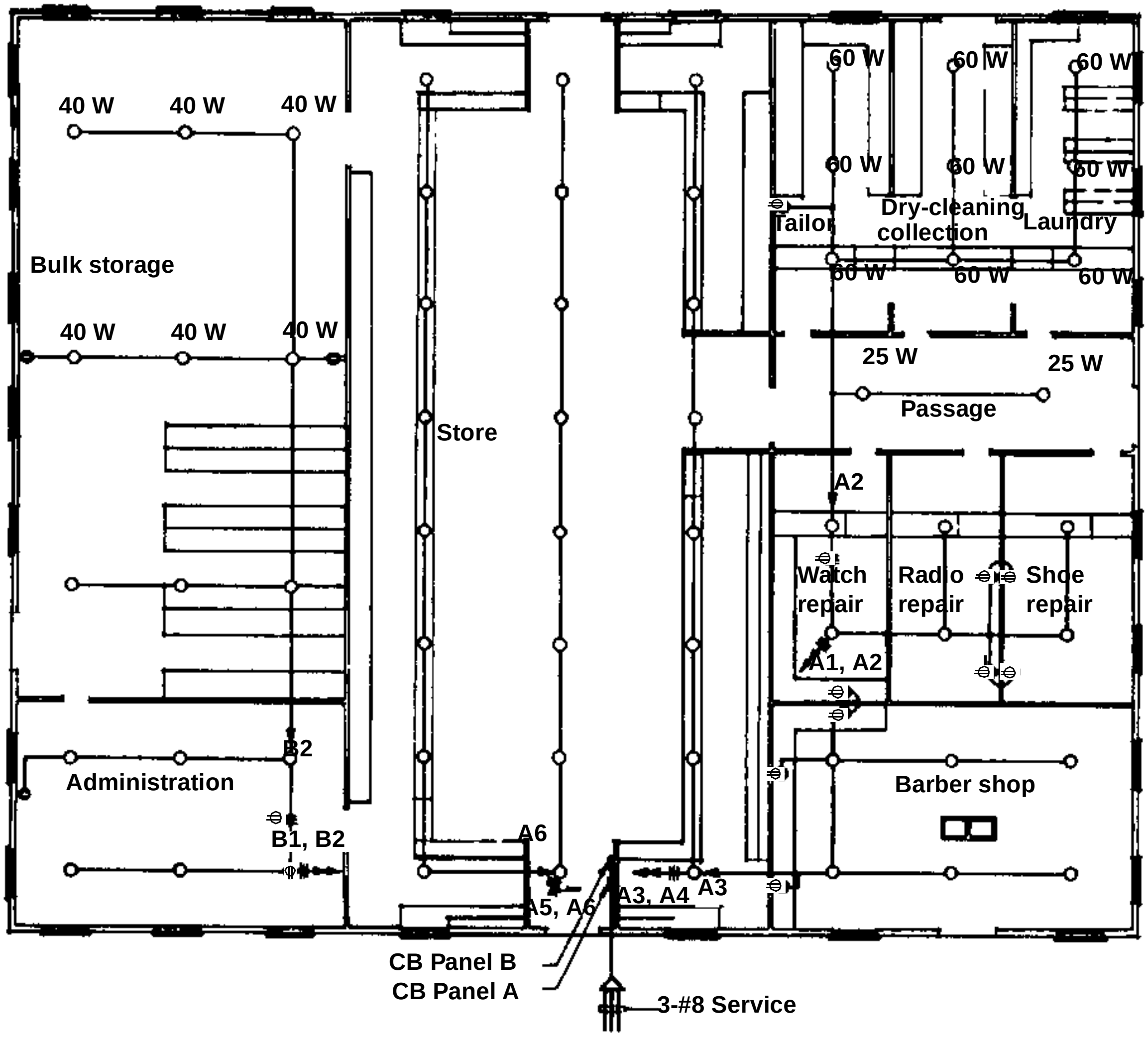
SYMBOLS

The more common symbols and line conventions used in wiring plans are shown in *Figures A-1 through A-6, pages A-1 through A-3.* These symbols enable the electrician to determine the precise location of electrical equipment in a building by studying the drawing.

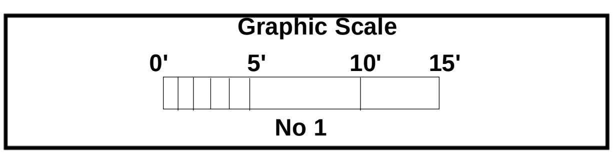
SCHEMATIC WIRING DIAGRAMS

Electrical plans show the items to be installed, their approximate location, and the circuits to which they are to be connected. A typical electrical plan for a post exchange is shown in *Figure 1-1*. The plan shows that the incoming service consists of three number (No) 8 wires and that two circuit-breaker panels are to be installed. Starting at the upper left, the plan shows that nine ceiling light outlets and two duplex wall outlets are to be installed in the bulk-storage area. The arrow designated B2 indicates that these outlets are to be connected to circuit 2 of circuit-breaker panel B. Note that three wires are indicated from this point to the double home-run arrows designated B1, B2. These wires are the hot wire from the bulk-storage area to circuit 2 of panel B, the hot wire from the administration area to circuit 1 of panel B, and a common neutral. The two hot conductors must be connected to different phases at the panel, thus allowing a cancellation of current in the neutral when both circuits are fully loaded. From the double arrowhead, these wires are run to the circuit-breaker panel without additional connections.

The wiring diagram shown in *Figure 1-1* is the type used most frequently for construction drawings. Single lines indicate the location of wires connecting fixtures and equipment. Two conductors are indicated in a schematic diagram by a single line. If more than two wires are together, short parallel lines through the line symbols indicate the number of wires represented by the line. A dot placed at the point of intersection indicates connecting wires. No dot is used where wires cross without connecting.



ELECTRICAL PLAN
Scale No 1



Electrical Notes	
Connected Load	
Lighting	5.15 kW
Recp est	1.2 kW
Total	6.35 kW
1. Unless otherwise noted on plan, all lamps to be 100 W. 2. All 40-, 60-, and 100-W lamps to have 8″ conical shades.	

Figure 1-1. Typical wiring diagram

You may encounter drawings in which the lines indicating the wiring have been omitted. This type of drawing shows only fixture and equipment symbols, and the electrician must determine the location of the actual wiring. Electrical drawings do not show any actual dimensions or dimension lines. Location dimensions and spacing requirements are given in the form of notes or follow the installation standards described in Chapter 3.

DRAWING NOTES

A list of drawing notes is ordinarily provided on a schematic wiring diagram to designate special wiring requirements and to indicate building conditions that alter standard installation methods.

COLOR CODING

Standard color coding requires that a grounded or neutral conductor be identified by an outer color of white or neutral gray for No 6 wire or smaller. Larger conductors can be identified either by an outer identification of white or neutral gray or by white markings at the terminals. The ungrounded conductors of a circuit should be identified with insulation colored black, red, and blue and used in that order in two-, three-, or four-wire circuits, respectively. All circuit conductors of the same color must be connected to the same hot feeder conductor throughout the installation. A grounding conductor, used solely for grounding purposes, should be bare or have a green covering.

SPLICES

A spliced wire must be as good a conductor as a continuous conductor. Splices should be avoided whenever possible, but they are permitted anywhere if they are located inside an electrical box. The best wiring practice (including open wiring systems) is to run continuous wires from the service box to the outlets.

SOLDERLESS

Connectors *(Figure 1-2)* are sometimes used in place of splices because they are easier to install. Since heavy wires are difficult to splice and solder properly, split-bolt connectors are commonly used for wire joints. Solderless connectors, popularly called *wire nuts*, are used for connecting small-gauge and fixture wires. One design consists of a funnel-shaped, metal spring insert that is molded into a plastic shell; the other type has a removable insert that contains a setscrew to clamp the wires. In either design, the plastic shell is screwed onto the insert to cover the joint.

Follow the steps below to connect a wire nut:

Step 1. Strip off about 1 inch of insulation from the ends of the wires that you are going to join. Twist the stripped ends clockwise at least one and one-half turns.

Step 2. Snip 3/8 to 1/2 inch off the twisted wires so that the ends are even.

Step 3. Screw the wire nut on clockwise.

DANGER

Under no conditions should splices be pulled through conduit. Splices must be placed in appropriate electrical boxes so that the hot wire will not come into contact with the grounding system.

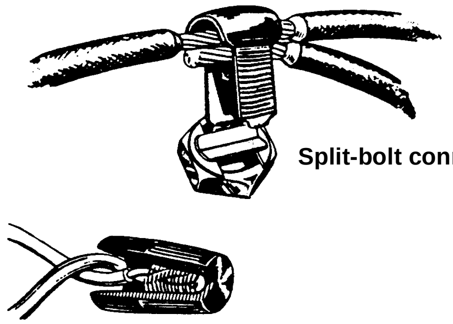


Figure 1-2. Solderless connectors

SOLDERED

When a solderless connector is not used, the splice must be soldered before it is considered to be as good as the original conductor. The primary requirements for obtaining a good solder joint are a clean soldering iron, a clean joint, and a nonacid flux. These requirements can be satisfied by using pure rosin on the joint or by using a rosin-core solder. To ensure a good solder joint, apply the electric-heated or copper soldering iron to the joint until the joint melts the solder by its own heat.

TAPED

Use plastic tape to insulate splices for temporary or expedient wiring. On a two-conductor cable, separate the two legs. Secure the tape on one leg, tape the first leg, close the legs together, and tape the wire splice past the end. Adequately cover all bare copper. Apply three layers for voltages up to 600 volts. Half lap the tape (overlap by half the width of the tape) for padded mechanical protection.

INSULATION AND WIRE CONNECTIONS

When attaching a wire to a switch or an electrical device or when splicing a wire to another wire, remove the wire insulation to bare the copper conductor. Make the cut at an angle to the conductor to avoid nicking and weakening the wire. After removing the protective insulation, scrape or thoroughly sand the conductor to remove all traces of insulation and oxide from the wire.

To attach the trimmed wire to the terminal, always insert the wire loop under the terminal screw *(Figure 1-3, page 1-6)*, so that tightening the screw tends to close the loop. When correctly inserted, the loop brings the wire insulation ends close to the terminal.

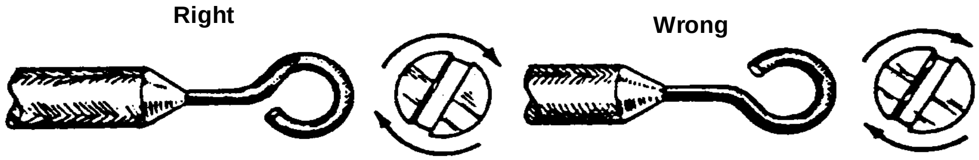


Figure 1-3. Wire attachment to terminals

JOB SEQUENCE

SCOPE

The installation of interior wiring is generally divided into two major divisions called *roughing-in* and *finishing*. Roughing-in is the installation of outlet boxes, cable wire, and conduit. Finishing includes the installation of switches, receptacles, covers, and fixtures and the completion of the service. Other trades use the interval between these two work periods for plastering, enclosing walls, finishing walls, and trimming.

ROUGHING-IN

Step 1. Mounting outlet boxes. This step can be expedited if the locations of all boxes are first marked on the studs and joists of the building. Some boxes have special brackets for mounting on the building members. All boxes that are to be concealed must be installed so that the forward edge or plaster ring of the boxes will be flush with the finished walls.

Step 2. Circuiting and installing wire, cable, or conduit. This involves drilling and cutting the building members to allow for the passage of the conductor or its protective covering. For surface-type wiring, this includes installing conduit, cable, and surface-type boxes and covers on a finished wall. The production-line method of first drilling the holes for all *runs* (installations between boxes) at one time and then installing all of the wire, cable, or conduit will expedite the job.

Step 3. Pulling wires in conduit between boxes. This step, which can be included as the first step in the finishing phase, requires care in handling of the wires to prevent marring the finished wall or floor surfaces.

FINISHING

Step 1. Splicing the joints in the outlet and junction boxes and connecting the grounding wires. This step ensures the proper installation of leads to the terminals of switches, ceiling and wall outlets, and fixtures.

Step 2. Attaching the devices and their cover plates to the boxes. This step ensures that the service-entrance cable and fusing or circuit-breaker panels are connected and the circuits are fused. The fixtures are generally supported by the use of special mounting brackets called *fixture studs* or *hickeys*.

Step 3. Testing for proper circuiting. The final step in the wiring of any building requires the testing of all outlets by inserting a test prod or test lamp, operating all switches in the building, and loading all circuits to ensure that the proper circuiting has been installed.

CHAPTER 2

Tools and Equipment

The electrical apparatus and materials that an electrician is required to install and maintain are different from other building materials. Their installation and maintenance require the use of special hand-tools.

Section I. Interior Wiring

This section describes the tools normally used by an Army electrician in interior wiring. Appendix A shows some of these tools. For additional information on proper tool usage, see TM 9-243.

PLIERS

Pliers have either insulated or uninsulated handles. Long-nosed pliers are used for close work in panels or boxes. Side-cutter pliers are used to cut wire and cable to size. Slip-joint pliers are used to tighten locknuts, small nuts on devices, and conduit bushings and fittings. Round-nosed pliers are used for making screw loops and working in limited-space areas.

CAUTION

Although insulated-handle pliers are always used when working on or near hot wires, they must not be considered sufficient protection alone. Other precautions must be taken.

FUSE PULLER

The fuse puller shown in *Figure A-7(1), page A-4*, is designed to eliminate the danger of pulling and replacing cartridge fuses by hand. It is also used for bending fuse clips, adjusting loose cutout clips, and handling live electrical parts.

The second type of fuse puller (*Figure A-7[2]*) has the same general configuration but is made of molded plastic. Encased in the handle is an electrical circuit that is similar to a voltmeter, except that the indicating device is a neon-glow tube. Test probes are attached to the handle and may be used to determine if voltage is present in a circuit.

SCREWDRIVERS

Screwdrivers come in many sizes and tip shapes. Those used by electricians should have insulated handles. Electricians generally use screwdrivers to attach electrical devices to boxes and attach wires to terminals. One variation of the screwdriver is the screwdriver bit, which is held in a brace and used for heavy-duty work. For safe and efficient operation, select a screwdriver that matches the screw slot and keep the tips square and properly tapered.

WRENCHES

Adjustable open-end wrenches (commonly called *crescent wrenches*) and open-end, closed-end, and socket wrenches are used on hexagonal and square fittings such as machine bolts, hexagon nuts, or conduit unions. Pipe wrenches are used for pipe and conduit work and should not be used where crescent, open-end, closed-end, or socket wrenches can be used. Pipe-wrench construction will not permit application of heavy pressure on square or hexagonal material, and continued misuse of a pipe wrench will deform the teeth on the jaw faces and mar the surface of the material.

SOLDERING EQUIPMENT

Electricians use a standard soldering kit consisting of—

- Soldering irons (electric/nonelectric).
- A blowtorch (for heating a nonelectric soldering wire and pipe or wire joints). An alcohol or propane torch can be used in place of a blowtorch.
- A spool or solid tin-lead wire solder or flux-core solder. Acid-core solder should never be used in electrical wiring.
- Soldering paste.

DRILLING EQUIPMENT

Drilling equipment is required to drill holes in building structures for the passage of conduit or wire in new or modified construction. High-speed drills are used to drill holes in sheet-metal cabinets and boxes. Carbide drills are used for tile or concrete work. Electric power drills aid in this phase of an electrician's work.

Standard drilling equipment consists of—

- A brace.
- A joist-drilling fixture.
- An extension bit for drilling into and through deep cavities.
- An adjustable wood bit.
- A standard wood bit.
- A ship auger, which is used with an electric drill.

WOODWORKING TOOLS

Electricians use wood chisels and cross-cut or keyhole saws to remove wooden structural members that are obstructing a wire or conduit run and to notch studs and joists for conduit, cable, or box-mounting brackets. They are also used to construct wood-panel mounting brackets. The keyhole saw may be used to cut openings in walls of existing buildings where boxes need to be added.

METALWORKING TOOLS

Electricians use cold chisels and center punches, as well as several other types of metalworking tools, when working on steel panels. The knockout punch is used to make or enlarge a hole in a steel cabinet or outlet box. The hacksaw is usually used for cutting conduit, cable, or wire that is too large for wire cutters. A light, steady stroke of about

40 to 50 times a minute is best. Always insert a new blade with the teeth pointing away from the handle and tighten the tension wing nut until the blade is rigid. Hacksaw blades have 14, 18, 24, or 32 teeth per inch. The best blade for general use is one having 18 teeth per inch. A blade with 32 teeth per inch is best for cutting thin material. The mill file is used to file the sharp ends of cutoffs as a precaution against short circuits.

MASONRY DRILLS

An electrician should have several sizes of masonry drills in his tool kit. These drills, which are normally carbide-tipped, are used for drilling holes in brick or concrete walls to anchor apparatus with expansion screws or allow the passage of conduit or cable.

CONDUIT THREADERS, REAMERS, AND CUTTERS

Rigid conduit is normally threaded for installation. The tapered pipe reamer is used to ream the inside edge of the conduit as a precaution against wire damage. The thin-wall conduit cutter has a tapered-blade attachment for reaming the conduit ends.

INSULATION-STRIPPING TOOLS

Knives and patented wire strippers are used to bare the wire of insulation before making connections. Scissors are used to cut the insulation and the tape. The multipurpose tool is designed to cut and skin wires, attach terminals, gauge wire, and cut small bolts. The cable cutter may be used instead of a hacksaw to remove the armor from electrical conductors at the box entry or when cutting cable to length.

HAMMERS

Hammers are used with other tools, such as chisels, or for nailing equipment to building supports. Electricians can use a carpenter's claw hammer and a machinist's ball-peen hammer advantageously.

TAPE

Various types of tape are used to replace insulation and wire coverings.

FRICTION TAPE

Friction tape is made of cotton and impregnated with an insulating adhesive compound. It provides weather resistance and limited mechanical protection to a splice that is already insulated.

RUBBER OR VARNISHED CAMBRIC TAPE

Rubber or varnished cambric tape may be used as an insulator when replacing wire covering.

PLASTIC ELECTRICAL TAPE

Plastic electrical tape has adhesive on one face. It has replaced friction and rubber tape in the field for 120- to 600-volt circuits. Because it serves a dual purpose in taping joints, it is preferred over the former methods.

FISH TAPE

Fish tape is used primarily to pull wire through conduit. Many pulls are quite difficult and require a fish-tape *grip* or *pull* to obtain adequate force on the wire. Fish tape is made of tempered spring steel, is about 1/4-inch wide, and is available in different lengths to suit requirements. It is stiff enough to preclude bending under normal operation but can easily be pushed or pulled around bends or conduit elbows.

DROP CHAIN

When pulling wire and cable in existing buildings, an electrician will normally employ a fish wire or a drop chain between studs. A drop chain consists of small chain links attached to a lead or iron weight. It is used only to feed through wall openings in a vertical plane.

RULER AND MEASURING TAPE

Each electrician should keep a folding rule and a steel tape on hand so he can cut conduit to the proper size and determine the quantity of material required for each job.

WIRE GRIP AND SPLICING CLAMP

A wire grip (*Figure A-8, page A-4*) is an invaluable aid for pulling wire through conduit and for pulling open-wire installations tight. It has been designed so that the harder the pull on the wire, the tighter the wire will be gripped. A splicing clamp *(Figure A-8*) is used to twist the wire pairs into a uniform, tight joint when making splices.

EXTENSION LIGHT

An extension light normally includes a long extension cord and is used by electricians when normal building lighting has not been installed or is not functioning.

THIN-WALL CONDUIT IMPINGER

When an electrician uses indenter-type couplings and connectors with thin-wall conduit, an impinger (*Figure A-9, page A-4*) must be used to permanently attach the fitting to the conduit. An impinger forms indentations in the fitting, pressing it into the outside wall of the conduit. The use of slip-on fittings and an impinger reduces the installation time required and thus reduces the cost of thin-wall conduit installations.

WIRE CODE MARKERS

Tape with identifying numbers of nomenclature is available to permanently identify wires and equipment. The markers are particularly valuable to identify wires in complicated wiring circuits, fuse circuit-breaker panels, or junction boxes.

METERS AND TEST LAMPS

TEST LAMPS

An indicating voltmeter or a test lamp is useful when determining the system voltage, locating the ground lead, and testing the circuit continuity through the power source. They both have a light that glows when voltage is present.

VOLT PROBE INDICATOR

A tester is used to test 120- to 600-volt AC circuits, as well as the polarity of DC circuits.

MULTIMETER

A modern method of measuring current flow in a circuit uses the clamp-on tester of a multimeter (*Figure A-10, page A-4*), which does not need to be hooked into the circuit. When measuring AC amperage, electricians clamp only one wire at a time. The multimeter is capable of measuring voltage, current, resistance, and continuity.

The basic unit of measurement for electric power is the *watt*. In the power ratings of electric devices used by domestic consumers of electricity, the term *watt* signifies that the apparatus will use electricity at the specified rate when energized at the normal line voltage. In AC circuits, power is the product of three quantities: the potential (volt), the current (amperage), and the power factor (percent).

Power is measured by a multimeter (*Figure 2-1*). This instrument is connected so that the current in the measured circuit flows through the stationary field coils in the multimeter and the voltage across the measured circuit is impressed upon the multimeter-armature circuit, which includes movable coils and a fixed resistor. The power factor is automatically included in the measurement because the torque developed in the multimeter is always proportional to the product of the instantaneous value of current and voltage. Consequently, the instrument gives a true indication of the power, or rate, at which energy is being used.

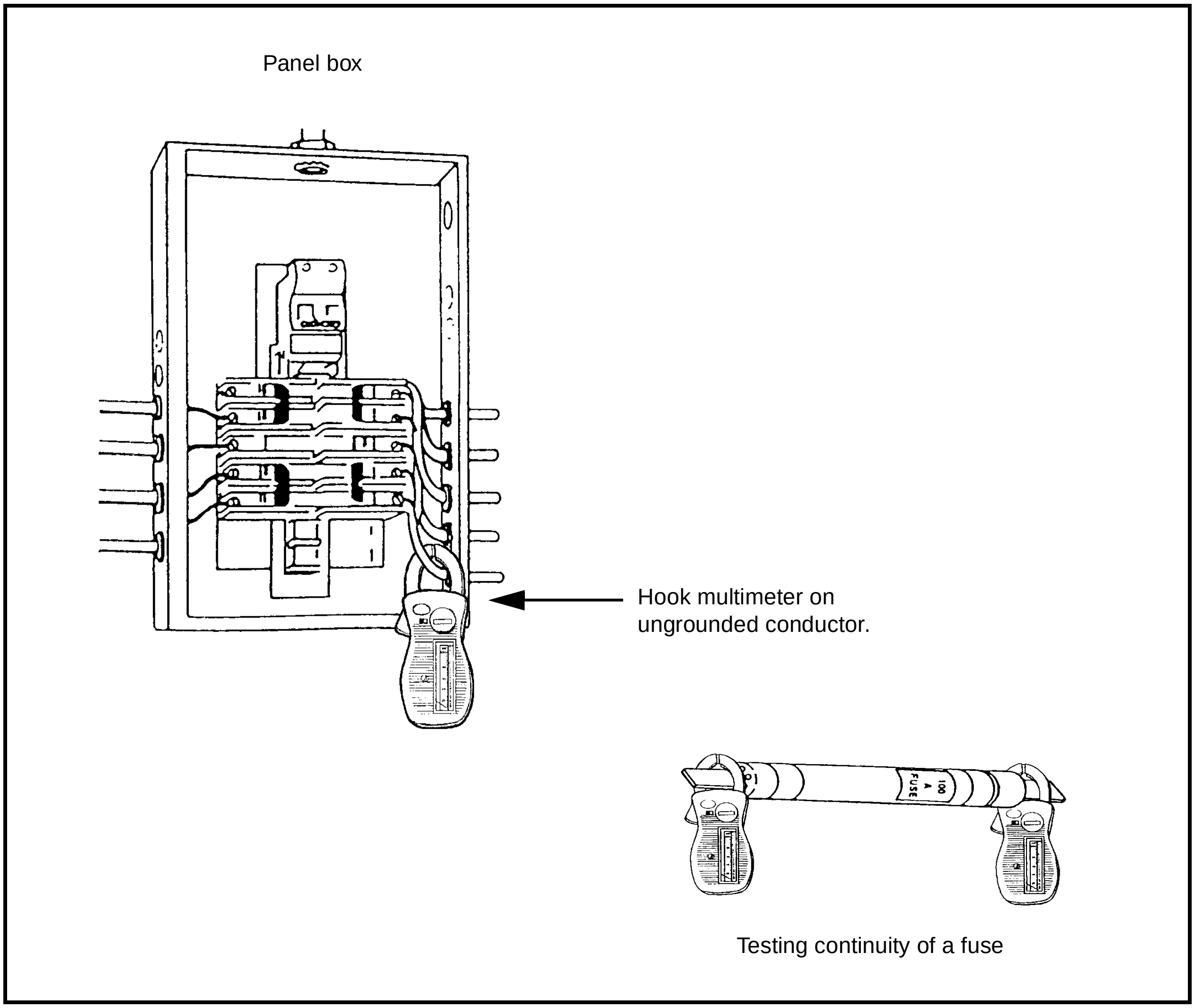


Figure 2-1. Multimeter connection

Section II. Wiring Materials

Many different wiring systems currently in use vary in complexity from the simple-to-install open wiring to the more complex conduit systems. These systems contain common components.

ELECTRICAL CONDUCTORS

SINGLE CONDUCTORS

A single conductor is an individual wire that is usually sheathed with insulating material, but a ground wire may be bare. American Wire Gauge (AWG) numbers assigned to electrical wires indicate the diameter of the metal conductor only; they do not include the insulation. Conductors are shielded from one another by material that does not carry current, color-coded thermoplastic. White or gray insulation indicates neutral wires, green indicates ground wires, and all other colors are used to identify hot wires.

Although copper is the best and most commonly used metal for conductors, aluminum and copper-clad aluminum are also used. Because aluminum is not as efficient a conductor as copper, aluminum or copper-clad aluminum wire must be larger than copper wire to conduct the same amount of electricity. To assure a good connection when using No 6 or larger aluminum conductors, electricians smear an oxide inhibitor on the end of the conductor first, then tighten the terminal. They go back the next day and tighten the terminal once again. Electrical codes take the guesswork out of conductor selection by prescribing wire use.

Wires or conductors are initially classified by the type of insulation applied and the wire gauge. The various types of insulation, in turn, are subdivided according to their maximum operating temperatures and the nature of use. *Table B-2, pages B-2 through B-4,* lists the common trade classification of wires and compares them as to type, temperature rating, and recommended use.

WIRE SIZES

Wire sizes are denoted by the use of the AWG standards. The largest gauge size is No 4/0. Wires larger than this are classified in size by their circular mil cross-sectional area. One circular mil is the area of a circle with a diameter of 1/1,000 inch. Thus, if a wire has a diameter of 0.1 inch or 100 mil, the cross-sectional area is 100 by 100, or 10,000 circular mils. The most common wire sizes used in interior wiring are 14, 12, and 10; and they are usually of solid construction. *Table B-23, page B-20,* lists some characteristics of specific wire sizes.

- The size of the wire decreases as the numbers become larger.
- The sizes normally used have even numbers, such as 14, 12, and 10.
- No 8 and 6 wires, which are furnished either solid or stranded, are normally used for heavy-power circuits or as service-entrance leads to buildings. Wire sizes larger than these are used for extremely heavy loads and for pole-line distribution. *Tables B-3 through B-6, pages B-5 through B-8,* show the allowable current-carrying capacity for copper and aluminum conductors. *Table B-7, page B-9,* shows the percent of reduction in current capacity if more than three conductors are in a cable or a raceway.

MULTICONDUCTOR CABLES

In many types of electrical wiring installation, the use of individual conductors spaced and supported side by side becomes an inefficient and hazardous practice. Multiconductor cables have been designed and manufactured for such installation. Multiconductor cables consist of the individual conductors as outlined above, arranged in groups of two or more. An additional insulating or protective shield is formed or wound around the group of conductors. The individual conductors are color-coded for proper identification. The description and use of each type are given below.

Armored Cable

Armored (Type BX) cable can be supplied either in two- or three-wire types and with or without a lead sheath. The wires in armored cable, matched with a bare bonding wire, are initially twisted together. This grouping, totaling two or three wires with the bonding wire, is then wrapped in coated paper and a formed self-locking steel armor. The cable without a lead sheath is widely used for interior wiring under dry conditions. The lead sheath is required for installation in wet locations and through masonry or concrete building partitions where added protection for the copper conductor wires is required. Metal-clad (Type MC) resembles armored cable and has a ground wire enclosed in the cable. It is used primarily in industrial wiring.

Nonmetallic-Sheathed Cable

Nonmetallic-sheathed cable is manufactured in two types—NM and NMC. Type NM consists of two or three thermoplastic-insulated wires, each covered with a jute-type filler material that acts as a protective insulation against mishandling. The cable is lightweight, simple to install, and comparatively inexpensive. It is used quite extensively in interior wiring but is **not** approved for use in damp locations.

Type NMC is a dual-purpose, plastic-sheathed cable with solid copper conductors and can be used outdoors or indoors. It needs no conduit, and its flat shape and gray or ivory color make it ideal for surface wiring. It resists moisture, acid, and corrosion and can be run through masonry, between studding, or in damp locations.

Plastic-Sheathed Cable

Type UF (underground feeder) is similar to Type NMC except that it has added water protection and is designed for direct ground contact.

Lead-Covered Cable

Lead-covered cable consists of two or more rubber-covered conductors surrounded by a lead sheathing that has been extruded around it to permit its installation in wet and underground locations. Lead-covered cable can also be immersed in water or installed in areas where the presence of liquid or gaseous vapors would attack the insulation on other types of cable.

Service-Entrance Cable

Service-entrance (Type SEC) cable normally has three wires, with two insulated and braided conductors laid parallel and wound with a bare conductor. Protection against damage for this assembly is obtained by encasing the wires in heavy tape or armor, which serves as an inner cushion, and covering the whole assembly with braid. Though the cable normally serves as a power carrier from the exterior service drop to the service equipment of a building, it may also be used in interior wiring circuits to supply power to electric ranges and water heaters at voltages not exceeding 150 volts to ground if the outer covering is armor. It may also be used as a feeder to other buildings on the same premises and under the same conditions, if the bare conductor is used as an equipment grounding conductor from a main distribution center located near the main service switch.

CORDS

Many items using electrical power are pendant, portable, or vibration type. In such cases, the use of flexible cords is authorized for power delivery. These cords can be grouped and designated as lamp, heater, or heavy-duty power cords. Lamp cords are supplied in many forms. The most common types are the single-paired, rubber-insulated, and twisted-paired cords. Flexible cord is used to connect appliances, lamps, and portable tools to outlets. It can never be used as a permanent extension of fixed wiring.

ELECTRICAL BOXES

Outlet boxes are simply connection points for joining wires or connecting to outside devices such as receptacles, switches, and fixtures. They bind the elements of a conduit or a cable system into a continuous grounded system. Electrical boxes provide a means of holding the conduit in position, space for mounting such devices as switches and receptacles, protection for the device, and space for making splices and connections. Regardless of general trade terminology, most boxes are used interchangeably. For example, with appropriate contents and covers, the same box could be used as an outlet box, a junction box, or a switch box.

DESIGN

The variety of sizes and shapes corresponds to variations in wiring methods, the type and number of devices attached to the box, and the number of wires entering it. One important factor is that boxes come in both metallic and nonmetallic versions. Outlet boxes are manufactured in sheet steel, porcelain, bakelite, or fiberglass and are round, square, octagonal, or rectangular. The fabricated steel box is available in a number of different designs. For example, some boxes are of the sectional or *gang* variety, while others have integral brackets for mounting on studs and joists. Moreover, some boxes have been designed to receive special cover plates so that switches, receptacles, or lighting fixtures can be installed easier. Other designs facilitate installation in plastered surfaces.

Each box has a certain volume in cubic inches that determines how many wires of a certain size may be brought into it. Regardless of the design or material, they all should have sufficient interior volume to allow for splicing conductors or making connections. For this reason, the allowable minimum depth of outlet boxes is limited to 1 1/2 inches in all cases except where building-supporting members would have to be cut. In this case, the minimum depth can be reduced to 1/2 inch.

SELECTION

The selection of boxes in an electrical system should be made according to *Tables B-9 and B-10, page B-13,* which list the maximum allowable conductor capacity for each type of box. In these tables, a conductor running through the box is counted along with each conductor terminating in the box. For example, one conductor running through a box and two terminating in the box would equal three conductors in the box. Consequently, any of the boxes listed would be satisfactory. The tables apply for boxes that do not contain receptacles, switches, or similar devices. Each of these items mounted in a box will reduce the maximum number of conductors allowable by one, as shown in the tables.

OUTLET BOXES FOR RIGID AND THIN-WALL CONDUIT AND ARMORED CABLE

Steel outlet boxes (*Figure A-11, page A-5*) are generally used with rigid and thin-wall conduit or armored cable. The steel boxes are either zinc- or enamel-coated; the zinc coating is preferred for conduit installation in wet locations. All steel boxes have *knockouts*. These knockouts are indentations in the side, top, or back of an outlet box, sized to fit the standard diameters of conduit fittings or cable connectors. They can usually be removed with a small cold chisel or punch to facilitate entry into the box of the conduit or cable. Boxes designed specifically for armored cable use also have integral screw clamps located in the space immediately inside the knockouts and thus eliminate the need for cable connectors. This reduces the cost and labor of installation. Box covers are normally required when it is necessary to reduce the box openings, provide mounting lugs for electrical devices, or cover the box when it is to be used as a junction. The antishort bushing is inserted between the wires and the armor to protect the wire from the sharp edges of the cut armor when it is cut with a hacksaw or cable cutter.

OUTLET BOXES FOR NONMETALLIC-SHEATHED CABLE AND SURFACE WIRING

Steel

Steel boxes are also used for nonmetallic cable and surface or open wiring. However, the methods of box entry are different from those for conduit and armored-cable wiring, because the electrical conductor wires are not protected by a hard surface. The connectors and interior box clamps used in nonmetallic and surface or open wiring are formed to provide a smooth surface for securing the cable rather than being the sharp-edged type of closure normally used.

Nonmetallic

Nonmetallic outlet boxes are made of plastic or fiberglass, and they are used with open and nonmetallic-sheathed wiring. Cable or wire entry is generally made by removing the knockouts of preformed, weakened blanks in the boxes.

Special

When adding an outlet or doing remodeling work, it is sometimes necessary to install an outlet box in a finished wall. Boxes with beveled corners and internal cable clamps simplify the procedure (*Figure A-12, page A-6).*

ATTACHMENT DEVICES FOR OUTLET BOXES

Outlet boxes that do not have brackets are supported by wooden cleats or bar hangers as shown in *Figure A-13, page A-7*.

Wooden Cleats

Wooden cleats are first cut to size and nailed between two wooden members. The boxes are nailed or screwed to these cleats through holes provided in their backplates.

Mounting Straps

If the outlet box is to be mounted between studs, mounting straps are necessary. The ready-made straps are handy and accommodate not only a single box but also a 2-, 3-, 4-, or 5-gang box.

Bar Hangers

Bar hangers are prefabricated to span the normal 16- and 24-inch joist and stud spacings and are obtainable for surface or recessed box installation. They are nailed to the joist or stud-exposed faces. The supports for recessed boxes are normally called *offset bar hangers*.

Patented Supports

When boxes have to be installed in walls that are already plastered, several patented supports can be used for mounting. These obviate the need for installing the boxes on wooden members and thus eliminate extensive chipping and replastering.

CABLE AND WIRE CONNECTORS

Safety codes and regulations require that conductors be spliced or joined with approved splicing devices (*Figure A-14, page A-8*) or be brazed, welded, or soldered with a fusible metal or alloy. Splices must be mechanically and electrically secure before they are soldered. Using soldering and splicing devices provides added protection. To assure a high-quality connection, electricians must select the proper size connector relative to the number and size of wires.

STRAPS AND STAPLES

POLICY

All conduits and cables must be attached to the structural members of a building in a manner that will preclude sagging. The cables must be supported at least every 4 1/2 feet for either a vertical or horizontal run and must have a support in the form of a strap or staple (*Figure A-15, page A-8*) within 12 inches of every outlet box. Conduit-support spacings vary with the size and rigidity of the conduit. See *Table B-11, page B-13,* for support of rigid nonmetallic conduit and *Table B-17, page B-17,* for support of rigid metal conduit.

CABLE STAPLES

Use cable staples for a very simple, effective method of supporting armored cables on wooden members.

INSULATED STAPLES

Bell or signal wires are normally installed in pairs in signal systems. The operating voltage and energy potential is so low in these installations (12 to 24 volts) that protective coverings such as conduit or loom are not required. To avoid any possibility of shorting in the circuit, they are normally supported on wood studs or joists by insulated staples.

STRAPS

Conduit and cable straps (*Figure A-15*) are supplied as either one-hole or two-hole supports and are formed to fit the contour of the specific material for which they are designed. The conduit and cable straps are attached to building materials by *anchors* designed to suit each type of supporting material. For example, a strap is attached to a wood stud or joist by nails or screws. Expanding anchors are used for box or strap attachment to cement or brick structures and also to plaster or plaster-substitute surfaces. Toggle and *molly* bolts are used where the surface wall is thin and has a concealed air space that will allow for the release of the toggle or expanding sleeve.

RECEPTACLES

APPLICABILITY

Portable appliances and devices are readily connected to an electrical supply circuit by means of an outlet called a *receptacle* (*Figure A-16, page A-9*). For interior wiring, these outlets are installed either as single or duplex receptacles. Safety standards require that all receptacles for 15- or 20-amp, 120-volt branch circuits (most of the circuits in homes) must be the grounding type. Receptacles previously installed, as well as their replacements in the same box, may be two-wire receptacles. All others must be the three-wire type. The third wire on the three-wire receptacle is used to provide a ground lead to the equipment that receives power from the receptacle. This guards against dangers from current leakage due to faulty insulation or exposed wiring and helps prevent accidental shock. To eliminate the possibility of plugging a 120-volt appliance into a 240-volt receptacle, higher-voltage circuits use special receptacles and matching attachment plugs. The receptacles are constructed to receive plug prongs either by a straight push action or by a twist-and-turn push action. Fixtures are similar to receptacles but are used to connect the electrical supply circuit directly to lamps inserted in their sockets.

CONDUIT AND CABLE

Like switches, all receptacles are rated for a specific amperage and voltage. Receptacles marked CO-ALR can be used with either copper or aluminum wire. Unmarked receptacles and those marked CU-AL may be used with copper wire only. The receptacles commonly used with conduit and cable installations are constructed with yokes to facilitate their installation in outlet boxes. In this case, they are attached to the boxes by metal screws through the yokes. Wire connections are made at the receptacle terminals by screws that are an integral part of the outlet. Receptacle covers made of brass, steel, or nonmetallic materials are then attached to box and receptacle installations to afford complete closure at the outlets.

SURFACE METAL RACEWAYS

Surface metal raceways *(Figure A-17, page A-10)* provide a quick, inexpensive electrical wiring installation method, since they are installed on the wall surface instead of inside the wall. Surface metal raceways are basically either one- or two-piece construction. Electricians working with the one-piece construction type install the metal raceway like conduit, then pull the wires to make the necessary electrical connections. When working with the two-piece construction type, electricians install the base piece along the wiring run, lay wiring in the base piece, and hold the wiring in place with clamps. After the wires are laid, they snap on the capping and the job is complete.

A multioutlet system, with ground inserts if desired, has outlets spaced every few inches so that several tools or pieces of equipment can be used simultaneously. An *over-floor* metal raceway system handles telephone and signal or power and light wiring where the circuits must be brought to locations in the middle of the floor area. These systems are all designed so that they can either be installed independently of other wiring systems or economically connected to existing systems.

PLUGS AND CORD CONNECTORS

PLUGS

Portable appliances and devices that are to be connected to receptacles have electrical cords that are equipped with plugs (*Figure A-18, page A-11*). These plugs, called *male plug*s, have prongs that mate with the slots in the outlet receptacles. A three-prong plug can fit into a two-prong receptacle by using an adapter. If the electrical conductors connected to the outlet have a ground system, the plug on the lead wire of the adapter is connected to the center screw holding the receptacle cover to the box. Many of these plugs are permanently molded to the attached cords. Other types of cord grips hold the cord firmly to the plug. Twist-lock plugs have patented prongs that catch and are firmly held to a mating receptacle when the plugs are inserted into the receptacle slots and twisted. When the plugs do not have cord grips, the cords should be tied with an Underwriter's knot (*Figure 2-2, page 2-12*) at the plug entry. This knot eliminates tension on the terminal connections when the cord is connected and disconnected from the outlet receptacle.

CORD CONNECTORS

In some operating conditions, a cord must be connected to a portable receptacle. This type of receptacle, called a *cord-connector body* or a *female plug*, is attached to the cord in a manner similar to the attachment of a male plug.

SWITCHES AND COVERS

DEFINITION

A switch is used to connect and disconnect an electrical circuit from the source of power. Switches may be either one-pole or two-pole for ordinary lighting or receptacle circuits (*Figure A-19, page A-11*). If they are of the

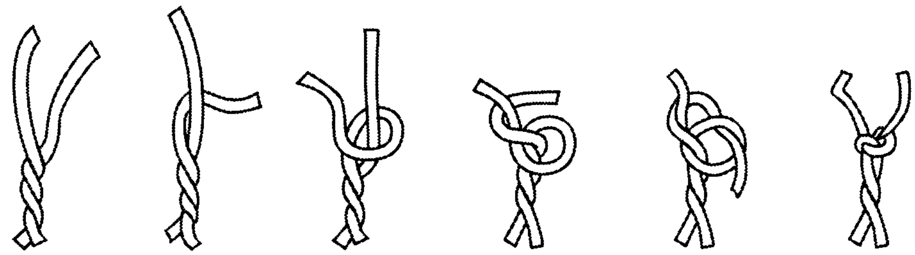


Figure 2-2. Underwriter's knot

one-pole type, they must be connected to break the hot or ungrounded conductor of the circuit. If they are of the two-pole type, the hot and ground connection can be connected to either pole on the line side of the switch. Switches are also available that can be operated in combinations of two, three, or more in one circuit. These switches are called *three-way* and *four-way switches* and are discussed fully in Chapter 3.

OPEN AND NONMETALLIC-SHEATHED WIRING

Switches used for exposed wiring and nonmetallic-sheathed cable wiring are usually of the tumbler type with the switch and cover in one piece. Other less-common ones are the rotary-snap and push-button types. These switches are generally nonmetallic in composition.

CONDUIT AND CABLE INSTALLATIONS

The tumbler switch and cover plates normally used for outlet-box installation are mounted in a manner similar to that for box-type receptacles and covers and are in two pieces. Foreign installations may still use push-button switches.

ENTRANCE SWITCHES

At every power-line entry to a building, a switch-and-fuse combination or a circuit-breaker switch must be installed at the service entrance (*Figure A-20, page A-12*). This switch must be rated to disconnect the building load while in use at the system voltage. Entrance, or *service switches* as they are commonly called, consist of one *knife switch blade* for every hot wire of the power supplied. The switch is generally enclosed and sealed in a sheet-steel cabinet. When connecting or disconnecting the building circuit, the blades are operated simultaneously through an exterior handle by the rotation of a common shaft holding the blades. The neutral or grounded conductor is not switched but is connected at a neutral terminal within the box. Many entrance switches are equipped with integral fuse blocks or circuit breakers that protect the building load. The circuit-breaker type of entrance switch is preferred, particularly in field installations, because it is easier to reset after the overload condition in the circuit has been cleared.

FUSES AND FUSE BOXES

FUSES

The device for automatically opening a circuit when the current rises beyond the safety limit is technically called a *cutout* but is more commonly called a *fuse*. All circuits and electrical apparatus must be protected from short circuits or dangerous overcurrent conditions through correctly rated fuses.

Standard

The cartridge-type fuse is used for current rating above 30 amperes in interior wiring systems. The ordinary plug or screw-type fuse is satisfactory for incandescent lighting or heating-appliance circuits.

Special

Whenever motors are connected on branch circuits, time-lag fuses should be used instead of the standard plug or cartridge-type fuse. These fuses have self-compensating elements that maintain and hold the circuit in line during a momentary heavy ampere drain, yet cut out the circuit under normal short-circuit conditions. The heavy ampere demand normally occurs in motor circuits when the motor is started. Examples of such circuits are the ones used to power oil burners or air conditioners.

FUSE BOXES

As a general rule, the fusing of circuits is concentrated at centrally located fusing or distribution panels. These panels are normally located at the service-entrance switch in small buildings or installed in several power centers in large buildings. The number of service centers, or fuse boxes in the latter case, is determined by the connected power load.

CIRCUIT BREAKERS

Circuit breakers (*Figure A-21, page A-12*) are devices resembling switches that trip or cut out the circuit in case of overamperage. They perform the same function as fuses and can be obtained with time-lag opening features similar to the special fuses discussed earlier. Based on their operation, they may be classified as *thermal*, *magnetic*, or *thermal-magnetic reaction*.

A thermal circuit breaker has a bimetallic element integrally built within the breaker that responds only to fluctuations in temperature within the circuit. The element is made by bonding together two strips of dissimilar metal, each of which has a different coefficient of expansion. When a current is flowing in the circuit, the heat created by the resistance of the bimetallic element expands each metal at a different rate, causing the strip to bend. The element acts as a latch in the circuit as the breaker mechanism is adjusted so that the element bends just far enough under a specified current to trip the breaker and open the circuit.

A magnetic circuit breaker responds to changes in the magnitude of current flow. In operation, an increased current flow will create enough magnetic force to pull up an armature, opening the circuit. The magnetic circuit breaker is usually used in motor circuits for closer adjustment to motor rating, while the circuit conductors are protected, as usual, by another circuit breaker.

The thermal-magnetic circuit breaker combines the features of the thermal and magnetic types. Practically all of the molded-case circuit breakers used in lighting panel boards are of this type. The thermal element protects against overcurrents in the lower range, and the magnetic element protects against the higher range usually occurring from short circuits.

Circuit breakers are preferred over fuses because they can be manually reset after tripping, and fuses must be replaced. Also, fuses can easily be replaced with higher-capacity ones that do not protect the circuit, but this is difficult to do with circuit breakers. Circuit breakers combine the functions of a fuse and a switch. When tripped by overloads or short circuits, all of the ungrounded conductors of a circuit are opened simultaneously. Each branch circuit must have a fuse or circuit breaker protecting each ungrounded conductor. Some installations may or may not have a main breaker that disconnects everything.

As a guide during installation, a main breaker or switch is not required ahead of the branch circuit breaker if less than six movements of the hand are required to open all the branch circuit breakers. However, if more than six movements of the hand are required, a separate disconnecting main circuit breaker is required ahead of the branch circuit breaker. Each 120-volt circuit requires a single-pole breaker that has its own handle. Each 240-volt circuit requires a double-pole breaker to protect both ungrounded conductors. However, you can place two single-pole breakers side by side and tie the two handles together mechanically to give double-pole protection. Both handles could then be moved by a single movement of the hand. A two-pole breaker may have one handle or two handles that are mechanically tied together, but either one requires only one movement of the hand to break the circuit.

LAMP HOLDERS AND SOCKETS

Lamp sockets (*Figure A-22, page A-13*) are generally screw-base units placed in circuits as holders for incandescent lamps. A special type of lamp holder has contacts, rather than a screw base, which engage and hold the prongs of fluorescent lamps when they are rotated in the holder. The sockets can generally be attached to a hanging cord or mounted directly on a wall or ceiling in open wiring installations. This requires using screws or nails in the mounting holder that is provided in the nonconducting material, which is molded or formed around the lamp socket. The two mounting holes in a porcelain lamp socket are spaced in such a way that the sockets may also be attached to outlet box *ears* or a plaster ring with machine screws. The screw threads molded or rolled in the ends of the lamp-holder sockets also facilitate their ready integration in other types of lighting fixtures such as table lamps, floor lamps, or hanging fixtures that have reflectors or decorative shades. In an emergency, a socket may also serve as a receptacle. The socket is converted to a receptacle by screwing in a female plug. One type of ceiling lamp holder has a grounded outlet located on the side.

SIGNAL EQUIPMENT

The most common components in interior wiring signal systems (*Figure A-23, page A-14*) normally operate at voltages of 6, 12, 18, or 24 volts, AC or DC. As a general rule, they are connected by open-wiring methods and are used as interoffice or building-to-building signal systems.

REFLECTORS AND SHADES

Many types of reflectors and shades (*Figure A-23*) are used to focus the lighting effect of bulbs. Of these, some are used to flood an area with high-intensity light and are called *floodlights*. Others, called *spotlights,* concentrate the useful light on a small area. Both floodlights and spotlights come in two- or three-light clusters with swivel holders. They can be mounted on walls or posts or on spikes pushed into the ground.

INCANDESCENT LAMPS

The most common light source for general use is the incandescent lamp (*Figure A-23, page A-14*). Though it is the least efficient type of light, its use is preferred over the fluorescent type because of its low initial cost, ease of maintenance, convenience, and flexibility. Its flexibility and convenience is readily seen by the wide selection of wattage ratings that can be inserted in one type of socket. Further, since its emitted candlepower is directly proportional to the voltage, a lower-voltage application will dim the light. A higher-voltage application from a power source will increase its intensity. Although an incandescent light is economical, it is also inefficient because a large amount of the energy supplied to it is converted to heat rather than light. Moreover, it does not give a true light because the tungsten filament emits a great deal more red and yellow light than does the light of the sun. Incandescent lights are normally built to last 1,000 hours when operating at their rated voltage.

FLUORESCENT LAMPS

Bulb for bulb and watt for watt, a fluorescent light provides more light for the money than an incandescent light does. For example, a 40-watt fluorescent tube produces almost six times as much light as a 40-watt incandescent bulb, and a fluorescent tube will last about five times longer than an incandescent bulb.

Unlike the simple principle of an incandescent bulb, which glows when current flows through the filament, an intricate electrical process takes place before a fluorescent tube gives light. Because a fluorescent tube does not have a filament, a *ballast* (also called a *transformer*) is necessary to set up voltage within the tube. In addition to ballasts, older-type fluorescent fixtures have starters that assist the ballast in the initial starting process.

The two most common types of fluorescent light fixtures for homes are rapid-start and preheat. It is easy to distinguish between them because the starter mechanism of the rapid-start type is built right into the ballast, whereas each tube on the preheat type has a visible starter unit. The starters, which look like small aluminum cylinders, tend to burn out as often as the bulbs do. A third type, less commonly used in the home, is the *instant start*. This type has no starter and is distinguished by a tube with a single pin on each end.

GLOW LAMPS

Glow lamps are electric-discharge light sources that are used as indicator or pilot lights for various instruments and on control panels. Because these lamps have relatively low light output, they are used to indicate that circuits are energized or that electrical equipment installed in remote locations is in operation.

A glow lamp consists of two closely spaced metallic electrodes sealed in a glass bulb that contains an inert gas. The color of the light emitted by the lamp depends on the gas; for example, neon gas produces a blue light. The lamp must be operated in series with a current-limiting device to stabilize the discharge. This current-limiting device consists of a high resistance that is usually contained in the lamp base.

A glow lamp produces light only when the voltage exceeds a certain striking voltage. As the voltage is decreased somewhat below this value, the glow suddenly vanishes. When the lamp is operated on AC, light is produced only during a portion of each half cycle, and both electrodes are alternately surrounded with a glow. When the lamp is operated on DC, light is produced continuously and only the negative electrode is surrounded with a glow. This characteristic makes it possible to use the glow lamp as an indicator of AC and DC. The lamp also has the advantages of small size, ruggedness, long life, and negligible current consumption; and it can be operated on standard lighting circuits.

TRANSFORMERS

The transformer is a device for changing AC voltages into either high voltages for efficient power-line transmission or low voltages for consumption in lamps, electrical devices, and machines. Transformers vary in size according to their power-handling rating. Their selection is determined by input and output voltage and load-current requirements. For example, the transformer used to furnish power for a doorbell reduces 115-volt AC to about 6 to 10 volts. This is accomplished by two primary wire leads that are permanently connected to the 115-volt circuit and two secondary screw terminals from the low voltage side of the transformer.

POLE-LINE HARDWARE

Pole-line hardware includes bolts, nuts, washers, braces, eyebolts, anchor rods, lag screws, pole steps, guy clamps, guy clips, guy hooks, guy plates, thimble-eyes, and steel pins. To increase the life of the material, electricians should use hardware galvanized according to specifications of the American Society for Testing Materials (ASTM). *Figures A-24 through A-27, pages A-15 through A-18*, illustrate many items of pole-line hardware.

Part Two. Wiring Procedures

CHAPTER 3

Design and Layout

The different wiring systems in common use for civilian and armed-forces construction are often called *cable* and *conduit* systems. Chapters 4 and 5 cover the installation details for each of these systems. Many installation methods and procedures used in the wiring processes are common to all systems. In most wiring installations, the blueprints specify the type of wiring to be installed. If the type of wiring is not specified, the electrician must determine the installation method. In general, the type of wiring used should be similar to that installed in adjacent or nearby buildings. Section I of this chapter describes common wiring methods and procedures, and Section II describes methods for *tactical* or *expedient wiring.*

Section I. Interior Wiring

TYPES OF DISTRIBUTION

The electrical power load in a building cannot be properly circuited until the type and voltage of the central power-distribution system is known. The voltage and the number of wires from the power lines to the buildings are normally shown or specified on the blueprints. However, the electrician should check the voltage and type of distribution at the power-service entrance to every building in which wiring is to be done. This is especially necessary when he is altering or adding circuits. Voltage checks are usually made with an indicating voltmeter at the service-entrance switches or at the distribution load centers. The type of distribution is determined by a visual check of the number of wires entering the building (*Table B-1, page B-1*).

If only two wires enter the building, the service is either DC or single-phase AC. The voltage is determined by an indicating voltmeter. When three wires enter a building from an AC distribution system, the service can be single-phase, three-phase, or two ungrounded conductors and a neutral of a three-phase system (*V-phase*).

If the service is single-phase, two of the conductors are hot, and the third is ground. A voltmeter reading between the two hot conductors will be twice as great as the reading between either hot conductor and the neutral or ground conductor. If the service is three-phase, the voltage between any two of the conductors is the same. Normally, one of the conductors is grounded to establish a ground reference voltage for the system.

A V-phase system is the most common service for TO construction. The distribution system is described below. The voltage between the two hot conductors will be 1.732 times greater than the voltage between either hot conductor and the neutral or ground.

Four-wire distribution denotes three-phase and neutral service. When tested, voltages between the neutral conductor and each of the three conductors should all be the same. The voltage readings between any two of these three wires are similar and should equal the neutral-to-hot wire voltage multiplied by 1.732. Common operating voltages for this type of service are 120 and 208 volts or 277 and 480 volts.

LOAD PER OUTLET

The first step in planning the circuit for any wiring installation is to determine the connected load per outlet. It is best to use volt-amperes as the method of determining electrical needs. This eliminates power-factor considerations. The power needed for each outlet or the load per outlet is used to find the number of circuits. It is also used to find the power needed for the whole building. The load per outlet can be obtained in several different ways.

The most accurate method of determining the load per outlet is to obtain the stated value from the blueprints or specifications. Commonly, the lighting outlets shown on the blueprints are listed in the specifications along with their wattage ratings. If the lights to be used are incandescent, this figure represents the total wattage of the lamp.

When fluorescent lights are specified, the *wattage drain* (also called *load per outlet*) should be increased approximately 20 percent to provide for the ballast load. For example, when the fixture is rated as a two-lamp, 40-watt unit, the actual wattage drain is 80 watts, plus approximately 16 watts for both lamp ballasts, or a total load of 96 watts.

If the specifications are not available, the blueprints in many cases designate the type of equipment to be connected to specific outlets. Though the equipment ultimately used in the outlet may come from a different manufacturer, equipment standards provide the electrician with assurance that the outlets will use approximately the same wattage. If the equipment is available, the nameplate will list the wattage used for ampere drain. If not, *Table 3-1* may be used to obtain the average wattage consumption of electrical appliances.

Table 3-1. Wattage consumption of electrical appliances

Appliance	Average Wattage
Clock	3
Coffeemaker	1,000
Fan, 8-inch	30
Fan, 10-inch	35
Fan, 12-inch	50
Heater (radiant)	1,300
Griddle	450
Grill	600
Hot plate	1,250
Humidifier	500
Iron	1,000
Mixer	200
Phonograph	40
Range	8,000
Refrigerator	500
Radio	100
Soldering iron	200
Television	300
Toaster	1,200
Washing machine	1,200
Water heater	4,500

To provide adequate wiring for systems where the blueprints or specifications do not list any special or appliance loads, the following general rules apply:

- For heavy-duty outlets or mogul-size lamp holders, the load per outlet should be figured at 5 amperes each.
- For all other outlets, both ceiling and wall, the wattage drain (load per outlet) should be computed at 1.5 amperes per outlet.

The total outlet load may also be determined on a watts-per-square-foot basis. In this load-determination method, the floor area of the building to be wired is computed from the outside dimensions of the building. This square-footage area is then multiplied by the standard watts-per-square-foot requirement, based on the type of building to be wired. *Table B-14, page B-15*, lists these constants along with a feeder-demand factor for various types of building occupancies. This table gives planning loads based on lighting and appliance needs. Large appliance loads (those in excess of 5 amperes each) should be added to this standard load figure.

CIRCUITING THE LOAD

If all the power load in a building was connected to a single pair of wires and protected by a single fuse, the entire establishment would be without power in case of a breakdown, a short circuit, or a fuse blowout. In addition, the wires would have to be large enough to handle the entire load and, in some cases, they would be too large to make connections to individual devices. Consequently, the outlets in a building are divided into small groups known as *branch circuits*. These circuits are normally rated in amperes as shown in *Table B-15, page B-15*. This table contains a comparison of the various ampere requirements of the branch circuits with the standard circuit components. Normally, the total load per circuit should not exceed 80 percent of the circuit rating.

The method of circuiting the building load varies with the size of the building and the power load. In a small building with little load, the circuit breakers or fuses are installed at the power-service entrance, and the individual circuits are run from this location. For medium-size buildings with numerous wiring circuits, the fuse box should be located at the center of the building load so that all the branch runs are short, minimizing the voltage drop in the lines. When buildings are large or have the loads concentrated at several remote locations, the ideal circuiting would locate fuse boxes at each load center. It is assumed that the branch circuits would be radially installed at each of these centers to minimize the voltage drops in the runs.

The number of circuits required for adequate wiring can be determined by adding the connected load in watts and dividing the total by the wattage permitted on the size of branch circuit selected. This method should not include special heavy loads such as air conditioners that require separate circuits.

The total wattage is obtained from the sum of the loads of each outlet determined by one of the three methods discussed previously. For example, if 20-ampere, 120-volt circuits are to be used, 80 percent of this rating (16 amperes per circuit) is allowed.

The maximum wattage permitted on each circuit equals 16 times 120, or 1,920 watts. If the total connected load is assumed to be 18,000 watts, 18,000 divided by 1,920 shows that 9.375 circuits are required. Since only whole circuits are allowed, ten 20-ampere circuits should be used to carry the connected load. The number of circuits determined by this method should be the basic minimum. For long-range planning in permanent installations, the best practice requires the addition of several circuits to the minimum required or the installation of the next larger modular-size fusing panel to allow for future wiring additions. If additional circuits are used over the minimum required, the number of outlets per circuit can be reduced, therefore making the electrical installation more efficient. This is true because the voltage drop in the system is reduced, allowing the apparatus to operate more efficiently.

The following industry standards are established to ensure that adequate electrical power, switches, and receptacles are available for modern demands. In TO construction, you may not always meet these standards due to the unavailability of equipment, the time required for installation, or the short period of time facilities will be occupied.

SWITCH OUTLETS

- Wall switches are usually located on the latch side of doorways or the traffic side of arches or other wall openings. They are mounted approximately 48 inches from the floor.
- Areas that have more than one entrance will be equipped with a multiple-control wall switch at each principle entrance, unless this requires placing switches within 10 feet of each other.
- At least one switch-controlled lighting outlet must be provided for each dining area that is combined with another room, such as a breakfast nook. The lighting outlet is normally placed over the probable location of the dining table.
- At least one ceiling light outlet in each major room should be wired for a ceiling fan. This is accomplished by running an extra conductor between the light and the controlling light switch.
- Provide for switched lighting on both sides of mirrors and at least one switched light in the ceiling in bathrooms and dressing rooms.
- Kitchen areas require more lighting than other areas of a house. Plan for switch-controlled lights over the sink, the range hood, the breakfast bar, and general counter-top work space. Mount switches at convenient locations.
- Hallways require a switch at each doorway leading into the hall. Switches should be mounted on the latch side of the doorway.
- Stairways should be provided with at least one switch-controlled lighting outlet. Switches should be located at each landing where a doorway is provided for access.

RECEPTACLE OUTLETS

- Each kitchen, family room, dining room, living room, library, den, bedroom, or similar room will have receptacle outlets every 6 feet and near the ends of walls where possible. Unless otherwise specified, receptacle outlets should be placed approximately 12 inches from the floor.
- Each kitchen, pantry, breakfast room, dining room, or similar room should have two or more 20-amp appliance circuits that serve all receptacle outlets. Outlets in other rooms are not to be connected to these circuits. In kitchens and dining areas, a receptacle outlet will be installed along counter-top space every 4 feet. Counter space separated by a range top, a refrigerator, or a sink is considered a separate counter. Outlets will not be installed in a face-up position in the counter top. Any receptacle outlet within 6 feet of a sink must be protected by a ground-fault circuit interrupter (GFCI).
- Bathrooms will have at least one wall-mounted receptacle outlet at each basin. All receptacles must be protected by a GFCI.
- Install at least one receptacle outlet on the front and one on the back of each building. All receptacle outlets within grade-level access will be protected by a GFCI.

- Laundry areas will be provided with at least one receptacle outlet. If the laundry equipment is located in the basement or the garage, at least one additional receptacle outlet must be provided. The laundry receptacle will be wired for 20-amp service and no other outlets will be connected to this circuit.
- Hallways that are 10 feet long or longer will have at least one receptacle outlet. **NOTE: Hallway length is determined along the centerline without passing through a doorway.**

Motors that are used on portable appliances are normally disconnected from the power source either by removal of the appliance plug from its receptacle or by operation of an attached built-in switch. Some large-horsepower motors, however, require a permanent power installation with special controls. Motor switches *(Figure 3-1)* are rated in horsepower capacity. In a single-motor installation, a separate circuit must be run from the fuse or circuit-breaker panel to the motor, and individual fuses or circuit breakers must be installed.

For multiple motor installations, the National Electrical Safety Code requires that—

> *Two or more motors may be connected to the same branch circuit, protected at not more than 20 amperes at 125 volts or less or 15 amperes at 600 volts or less, if each does not exceed 1 horsepower in rating and each does not have a full load rating in excess of 6 amperes. Two or more motors of any rating, each with individual overcurrent protection (provided integral with the motor start switches or an individual unit), may be connected on one branch circuit if each motor controller and motor-running overcurrent device is approved for group installation, and the branch circuit fusing rating is equal to the rating required for the largest motor plus an amount equal to the sum of the full load ratings of the other motors.*

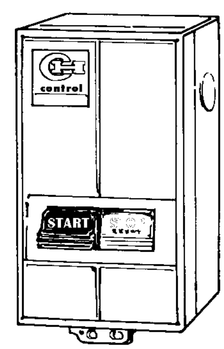


Figure 3-1. Motor switch

BALANCING THE POWER LOAD ON A CIRCUIT

The ideal wiring system is planned so that each wiring circuit will have the same ampere drain at all times. Since this can never be achieved, the circuiting is planned to divide the connected load as evenly as possible. Thus, each circuit uses approximately the average power consumption for the total system to make for minimum service interruption. *Figure 3-2, page 3-6*, demonstrates the advantage of a balanced circuit when using a three-wire, single-phase, 110/220-volt distribution system.

The current used is known as *alternating current* because the current in each wire changes or alternates continually from positive to negative to positive and so on. The change from positive to negative and back again to positive is known as a *cycle*. This usually takes place 60 times every second, and such current is then known as 60-cycle current. Sixty times every second each wire is positive, 60 times every second each wire is negative, and 120 times every second there is no voltage at all on the wire. The voltage is never constant but is always gradually changing from zero to maximum, with the average being about 120 volts. The current in the neutral conductor of a balanced three-wire, single-phase system will remain at zero as a result of the applied AC.

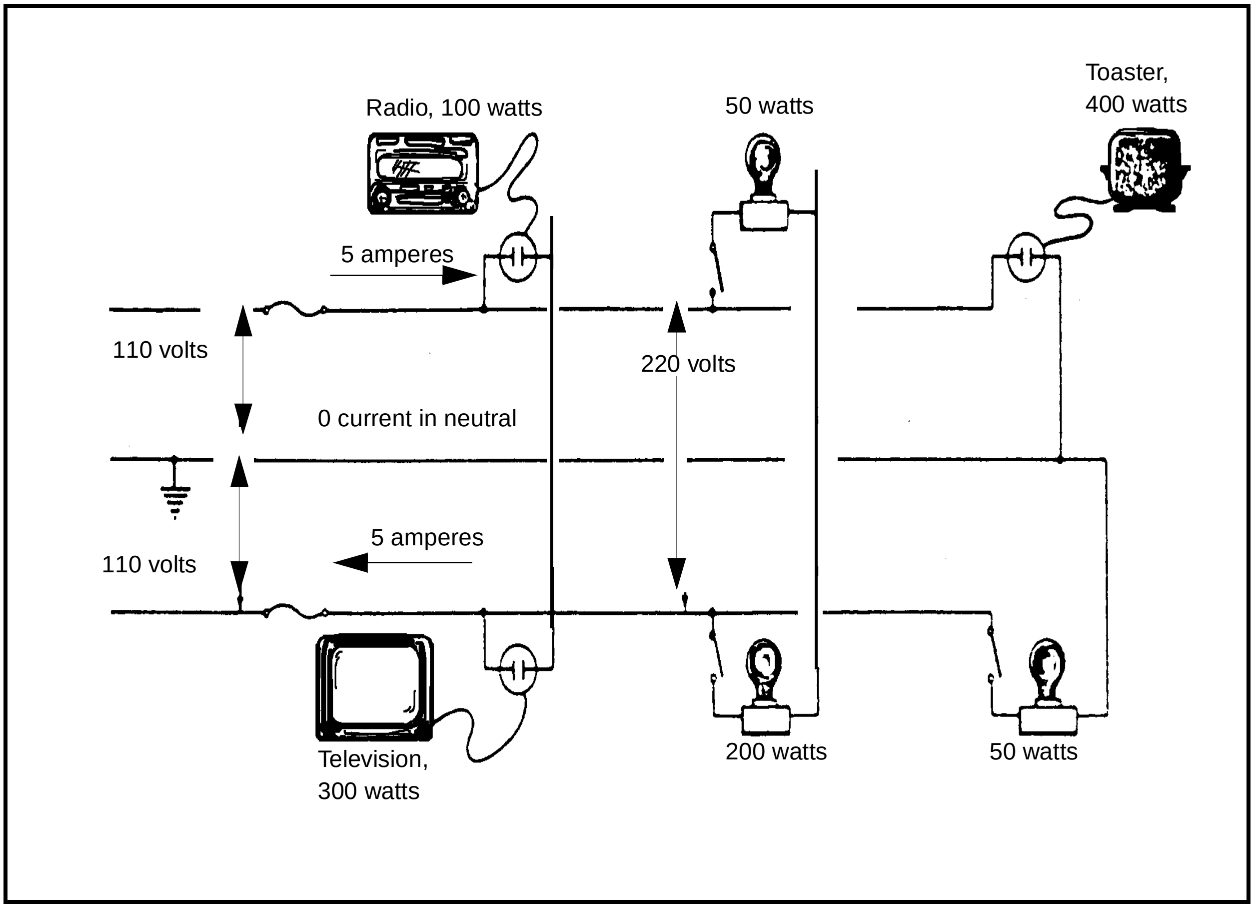


Figure 3-2. Circuit balancing

LOAD PER BUILDING

MAXIMUM DEMAND

In some building installations, the total possible power load may be connected at the same time. In this case, the demand on the power supply (which must be kept available for these buildings) is equal to the connected load. In the majority of building installations where armed-forces personnel work, the maximum load which the system is required to service is much less than the connected load. This power load, which is set at some arbitrary figure below the possible total connected load, is called the *maximum demand* of the building.

DEMAND FACTOR

The ratio of maximum demand to total connected load in a building expressed as a percentage is termed *demand factor*. The determination of building loads can be obtained by using the standard demand factors shown in *Table B-14, page B-15*. For example, if the connected load in a warehouse is 22,500 watts for warehouses, the actual building load can be obtained as follows: 100 percent of the first 12,500 watts equals 12,500; 50 percent of the remaining 10,000 watts equals 5,000; therefore, the total building load is 12,500 plus 5,000 watts, or 17,500 watts.

BALANCING THE POWER LOAD OF A BUILDING

The standard voltage-distribution system from a generating station to individual building installation is the three- or four-wire, three-phase type. Distribution transformers on the power-line poles, which are designed to deliver three-wire, single-phase service, change the voltage to 120 or 240. These transformers are then connected across the distribution phase loads in a balanced arrangement. Consequently, for maximum transformer efficiency, the building loads assumed for power distribution should also be balanced, as previously illustrated in *Figure 3-2*.

WIRE SIZE

Wire sizes No 14 and larger are classified according to their maximum allowable current-carrying capacity based on their physical behavior when subjected to the stress and temperatures of operating conditions. No 14 wire is the smallest wire size permitted in interior wiring systems.

The size of the conductor used in feeder and branch circuits depends on the maximum allowable current-carrying capacity and the voltage drop coincident with each wire size. The size of the conductor for branch circuits (that portion of the wiring system extending beyond the last overcurrent device protecting the circuit) should be such that the voltage drop will not exceed 3 percent to the farthest outlet for power, heating, or lighting loads. The maximum voltage drop for feeders is also 3 percent, provided that the total voltage drop for both feeder and branch circuit does not exceed 5 percent. *Table B-16, page B-16,* which is based on an allowable 3 percent voltage drop, lists the wire sizes required for various distances between supply and load at different amperages. This table may be used for branch circuits originating at the service entrance. This is the common house or small building circuit. Use *Table B-15, page B-15,* to determine the proper wire size

The minimum gauge for service-wire installation is No 8. The service-wire sizes are increased because they must not only meet the voltage-drop requirement but also be inherently strong enough to support their own weight, plus any additional loading caused by climatic conditions such as ice or branches.

GROUNDING AND BONDING

REQUIREMENTS

The neutral conductor must be grounded on all electrical systems if the voltage between the hot lead and the ground is less than 150 volts. In addition, all systems should have a grounded neutral where the voltage to ground does not exceed 300 volts. Interior circuits operating at less than 50 volts need not be grounded if the transformer supplying the circuit is connected to a grounded system.

TYPES OF GROUNDING

A *system ground* is the ground applied to a neutral conductor. It reduces the possibility of fire and shock by reducing the voltage of one of the wires of a system to 0 volts potential above ground.

An *equipment ground* is an additional ground that should be attached to all appliances and machinery. An equipment ground is advantageous because the appliances and machinery can be maintained at zero voltage. Also, if a short circuit occurs in a hot lead, the fuse protection will open the circuit and prevent serious injury to operating personnel.

METHODS OF GROUNDING

A system ground is provided by placing a No 6 copper (or No 4 aluminum) wire between the neutral wire, service box, bonding wire, and a grounding electrode at the building's service entrance. The grounding electrode may be a buried water pipe, the metal frame of a building, a local underground system, or a fabricated device. If more than one electrode is used, they must be placed a minimum of 6 feet apart.

Water Pipe

An underground water piping system will always be used as the grounding electrode if such a piping system is available. If the piping system is less than 10 feet deep, supplemental electrodes will be used. Interior, metallic, cold-water piping systems will always be bonded to the grounding electrode or electrodes.

Plate Electrodes

Each plate electrode will have at least 2 square feet of surface exposed to the soil. Iron or steel electrodes must be at least 1/4 inch thick, and nonferrous metal must be at least 0.06 inch thick. Plates should be buried below the permanent moisture level if possible.

Pipe Electrodes

Clean, metallic pipe or conduit at least 3/4-inch trade size may be used. Each pipe must be driven to a depth of at least 8 feet. If this cannot be done, the electrodes may be buried in a horizontal trench. In this case, the electrode must be at least 8 feet long.

Rod Electrodes

Rod electrodes of steel or iron must be at least 3/8 inch in diameter. Rods of nonferrous material must be at least 1/2 inch in diameter. The standard ground rod for the military is a 5/8-inch steel rod with three sections of 3 feet each. Installation of rod electrodes is the same as for pipe electrodes. *Figure 3-3* shows typical grounding procedures.

GROUND RESISTANCE

Electrodes should have a resistance to ground of 25 ohms or less. Underground piping systems and metal frames of buildings normally have resistance to ground of less than 25 ohms. Resistance to ground of fabricated electrodes will vary greatly depending on the soil and the method of installation. Burying an electrode below the permanent moisture level of the soil normally reduces the resistance to ground to acceptable values. Grounding systems should be tested by using a *Megge*r ground tester. This device may be found in organizations such as the installation's Department of Public Works (DPW) or engineer division.

The voltage between the neutral or grounded conductor of a grounded system and the ground (water pipes, metal frames of buildings, ground rods) should be zero at all times. The detection of any voltage indicates a faulty wiring system.

BONDING

Bonding is a method of providing a continuous, separate electrical circuit between all metallic circuit elements (conduit, boxes, and so forth) and the service-entrance ground. The ground or neutral conductor is attached to the bonding circuit only at the service entrance. At this point, the neutral wire and a bonding wire from the service box are attached to the grounding electrode. All other metallic circuit elements are connected to this grounded point through physical connections of the metallic conduit, armored cable, or flexible metal conduit. Nonmetallic conduit or cable must have a conductor in it to provide this bonding circuit. This conductor should be attached to the metal boxes or fixtures where the nonmetallic cable or conduit terminates.

All metal-to-metal connections must be tight to ensure a continuous bonding circuit. When the electrical continuity of a metal-to-metal connection is doubtful, use a wire jumper between the two metal pieces. As an example, the equipment ground wire of a receptacle (the green wire) is connected to the bonding circuit through the two screws fastening the receptacle to the box. If the box is recessed to obtain a flush receptacle, the connecting screws are not tightened but are used as adjusting screws to properly locate the receptacle. In this case, a wire must be placed between the box and the equipment ground terminal of the receptacle. Proper bonding prevents shocks from metal surfaces of an electrical system.

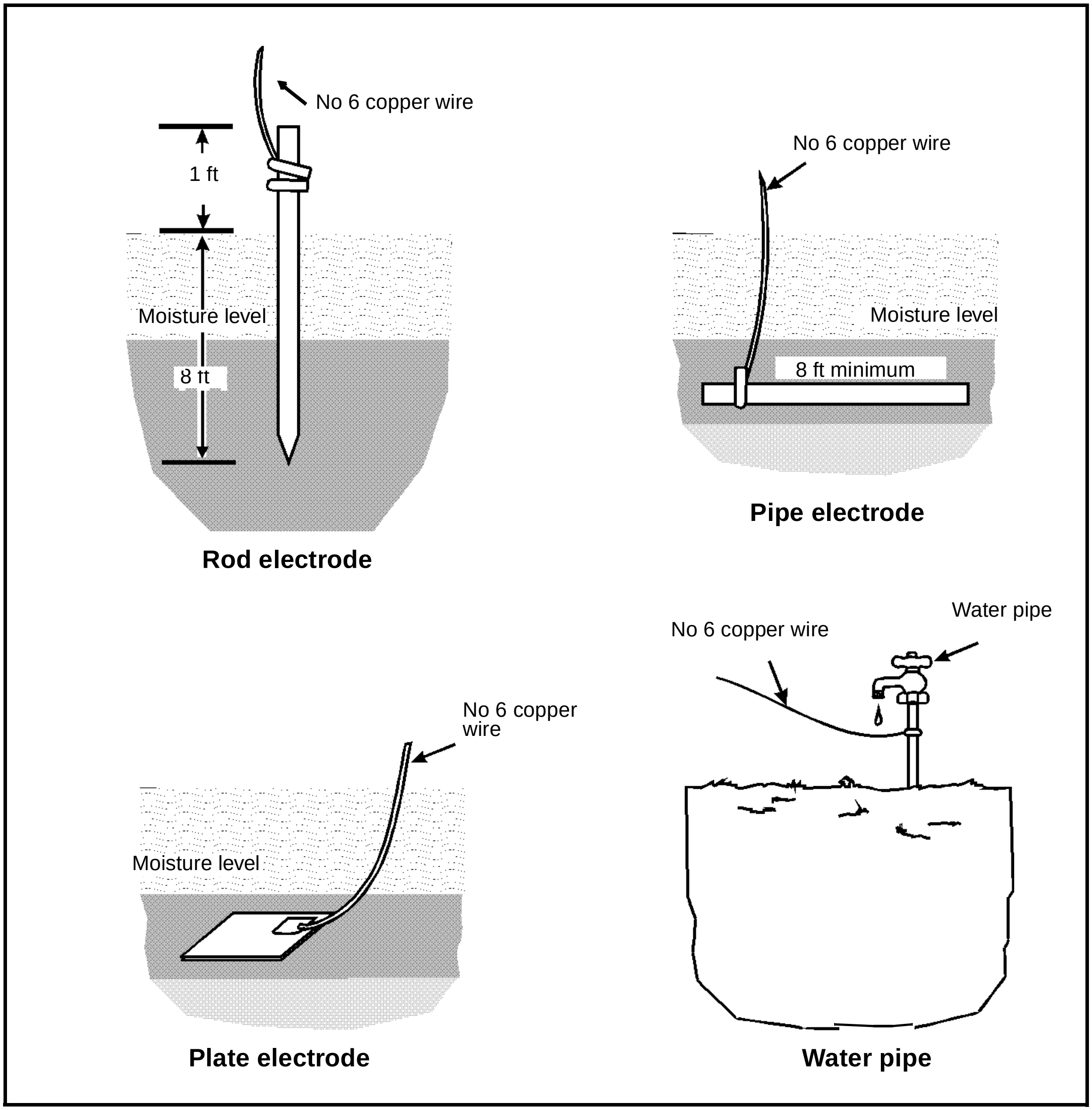


Figure 3-3. Methods of grounding

WIRING FOR HAZARDOUS LOCATIONS

Special materials and procedures must be used to install electrical systems in areas where a spark could cause a fire or an explosion. Typical areas of this type are hospital operating rooms and acetylene storage or production facilities. Hazardous locations are divided into three classes:

CLASS I

Class I includes areas where flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.

CLASS II

Class II includes areas where combustible dust is present.

CLASS III

Class III includes areas where easily ignitable fibers or filings are present but are not suspended in the air in sufficient quantities to produce ignitable mixtures.

Each class is further subdivided into two divisions. In division one of each class, the hazardous material is present in free air so that the atmosphere is dangerous. In division two of each class, the hazardous material is in containers, and dangerous mixtures in the air occur only through accidents.

INSTALLATION IN HAZARDOUS LOCATIONS

Detailed information on installation material and procedures must be obtained from theater commands and standard plans. The information below gives general guidance about the type of installation required for each class and division of hazardous locations:

CLASS I

In division one areas, wiring must be in threaded, rigid-metal conduit, with explosion-proof fittings or mineral-insulated, metal-sheathed (Type MI) cable. Division two areas may have flexible metal fittings, flexible metal conduit, or flexible cord that is approved for hard usage. All equipment such as generators, controllers, motors, fuses, and circuit breakers must be enclosed in explosion-proof housings.

CLASS II

In division one areas, wiring must be in threaded rigid conduit or Type MI cable with flexible metal conduit and threaded fittings where necessary. Equipment must be in dustproof cabinets with motors and generators in totally enclosed fan-cooled housings. In division two areas, electrical metallic tubing may also be used.

CLASS III

In division one areas, the same requirements exist as for class I, division one. In division two areas, open wiring is permitted. Motors and generators must be totally enclosed.

INSTALLATION OF SIGNAL EQUIPMENT

Signal equipment may occasionally be supplied for 120-volt operation, in which case it must be installed in the same manner as outlets and sockets operating on this voltage. Most bells and buzzers are rated to operate on 6, 12, 18, or 24 volts AC or DC. They can be installed with minimum consideration for circuit insulation, since there is no danger of shock to personnel or fire due to short circuits. The wire commonly used is insulated with several layers of paraffin-impregnated cotton or a thermoplastic covering. Upon installation, these wires are attached to building members with small insulating staples and are threaded through building construction members without insulators.

BATTERY OPERATION

Early installations of low-voltage signal systems were powered by 6-volt dry cells. For example, two of these batteries were installed in series to service a 12-volt system. If the systems involved a number of signals over a large area, one or more batteries were added in series to offset the voltage drop. Though this type of alarm or announcing system is still being used in some areas, it is a poor method because the batteries used as a power source require periodic replacement.

TRANSFORMER OPERATION

Most present-day buzzer and bell signal systems operate from a transformer power source. The transformers are equipped to be mounted on outlet boxes and are constructed so that the 120-volt primary-winding leads normally extend from the side of the transformer adjacent to the box mounting. These leads are permanently attached to the 120-volt power circuits, and the low-voltage secondary-winding leads of the transformer are connected to the bell circuit (*Figure 3-4*). If more than one buzzer and push button are to be installed, they are paralleled with the first signal installation. A typical wiring schematic diagram for this type of installation is shown in *Figure 3-5*.

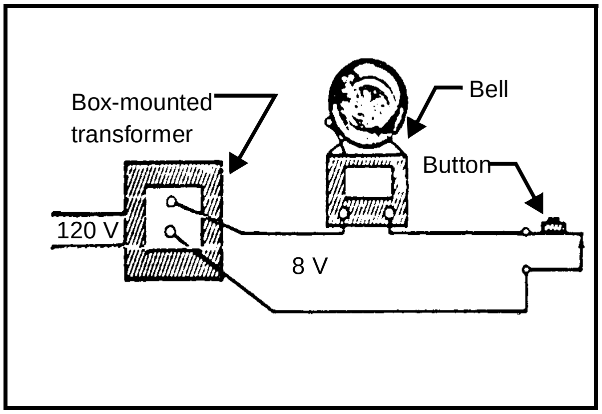


Figure 3-4. Bell and buzzer wiring

SPECIAL SWITCHES

THREE-WAY SWITCHING

A single-throw switch controls a light or a receptacle from only one location. When lights have to be controlled from more than one location, a double-throw, commonly called a *three-way switch*, is used. Three-way switches can be identified by a common terminal that is normally color-coded darker than the other terminals and located alone at the end of the switch housing. A schematic wiring diagram of a three-way switch with a three-wire cable is shown in *Figure 3-6*. In the diagram, terminals A and A^1 are the common terminals, and the switch operation

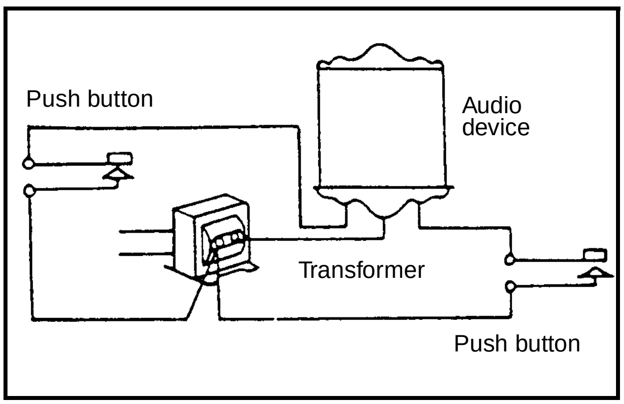


Figure 3-5. Two-push-button system

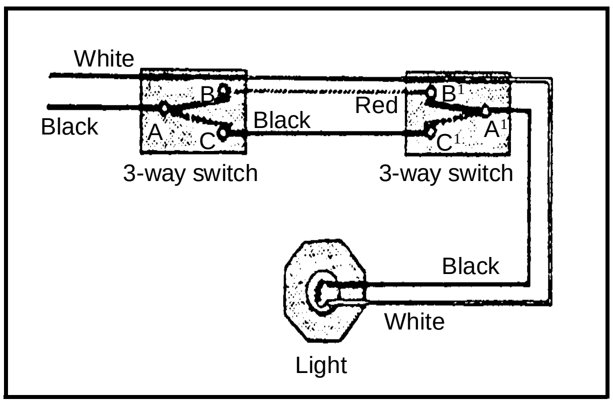


Figure 3-6. Three-way switch wiring

connects them either to B or C and B[1] or C[1], respectively. Either switch will open or close the circuit, turning the lights on or off.

FOUR-WAY SWITCHING

Occasionally, it is necessary to control an outlet or light from more than two locations. Two three-way switches plus a four-way switch will provide control at three locations as shown in *Figure 3-7*. The switches must be installed with the four-way units connected between the two three-way units and the three-wire cable installed between the switches.

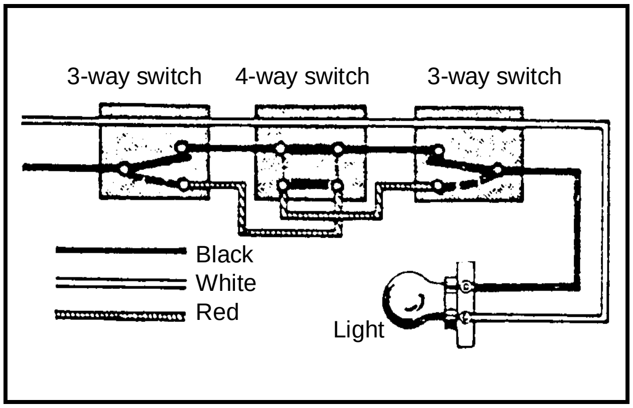


Figure 3-7. Four-way switch wiring

VARIABLE-CONTROL DEVICES

Electrical dimmers provide a full range of light from bright to dim for incandescent lighting. Special electronic dimmers exist for use with florescent lighting. A turn of the dial adjusts the brightness level, and a push-knob switch turns the light on or off without changing the brightness setting (*Figure 3-8*).

Another type of dimmer switch has a high-low control that provides two levels of illumination: full brilliance at the top position and approximately half brilliance at the bottom position. Variable-control devices are also used as speed-control devices that control the speed of tools and equipment using standard AC or DC motors. Some variable-control devices are electronic in nature since their construction uses solid-state circuitry and switches.

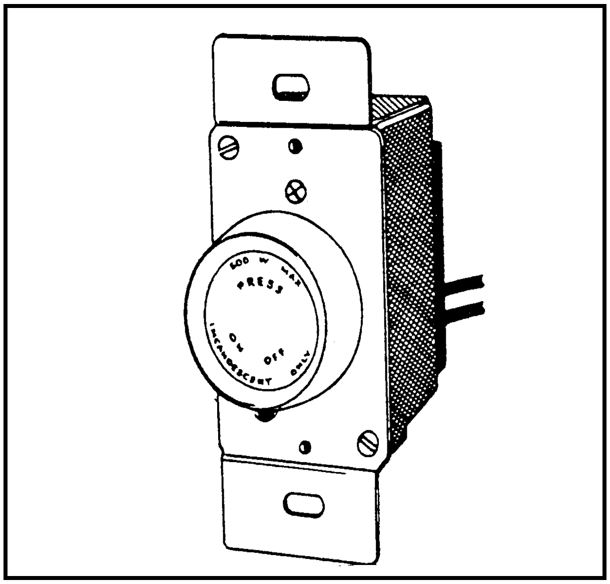


Figure 3-8. Push-pull rotary switch

ADDITIONS TO EXISTING WIRING

CIRCUIT CAPACITY

When installing additions to existing wiring in a building, the electrician first determines the available extra capacity of the present circuits. This can readily be obtained by ascertaining the fused capacity of the building and subtracting the present connected load. If all the outlets do not have connected loads, their average load should be used to obtain the connected load figure. When the existing circuits have available capacity for new outlets and are located near the additional outlet required, they should be extended and connected to the new outlets. Consideration must be given to the additional voltage drop created by extending the circuit. The proper wire size may then be determined.

NEW CIRCUITS

When the existing outlets cannot handle an additional load and a spare circuit has been provided in the local fuse or circuit-breaker panel, a new circuit is installed. This is also done if the new outlet or outlets are so located that a new circuit can be installed more economically than an existing circuit extension. Moreover, the installation of a new circuit will generally decrease the voltage drop on all circuits, resulting in an increase in appliance operating efficiency.

NEW LOAD CENTER

In many wiring installations, no provisions are made for spare circuits in the fuse or breaker panel. Moreover, the location of the new circuit required is often remote from the existing fuse box or circuit-breaker panel. In this case, the preferred method of providing service to the circuit is to install a new load center at a location that is close to the circuit outlets. This installation must not overload the incoming service and service-entrance switch. Should such an overload be indicated, the service equipment should also be changed to suit the new requirements. Sometimes, this can be accomplished in two-wire systems by pulling in an additional wire from the power line. This changes the service from two-wire to three-wire at 120 to 240 volts. In these cases, the fuse box or the circuit-breaker panel should also be changed and enlarged to accommodate the increased circuit capacity.

CIRCUIT DIAGRAMS

Figure 3-9, page 3-14, shows some typical arrangements for switches, fixtures, and receptacles. Although many other combinations are also possible, these drawings should help in planning circuit arrangements. Before you do any wiring, check with the supervisor to find out if there are any specific equipment requirements.

Section II. Expedient Wiring

PURPOSE

In many applications, electrical wiring installations are needed for temporary use. Examples are forward-area installations (tactical wiring), TO, field training exercises (FTXs), and civilian disaster-relief situations in foreign countries and the US. Complete installations of electrical systems would require too much time and be very costly, so they would not be practical.

Wiring situations in the TO could be considered tactical wiring and would require different types of wiring, such as open wiring where wiring systems and devices are exposed on studs, ceilings, and joists. Military light sets are also used in expedient or tactical installations.

WIRE

Wire sizes should be selected according to normal installations. The wire should be laid over the ceiling joist and fastened by nails driven into the joist and bent over the wire. The nails should exert enough force to firmly grip the wire without damaging the insulation. If possible, expedient wiring installations should be fastened to joists or studs at least 7 feet above the floor. This prevents accidental damage to the system or injury to personnel. The wires should be supported in accordance with normal installation.

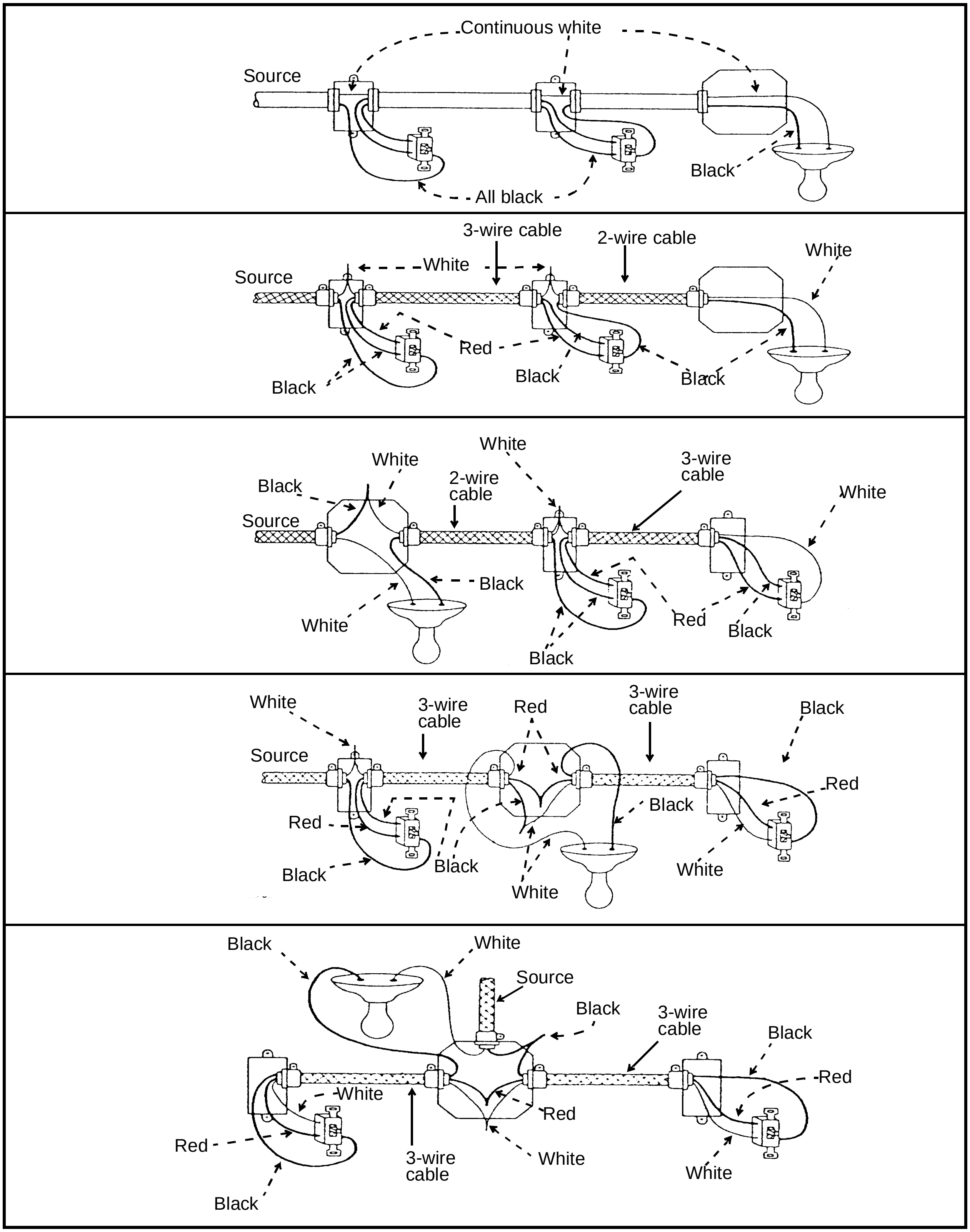


Figure 3-9. Typical wiring combinations

SUPPORTS

JOINTS, SPLICES, TAPS, AND CONNECTIONS

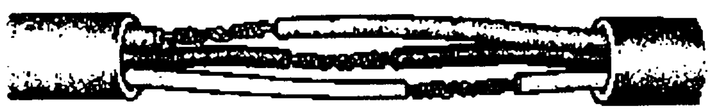
Joints, splices, taps, and connections are made as outlined in Chapter 1. In expedient wiring, use electrical tape as a protective covering on the connection and to provide additional protection where nails are bent over the wire.

FIXTURE DROPS

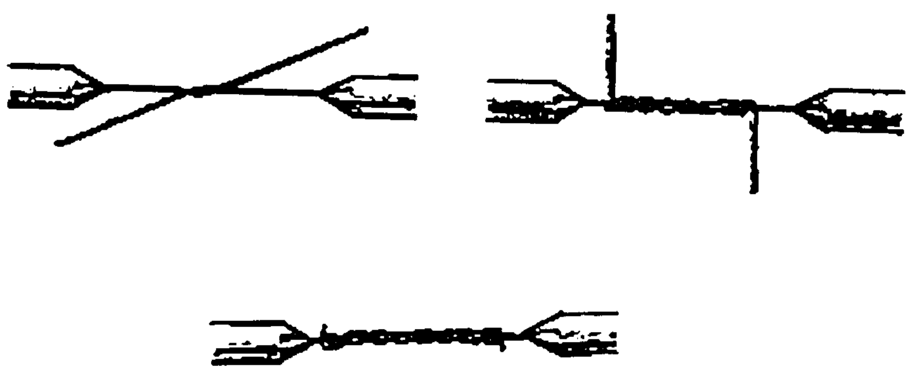
Fixture drops, preferably pigtail splices, are installed by taping their leads to wires and taping the taps. The sockets are supported by the tap wires.

CORDS OR NONMETALLIC-SHEATHED CABLE

Figure 3-10 shows how to tap a two-conductor cord or nonmetallic-sheathed cable in an expedient wiring installation. Remove the outer rubber or sheathing at the point of fixture attachment, and tap the fixture leads to the conductor with a Western Union splice, purposely maintaining the separation between taps as shown. Then, individually tape each tap.



NOTE: Portable cord splices should only be done in an emergency.



How to make a Western Union splice

Figure 3-10. Tapping stranded copper wire

CHAPTER 4

Cable Wiring

Cable systems are used where cost is a factor. They can be installed easily, and the material required is less expensive than that used for other systems. The absence of protection against mechanical injury and the fact that it is only moisture-resistant tend to restrict the areas where the cable system can be used. Temporary and expedient-wiring cable systems are ideally suited for the TO.

Section I. Armored Cable Wiring

ADVANTAGES AND USES

Armored-cable wiring is permissible by regulation for all interior installations, except where it is exposed to saturation by liquid or where it is in contact with acid fumes. In wet areas, a lead-covered cable is required. Because the material requirements for armored-cable wiring are greater, the overall cost is generally higher than Type NM cable systems. This increased cost is often warranted because an armored conductor has greater mechanical-damage protection. The installation of armored cable is relatively simple and is similar to that of nonmetallic-sheathed cable discussed in Section II. Much of the equipment and materials are the same.

MATERIALS

CABLE

Armored-cable construction consists of two or three rubber- or thermoplastic-covered wire combinations encased in flexible steel armor. Cable is obtained from the manufacturer as Type AC (without a lead sheath) and Type ACL (with a lead sheath under the armor). Type AC cable has a copper or aluminum bonding strip.

One of the conductors of armored cable is always white. Because of this color coding, the white wire in a switch installation (for both armored cable and nonmetallic-sheathed cable) can be used as a hot wire and be connected to a black wire.

SUPPORT

Armored cable may be fastened to wooden building members with a one- or two-hole mounting strap formed to fit the contour and size of the cable or by staples made specifically for armored cable. The cable is normally supported at the box entry either by integral armored-cable clamps built into the boxes or by armored-cable connectors.

BOXES AND DEVICES

Chapter 2 details boxes and devices recommended for use with armored-cable wiring. Electrical boxes with integral cable clamps and attached mounting brackets are used for quick installation.

INSTALLATION

CABLE SUPPORT

Whenever possible, run armored cable through holes centrally drilled in the building structural members and ensure that the holes are at least 1/8 inch oversize to facilitate easy *pull-through* of the armored cable. Avoid the flush-type mounting of armored cable accomplished by notching the joists and studs if possible because this type of installation exposes the armored cable to possible short circuits (by locating the cable in a position where it could be accidentally pierced by nails) and materially weakens the structural member.

When running armored cable between joists and studs, ensure that it is supported by staples or straps at least every 4 1/2 feet along the length of the cable run. These supports must also be installed within 12 inches of each box entry, unless the support interferes with installations that require extreme flexibility. This requirement assures the continuance of a satisfactory box connection by relieving the strain on the splices and the connection within the outlet box. When installing cable runs across the bottom of ceiling joists and stud faces at least 7 feet above the floor, ensure that runs are supported on each joist or stud. You may also install cable runs on running boards similar to those used in open-wiring installations.

Damage Protection

When installing armored cable on the top of ceiling joists or studs in accessible locations (such as attics and temporary buildings) at a distance of less than 7 feet from the floor, you must install guard strips at least as high as the cable.

Bending

When installing armored cable, avoid bending or shaping the cable in a manner that damages the protective armor. This type of installation damage may occur in drilled holes for armored cable, in corner runs, or when locating boxes on studs and joists. To prevent this, follow the rule that the radius of the inner edge of any bend must not be less than five times the cable diameter. *Figure 4-1* illustrates an acceptable armored-cable bend at the box entry.

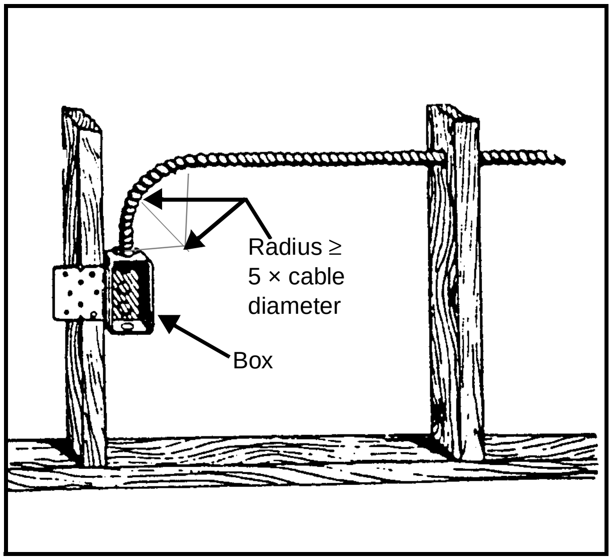


Figure 4-1. Armored-cable bend

BOX CONNECTION

Procedure

Armored cable may be spliced or connected to devices only in standard junction or outlet boxes. Therefore, you must cut all cable long enough to run from box to box. To prevent cutting the cable too short, first thread the armored cable through the mounting holes drilled in the joists or studs and attach the cable to one box. Take the slack out of the cable by using just enough force to maintain the proper bends. Keeping this tension, cut the cable from the roll and connect it to the box. *Figure 4-2* shows the procedure for preparing and attaching the cable to a box.

Cutting Cable

Though armored cable can be cut with an armored-cable cutter specifically designed for the job, most electricians use a hacksaw. When making an outlet connection, cut the cable about 8 inches longer on each end than is required for the run. When removing the armor from the wire, cut the armor approximately 8 inches from the cable end so that ample wire will be inserted in the box for connecting to the outlet device. These lead lengths may be increased when the wire run terminates in a fuse box or a circuit-breaker panel and a longer cable is required.

Cutting cable armor is a simple operation. With the hacksaw in one hand and the cable end held firmly in the other hand, make the cut with the blade of the hacksaw placed at a right angle to the lay of the armor strip. The hacksaw and the cable should form two legs of a 60-degree triangle. When the blade has cut almost through the armor strip, bend the cable end back and forth several times until it breaks. You can then strip the loose armor from the wire leads by twisting and pulling. If one end of the cable has already been attached to a box, pull the cable tight enough to assure a steady sawing surface. When cutting from a coil, hold the armor firmly by stepping on the coil cable end and pulling it tight. Smooth rough or sharp ends of the cut with a file.

WARNING

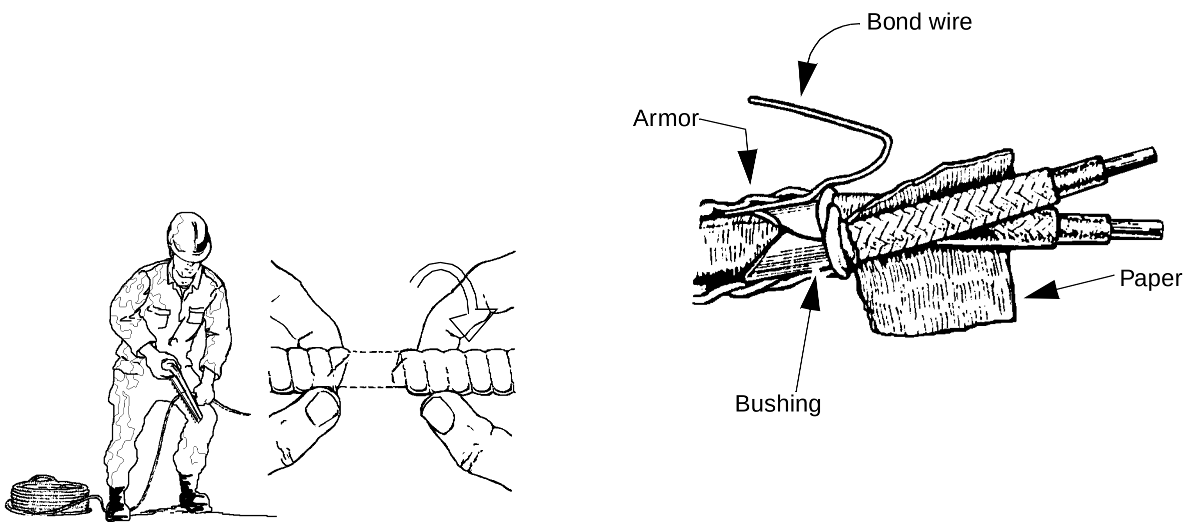
Avoid damaging the wire insulation or the metal bonding strip when cutting cable armor.

Unwrapping Paper

The fiber paper that is twisted around the conductors before the metallic armor is attached must be removed to allow free wire movement. Normally, you can remove two or three turns of the paper from under the armor by using a jerking action to tear the loose paper away from the wire at the armor end. The free space between the armor and the wires facilitates mounting the antishort bushing.

Attaching Antishort Bushing

When the ends of the cut armor are filed, only the outer burred edges are removed. The inner edges are always sharp and jagged at the cut end, and if not covered, they tend to puncture the wire insulation and cause short circuits and grounds. To prevent this and to protect the wire against



Left: Cutting the armor which is held taut by stepping on it and holding it over the knee.

Right: Note that the armor is cut at an angle to the lay.

Figure 4-2. Cutting and attaching cable

damage, you must insert a tough fiber bushing, commonly called an *antishort bushing*, between the armor and the wire.

Attaching Cable to a Box

When using an armored-cable connector, first insert the cable in the connector and then tighten the holding screw, securely connecting the cable and connectors. Then, insert the armored-cable connector through the box knockout opening, and secure it to the box with the locknut threaded on the connectors from inside the box.

When using the cable with a box having internal cable clamps, first remove the knockout at the point of entry. Next, loosen the clamp-holder screw, insert the cable through the knockout opening, and thread the leads through the clamp (*Figure 4-3*). Then, force the armor snugly against the clamp end and retighten the clamp screw, forcing the clamp into the ridges of the cables.

The bonding wire runs the entire length of the cable and must be bonded to the enclosure on the other receptacle into which the cable is entered. Bend the wire back over the cable before installing the connector or attaching it to a box with an internal clamp.

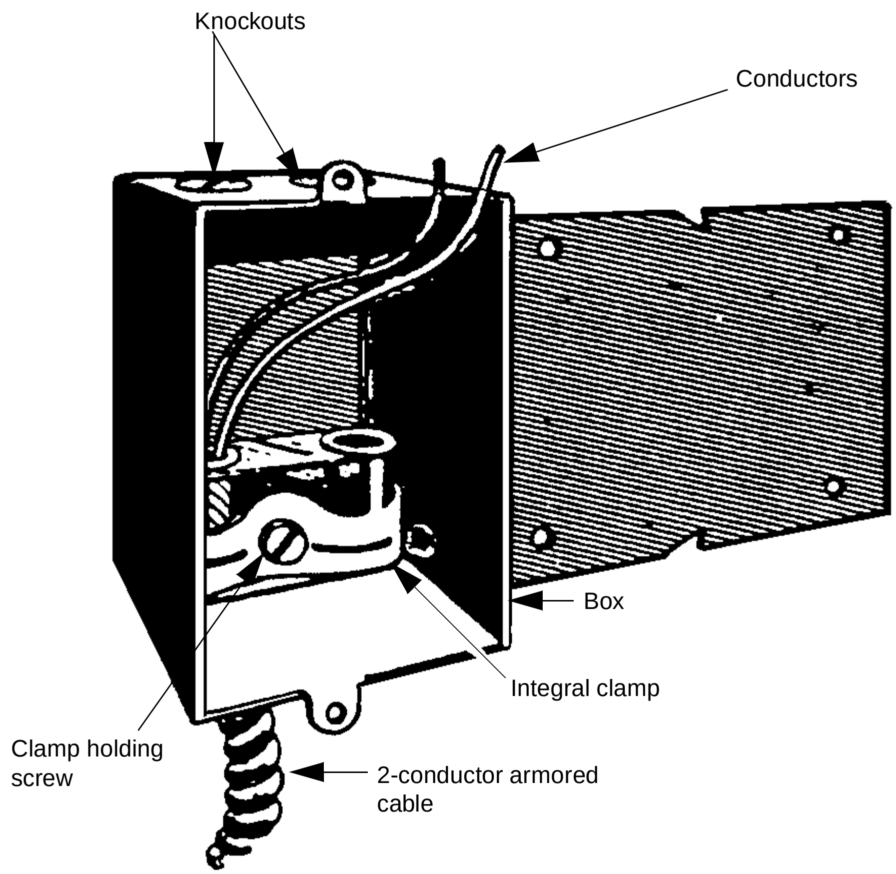


Figure 4-3. Cable connection to box with internal clamps

ADDITIONS TO EXISTING WIRING

CIRCUITING

Additions to existing armored-cable layouts require analysis to determine whether additional circuit capacity will be needed to handle the new load. These considerations are the same as those required for other types of installations.

CABLE CONNECTIONS

Armored-cable additions must always originate and terminate in electrical boxes. The junction box used for the addition should be located close enough to the desired outlets so that the voltage drop to the new device is within allowable limits. The box from which the additional outlet or outlets are to originate must have a neutral and a hot wire of the same circuit for the new load connection. This means that the conductors from an added outlet can be connected only to the conductors of an existing cable in an outlet box (white to white and black to black) if the existing conductors can be traced to the fuse or circuit breaker without interruption.

ARMORED-CABLE ADDITIONS

Exposed

The installation of exposed armored-cable additions to existing wiring must be patterned according to rules outlined for original installations. If an armored-cable installation is to be made into another type of wiring system, the changeover must be made in a junction box specifically installed for the purpose or in an existing outlet box if its conductor capacity will allow the entry of additional wires.

Concealed

Armored cable is preferred over all other types of wiring when additional outlets are required on completed buildings. The armor and the bonding strip provide adequate, continuous ground-to-metal outlet boxes. Armored cable is also flexible enough to be fed through small openings from attic or basement areas to boxes mounted on walls and ceilings. To do this, you will usually pull the cable into the concealed box with a fish tape or a drop chain. Use a fish tape when the cable will be fed from below the box location, and use a drop chain when the installation is to be made from above the box. In these cases, place the junction box in which the power tap is to be made in a clear, readily accessible area because the fishing and catching of a fish tape and a drop chain become a tedious and time-consuming operation if the junction box is concealed (see Section III). If it is difficult to feed into the power-tap box because of building construction, the finished wall may have to be removed to allow entry. If so, replastering will be necessary after the additional cable has been installed.

Section II. Nonmetallic-Sheathed Cable Wiring

ADVANTAGES AND USES

The conventional nonmetallic-sheathed cable, Type NM, is approved for use in concealed or exposed, dry, indoor locations and is recommended for use where a good system ground is not available. Since the cable is inexpensive and lightweight and requires no special installation tools, it is suited for use in military wiring systems. Because of its construction, nonmetallic-sheathed cable is **not** approved for imbedded installation in masonry, concrete, fill, or plaster.

WARNING

Do not install Type NM cable in potentially dangerous areas where wire damage may occur, such as commercial garages, theaters, storage-battery rooms, or hoistways. Additionally, do not use it in humid or wet areas, such as ice plants or cold-storage warehouses.

A newer nonmetallic-sheathed cable, Type NMC, is a dual-purpose, plastic-sheathed cable with solid-copper conductors. This cable needs no conduit, and its flat shape and gray or ivory color make it ideal for surface wiring. It resists moisture, acid, and corrosion and can be run through masonry and between studding.

MATERIALS

CABLE

Type NM cable consists of rubber- or thermoplastic-covered wires in two- or three-wire combinations, with a bare copper wire used for bonding. These wires are individually wrapped with a spiral paper tape for damage protection. The local codes in some areas also require the addition of a bare, uninsulated conductor in Type NMC cable. This bare wire provides the same type of equipment ground or bonding at the outlet boxes as the armor in armored-cable installation. The bare wire is attached to the outlet box by using a grounding clip *(Figure 4-4)*.

SUPPORT

Types NM and NMC cable are generally mounted on wooden building members with one- or two-hole mounting straps or staples. Armored-cable staples are **not** approved for this type of installation because of possible cable damage.

BOXES AND DEVICES

The boxes and devices used in Type NM and NMC cable wiring are similar to those used with conduit. They are made of metal or nonmetallic materials and come with built-in clamps or knockout holes for the connectors. Use metal boxes with internal clamps when possible to assure a safe, efficient installation. In exposed Type NM cable wiring, you may use insulated switches, outlets, and lamp-holder devices without boxes. The cable entry holes of these devices must clamp the cable securely, and the device must fully enclose the section of the cable from which the outer sheathing has been removed. Because no splicing is possible in these devices and all wires must be

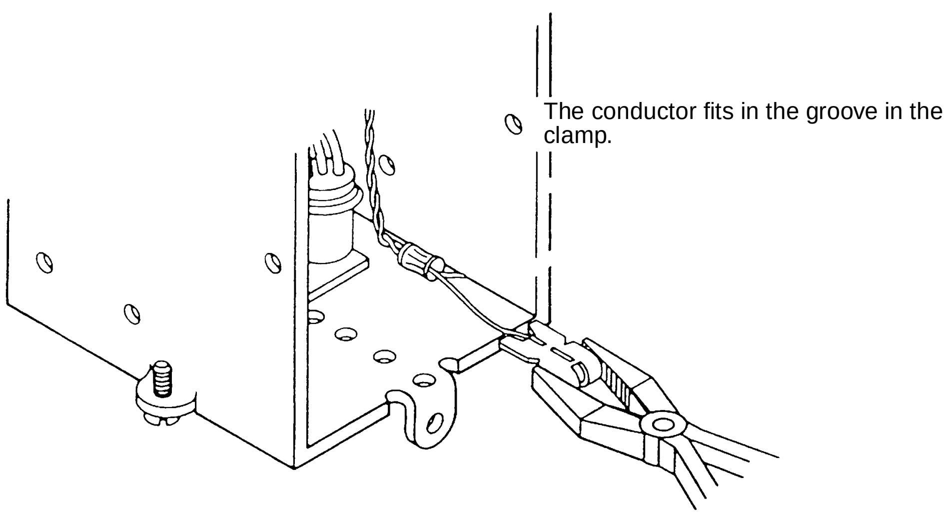


Figure 4-4. Installing a grounding clip

connected to terminals, limit the use of these devices to installation in rural areas or other areas in which only a small number of outlets and switches are required.

INSTALLATION

CABLE SUPPORT

Nonmetallic-sheathed cable should be supported in a manner similar to that outlined for armored cable (Section I). You can install cable on running boards, in holes drilled in the center of the joists, or on the sides of joists and studs. When using running boards or the sides of joists and studs, ensure that straps support the cable at distances not greater than 4 1/2 feet, and attach a cable strap within 12 inches of a box. When you are making the cable run at an angle in an overhead installation and supporting it on the edge of the joists, you must install the cable on running boards. Assemblies containing two No 6 or three No 8 conductors may be secured directly on the bottom of the joist.

DAMAGE PROTECTION

If you install the cable across the top of a floor or floor joist, protect it with guard strips that are at least as high as the cable. When the wire installation is in a location not normally used, such as an attic or a crawl space, damage-protection devices such as guard strips are required only within 6 feet of the entrance. If possible, do not install concealed cable near baseboards, door and window casings, or other possible locations of trim or equipment because of damage from building nails. If you are installing thermal insulation where cable is in place, use only noncorrosive, noncombustible, nonconductive insulation. While installing the insulation, avoid adding additional strain on the cable, its supports, or its terminal connections.

CABLE BENDING

To prevent accidental damage to the sheathing on Type NMC cable, the minimum allowable radius of bends is five times the cable diameter. Though this bend limit is similar to that for armored cable (Section I), nonmetallic-sheathed cable can be bent in a smaller arc because the cable diameters are smaller for the same wire-gauge combinations.

BOX CONNECTION

Cable runs must be continuous from outlet to outlet because wire splices are only permitted inside a box. Type NM cable is prepared for box connection in the same manner as that outlined for armored cable. When removing the protective sheathing from the conductors for connection, use an electrician's knife instead of a hacksaw. When removing the covering, cut a slit in the sheathing parallel to the wires without touching the individual wire insulation. A cut approximately 8 inches long for cable entry to ordinary boxes is satisfactory but can be increased to suit entry to panels. Then, use the knife to remove the slitted sheathing.

You should also remove the moisture-preventive paper from the wires. *Figure 4-5, page 4-8,* illustrates the slitting of a cable end and shows a special tool called a *cable stripper* that can be used instead of a knife to remove the sheathing from Type NM cable, lead-covered cable, and portable cords. The stripper is inserted over the cable, squeezed together, and then pulled off the conductor. This action rips the outer sheathing quickly and efficiently. The use of a stripper instead of a knife for outer sheathing removal is recommended since it cannot damage the wire insulation.

ENTERING BOXES

When wiring with nonmetallic-sheathed cable, you may use either metal or nonmetallic boxes. It would be difficult to recommend one type over the other because both have advantages. Several aspects of wiring, such as grounding and connecting cable to boxes, vary, depending on the kind of box used.

Metal Boxes

Cable must be secured to a metal box. You may do this by using either a box with built-in cable clamps or a separate cable connector. Either way, remember to leave 6 to 8 inches of cable extending into the box for connections.

As with most other terminal connectors, a grounding screw or clip is equipped to receive only one wire. When you install a switch, a self-grounding receptacle, or a light fixture in the last box of a circuit run, attach the grounding wire of Type NM cable directly to the box.

When you install a box that is not at the end of a circuit or a receptacle that is not self-grounding, you must make one or more grounding jumpers. For the grounding jumper, use wire that is the same size as the circuit wires. Twist all grounding wires and jumpers together, and crimp them with a compression ring or secure them with a wire nut.

Nonmetallic Boxes

Cable knockouts in nonmetallic boxes are held in place with thin webs of plastic. Break out a knockout wherever Type NM cable will enter a box. Ensure that the cable is supported within 8 inches of the box, the sheathing extends into the box at least 1/4 inch, and the cable is secured to the box.

When you are fishing cable behind walls, above ceilings, or under floors, you are not required to support cable, but you must clamp the cable to the box. Nonmetallic boxes are available with built-in cable clamps.

Since nonmetallic boxes do not conduct electricity, they need not be grounded. When using nonmetallic boxes, treatment of the grounding wire is based on whether the box holds a receptacle, a switch, or a light fixture.

Receptacles. Attaching a receptacle to a nonmetallic box is a simple process. If the box is at the end of a circuit, attach the grounding wire to the grounding screw of the receptacle. If the box is in the middle of a circuit run, join the cable grounding wires with a grounding jumper from the receptacle.

Switches. Many switches are now equipped with grounding terminals, which are treated as those on grounded receptacles. When using such a switch and it is in a nonmetallic box in the middle of a run, join the cable grounding wires. If the switch is at the end of a circuit, hold the grounding wire between the switch bracket and the box with the mounting screw.

Light Fixtures. To install a light fixture, use an octagon-shaped fixture box with a metal grounding bar. If the fixture is at the end of a circuit, attach the cable grounding wire to the bar (*Figure 4-6*). If the fixture is in the middle of a circuit, make a grounding jumper to join the grounding bar to the cable grounding wires. The light fixture will automatically be grounded when attached to the grounded box. **NOTE: Some chain-hung fixtures have a separate grounding wire. Join it to the circuit grounding wire and a jumper.**

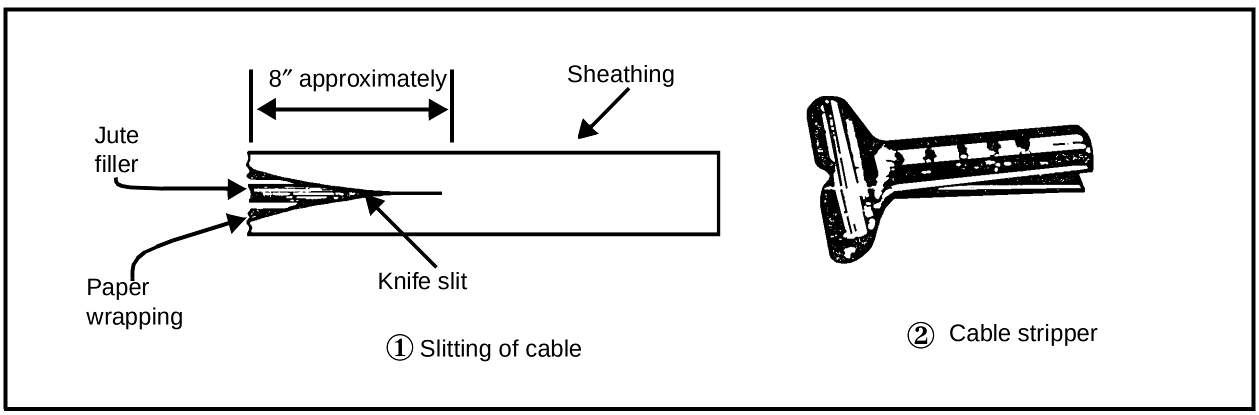


Figure 4-5. Removal of sheathing

ADDITIONS TO EXISTING WIRING CIRCUITING

The factors pertinent for additions to existing wiring systems are the same as those for Type NM cable wiring.

CABLE CONNECTIONS

Connection additions for nonmetallic-sheathed cable are the same as connection additions for armored cable outlined in Section I.

TYPE NM CABLE ADDITIONS

Exposed

The installation of exposed Type NM cable additions to existing wiring must conform to the same requirements outlined for original installations. If a wiring system other than nonmetallic-sheathed cable is to be extended with nonmetallic-sheathed cable, you must use a junction box to couple the systems. You may use existing boxes that have available spare conductor capacity.

Concealed

Additions to concealed nonmetallic-sheathed cable are similar in method and procedure to those for armored cable except that insulated receptacles, switches, and light fixtures may be installed without boxes on the wall surfaces. In these installations, the cable is fished through the wall and fed to the device at the point of entry.

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 4-6. Ceiling-mounted light

Section III. Cable Fishing With Access

Fishing cable where you have access requires some fishing gear. *Fish tapes* are the tools to use for long cable runs. For shorter distances, you can use straightened coat hangers or lengths of No 12 wire with one end bent into a tight, blunt hook. Ensure that whatever you use is long enough to span the entire distance plus 2 feet. You need an open space to fish through. If you are going to attempt fishing more than a foot or so, you need a partner to accomplish the following steps *(Figure 4-7, page 4-10)*:

Step 1. Make a hole for the box in an open space between studs.

Step 2. Using a 3/4-inch spade bit, drill a hole up through the sole plate from the basement or down through the top plates from the attic. Drill until you hit open space; you may have to use an extension bit.

Step 3. To install a wire from the basement, run a fish tape through the box hole and down through the drilled hole. Attach the cable as shown in *Figure 4-7* and draw it into the box hole. To ensure that the passage is clear, have someone shine a flashlight in the box hole while you peer into the drilled hole to see if the light beam is visible. If it is not, a fire block (or something else) is in the way. For drilling through this obstruction, you need several extension shafts for the drill bit. Drill through the block, then look for the light again. If you still cannot see the light beam, move to another location or cut away some of the wall covering and notch the block. Once the passage is clear, continue with steps 4 and 5.

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 4-7. Method of fishing long run with access

Step 4. To install a wire from the attic, your partner runs a second fish tape or a length of small chain down through the hole in the top plates. Hook the two fish tapes together outside the box hole.

Step 5. You push the fish tape up through the wall while your partner pulls it until he has a secure grip on the tape coming up from the box hole. Attach the cable to the fish tape from the box hole and pull it slowly to work it through the wall to the box opening.

Section IV. Cable Routing Without Access

ROUTING BEHIND A BASEBOARD

Step 1. Cut the box hole or holes. Remove the baseboard between the box locations. Drill a hole through the wall below each box and cut a channel in the wall to connect the holes.

Step 2. Fish the cable down through one box hole, along the channel, and up into the other box hole.

ADDING A LIGHT AND A SWITCH

Step 1. Mark the fixture-box location between the two ceiling joists. Cut a hole for the box. At the ceiling edge between the same two joists, make a hole in the ceiling and the wall where they meet. Cut a hole for the switch box. Unless you want to run the cable through notched wall studs or behind the molding to another switch location, plan to locate the switch directly below the ceiling hole. Run the cable from the power source to the switch box.

Step 2. Run the fish tape down from the top wall hole to the switch-box hole. Connect enough cable for the switch loop and pull it up and out of the top hole.

Step 3. Run the fish tape from the fixture hole to the ceiling hole. Connect it to the switch loop cable and pull the cable out of the fixture hole.

Step 4. Notch the top plates to inset the cable and staple the cable in place. Connect the cables to the boxes, mount the boxes, and hook them up to the fixture and the switch.

ROUTING CABLE ALONG A WALL

Step 1. Cut box holes in the wall. Neatly cut away a straight, narrow strip of wall covering to expose all studs between the box holes. Both ends of this slot should be centered over studs.

Step 2. Use a 3/4-inch spade bit to drill through the center of each stud. Run the cable through the holes.

ROUTING CABLE AROUND A DOORWAY

Step 1. Remove the molding around the door frame and as much baseboard as necessary on either side of the door.

Step 2. Run the cable between the jamb and the frame, notching spacers wherever necessary. When routing cable behind molding, keep these points in mind:

- Ensure that you can get replacements because the molding may split.
- Use a 4-inch-wide or wider putty knife or electrician's chisel to pry molding from the wall.
- Use a 1/16-inch metal plate or run in thin-wall conduit to protect cable that is installed less than 1 1/2 inches from a finished surface.
- Do not nail through the cable when renailing the molding.

ROUTING CABLE THROUGH BACK-TO-BACK DEVICES

Step 1. Make a hole in the wall for the new box. De-energize the circuit you will be working on.

Step 2. Pull the device that is to be the power source out of its box. Remove the knockout from the back of the source box.

Step 3. Insert the cable with the connector through the new box hole into the source box. Connect the cable to the new box and mount the box.

Step 4. Wire in the new device. Wire into the source. Turn the circuit back on.

Section V. Finishing Up

MOUNTING BOXES

To mount a box, screw a cable connector to the box (or use a box with internal clamps that make fitting the box in the hole easier) and thread the cable through. Leave 6 to 8 inches of cable sticking out of the box for connections. For information on stripping and preparing the wires in the box, see Sections I and II. How you mount the box will depend on its type.

PLAIN BOX WITH BRACKETS

Check the box for proper fit in the hole. If necessary, adjust the ears so that the front edge of the box will be flush with the finished wall. Put the two brackets in the wall, one on either side of the box, and pull the bracket tabs toward you so that they are snug against the back side of the wall. Bend the tabs over the sides of the box and secure them with needle-nose pliers.

PLAIN BOX WITHOUT BRACKETS

Check the box for proper fit in the hole. If necessary, adjust the ears so that the front edge of the box will be flush with the finished wall. Mark the screw placements on the lath at the top and bottom of the hole. Remove the box and drill pilot holes for screws. Screw the box to the stud. On wooden walls, screw the ears to the wall surface. The faceplate will hide the ears and screws.

CUT-IN BOX

Mounting this box is a one-time proposition. Once inside the wall or ceiling, the side teeth flare away from the box, making it difficult to remove. Tightening the screw at the back of the box simply pushes the teeth into the backside of the wall surface. Because you cannot remove the box, ensure that the cables are in place and the box fits the hole before you mount it. To test the fit, remove the metal spring ears from the box.

CEILING BOX ON HANGER BAR

If you do not have access from the attic, you must cut out the ceiling material between the two joists. Screw the hanger bar to the sides of the two joists.

CEILING BOX WITH OFFSET HANGER

This box works well where you do not have access from above. Screw the offset hanger bar to the bottom edges of two joists.

CEILING BOX WITH FLANGE

If you do not have access from above, you will have to cut out a rectangle from the ceiling material. Nail or screw the flange to a joist (*Figure 4-8*).

PANCAKE BOX

Simply screw this box to a joist or beam. Position the box so that it will hide the hole that was drilled for the cable. Do not make cable junctions in this kind of box.

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 4-8. Ceiling box with flange

WIRING INTO THE POWER SOURCE

If your rewiring involves adding a new circuit to the service-entrance panel or a subpanel, see Chapter 3. *Figures 4-9 through 4-12, pages 4-13 and 4-14,* show how to wire in a new cable at a receptacle, switch, light, and junction box, respectively.

When adding a receptacle, use the checklist in *Table 4-1, page 4-15,* to review your work.

CAUTION

Before hooking up the new cable to the power source, shut off the main breaker or disconnect the circuit you are wiring into.

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 4-9. Method of wiring into a receptacle

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 4-10. Method of wiring into a switch

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 4-11. Method of wiring into a light

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 4-12. Method of wiring into a junction box

Table 4-1. Checklist for adding a receptacle

CHAPTER 5

Conduit Wiring

Conduit wiring provides mechanical protection and electrical safety to persons and property and provides convenient and accessible ducts for the conductor. A well-designed electrical raceway system has adequate capacity for future expansion and is readily adaptable to changing conditions.

Section I. Rigid Conduit

USES AND ADVANTAGES

Black-enamel or galvanized rigid metal conduit is approved for use under most conditions and in most locations. Metal conduit and fittings that are protected from corrosion by enamel may only be used indoors and in areas that are not subject to severe corrosion. Although rigid conduit is generally the most expensive type of wiring installation, its inherent strength permits installation without running boards and provides additional damage protection. Its capacity facilitates carrying more conductors in one run than in any other system, and its rigidity permits installation with fewer supports than the other types of wiring systems. Moreover, the size of conduit used in the system's installation usually provides for the addition of several more conductors in the conduit when additional circuits and outlets are required in the run.

MATERIALS

Though the materials used in rigid conduit wiring have been outlined in detail in Chapter 2, the following discussion will review the advantages of these standard materials as well as their limitations.

Rigid conduit *(Figure 5-1, page 5-2)* has the same size designations as water pipe. Conduit smaller than 1/2 inch can only be used in finished buildings where extensions are to be made under plaster. In these installations, 5/16-inch conduit or tubing is permitted. The size of conduit is determined by the inside diameter. For example, 1/2-inch conduit has an inside diameter of approximately 1/2 inch. Standard conduit sizes used in interior wiring are 1/2, 3/4, 1, 1 1/4, 1 1/2, 2, and 2 1/2 inches. Larger sizes (up to 6 inches) are available for special use in certain commercial and factory installations.

Though conduit is made in dimensions similar to water pipe, it differs from water pipe in a number of ways. It is softer than water pipe and thus can be bent fairly easily. In addition, the inner surface is smooth to prevent damage to wires being pulled through it, and the finish is rust-resistant. Black-enamel conduit is used for dry and indoor installations, and galvanized conduit is used in outside installations to provide moisture protection for the conductors. For wiring installations in corrosive atmospheres, aluminum, copper-alloy, or plastic-jacketed conduit is available.

CONDUCTORS

Rubber-covered, insulated Types R and RH wire are used with conduit in most interior wiring installations; but thermoplastic, insulated Types T and TW are gaining favor because of their superior insulating characteristics. Underground or wet installations require the insertion of lead-covered cables in galvanized conduit for permanent protection.

SUPPORTS

The conduit straps described in Chapter 2 are preferred for use when mounting conduit in interior wiring systems. Rigid conduit should be supported on spacings as shown in *Table B-17, page B-17*.

FITTINGS

The two types of fittings are the standard, ordinary-size outlet box and the small junction or pull boxes called *condulets*. The standard outlet-box fittings are classified as Type F and are normally used in exposed installations to house receptacles or switches where a high quality of installation is desired. Condulets *(Figure 5-1)* provide intermediate points in long conduit runs for the pull-through of wire or provide junctions for several concealed installations where they will not be accessible. They are classified by the manufacturers as follows:

- Service entrance, Type SE.
- Elbow or turn fittings, Type L.
- Through fittings, Type C.
- Through fittings with 90-degree take-off, Type T.

BOXES AND CONNECTORS

Steel or cast-iron outlet boxes are used in rigid-conduit installations. Boxes are normally supplied with knockouts that are removable for inserting conduit. Bushings and locknuts are provided for attaching the conduit to the boxes as shown in *Figure 5-1*. Boxes that are used in wet or hazardous locations must have threaded hubs into which the conduit is screwed.

DEVICES

The devices used to install conduit are all box-mounted units and are covered in Chapter 2.

ACCESSORIES

Threaded Couplings. Threaded couplings are furnished with each length of rigid conduit.

Threadless Couplings. Rigid conduit may be installed using threadless couplings if they are installed tightly.

Elbows. Standard conduit elbows are manufactured for use where 90-degree bends are required.

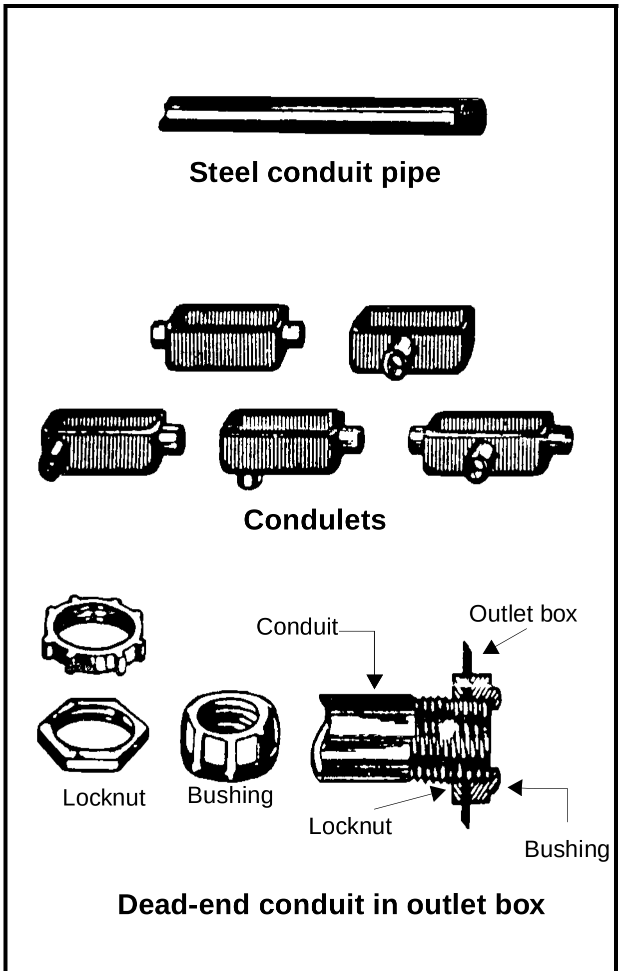


Figure 5-1. Rigid conduit and fittings

Conduit Unions. Conduit unions are installed to permit the opening of a conduit at any point without sawing or breaking the conduit run. By using unions, conduit may be started from two outlets and joined together at any convenient place in the run.

PROCEDURES

MAKING BENDS

Bends in rigid conduit must be made without collapsing the conduit wall or reducing the internal diameter of the conduit at the bend. Electricians make most bends as an integral part of the installation procedure. These are called *field bends*. The radius of the curve on the inner edge of any field bend must be at least six times the internal diameter of the conduit for rubber-, braid-, or thermoplastic-covered conductors and at least 10 times the internal diameter of the conduit for lead-covered conductors. *Table B-18, page B-17,* shows the minimum radii for field bends. A maximum of four quarter bends can be placed in a conduit run between two openings. Moreover, a 10-foot length of conduit should have no more than three quarter bends.

Factory-made bends are available as an option rather than bending conduit on the job. However, these bends are not commonly used because of the increased costs inherent in the additional cutting and threading that is required and the additional couplings that must be used.

Conduit up to and including 3/4 inch is usually bent with a hand conduit bender called a *hickey* as shown in *Figure 5-2, page 5-4*. This hickey can be slipped over the conduit. Conduit-bending forms are also available as built-in units of pipe-vise stands. If these tools are not available, you can make bends using the lever advantage between two fixed posts or building members.

The following procedure *(illustrated in Figure 5-2*) is one method of making a right-angle bend in a length of 1/2-inch conduit. If you are making a 90-degree bend in a length of conduit at a distance of 20 inches from one end, you must—

- Mark off 20 inches from the end of the conduit.
- Place the hickey 2 inches in front of the 20-inch mark and bend the conduit about 25 degrees.
- Move the bender to the 20-inch mark and bring the bend up to 45 degrees.
- Move the bender 1 inch behind the 20-inch mark and bring the conduit up to 70 degrees.
- Move the bender back 2 inches behind the 20-inch mark and bring the bend up to 90 degrees.

You can make conduit bends more accurately if you use chalk to draw the contour of the bend on the floor, and then match the bend in the pipe with the chalk diagram as you form the bend. You will usually use a hydraulic bender to bend conduit in excess of 1 inch.

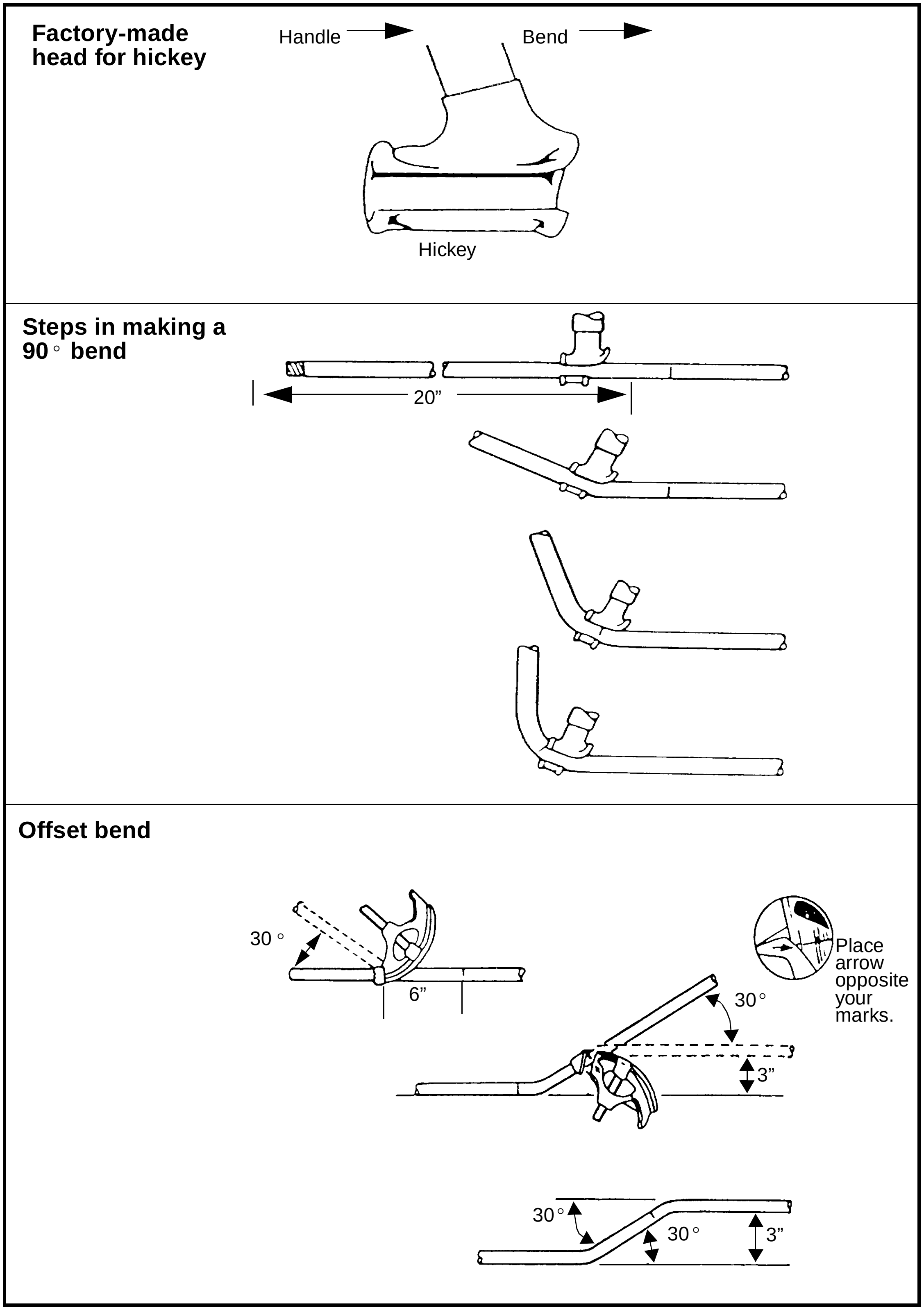


Figure 5-2. Bending rigid conduit

CUTTING CONDUIT

You can use a hacksaw or a standard pipe cutter to cut conduit. When using a hand hacksaw, hold the conduit in a vise and keep the cut at right angles to the length of the pipe. If a large amount of conduit is being cut, a power hacksaw is recommended. Even though you may use pipe cutters, which are standard equipment, a hacksaw is recommended for electrical conduit cutting because considerable time is required to remove the burr left in the inside of a pipe by a pipe cutter. Always use cutting oil when cutting pipe.

REAMING CONDUIT

Regardless of the cutting method used, a sharp edge always remains inside the conduit after cutting. Before installing the conduit, remove this edge with a pipe reamer or a file to avoid conductor damage. This process is called *reaming*.

CUTTING THREADS

Since the outside and inside diameters of rigid conduit are the same as those of gas, water, or steam pipes, the standard thread forms, threading tools, and dies are used. Normally, the smaller sizes of pipe are threaded with dies that cut a thread for every turn of the die. For larger sizes (1 1/2 inches and over), you will generally use a ratchet-type cutter. Motor-driven, pipe-threading machines are also available for large installations and when threading a considerable amount of conduit. As a good practice, you should examine each piece of threaded conduit before installation for—

- Foreign matter inside the pipe. Remove this material to prevent conductor damage.
- Thread condition. Mishandling, extraneous paint, or dirt may require the conduit to be rethreaded before installation. Always use cutting oil when threading conduit.

INSTALLING CONDUIT

Conduit should be run as straight and direct as possible. When you are installing a number of conduits parallel and adjacent to each other in exposed multiple-conduit runs, you should erect them simultaneously instead of installing one line and then another. You can use straps or hangers to support conduit installed on building surfaces.

Wood Surfaces. Use nails or wood screws to secure the straps.

Brick or Concrete Surfaces. Drill holes with a star or carbide drill, install expansion anchors, and secure the straps to the surface with machine screws.

Tile or Other Hollow Material. Secure the straps with toggle bolts.

Metal Surfaces. Drill holes, tap into the metal, and secure the straps with machine screws.

Provide an adequate number of supports according to *Table B-17, page B-17*. Cut the conduit between boxes (called a *conduit run*) to the proper length, thread it, ream it, and then bend it to suit the building contours. Attach the conduit-run ends to the boxes. In a concealed installation, you may notch the building members sufficiently to allow placing the conduit behind the wall surface, but avoid undue weakening of the structure.

CONNECTING BOXES

When the boxes are of threaded-hub construction, screw the conduit ends into the box hubs and connect the conduit runs at midpoint with a coupling. If the boxes are of knockout-type construction, use the following installation steps:

Step 1. Place the boxes loosely in the required position on studs and joists.

Step 2. Screw a bowed locknut, with the teeth of the locknut adjacent to the box, onto the threads at the run ends of the conduit.

Step 3. Insert the conduit ends into the knockout openings.

Step 4. Screw the bushings tightly onto the conduit ends in the boxes. (Bushings have smooth surfaces on their inside diameter to ensure damage-free conductor installation.)

Step 5. Tighten the locknuts against the boxes so that the teeth will dig into the metal sides of the boxes. You can do this by driving a drive punch against one of the locknut lugs and forcing the locknut to move on the threaded conduit against the box.

Step 6. Fasten the box securely to the building after you have made all the box connections.

PULLING WIRE

When installing boxes and conduit runs, pull the conductor wires into the conduit. For short runs with few wires, you can pair conductors and push them through the conduit run from box to box. When the conduit run has several bends and more than two conductors, you must use a fish tape to pull wire. After baring the conductor ends of insulation, connect them to the fish tape. Tape the conductor junction to the fish tape to preclude damaging the conduit interior and existing conductors in the conduit. Taping also compacts and strengthens the joint to ensure easier pulling. (See *Figure 5-3*.)

For efficient and safe operation, wire pulling is generally a two-man procedure. One electrician pulls the conductors through the conduit, while the other feeds the conductors into the conduit. In this operation, take care in feeding and pulling the wires so that they maintain their same relative position in the conduit throughout the run length, thus avoiding insulation injury. For ease of operation, you may rub a wire lubricant, such as powdered soapstone, on the conductors or blow the lubricant into the conduit. In intricate runs, you may perform wire pulling in sections between boxes. This procedure requires a large amount of additional splicing to be made in the boxes and requires that you take more time in wiring. The preferred practice in wire pulling is to pull the conductors from the source through to the last box in the conductor run. Make loops that extend about 8 inches from the box openings for each conductor that is to be tapped or connected to a device in the box. If conductors are not to be tapped, pull them directly through the box to their connection.

USING SPLICES

Wire splices in conduit installations are not under tension; therefore, you can use a simple pigtail splice that is carefully made to obtain a good electrical joint. Do not make

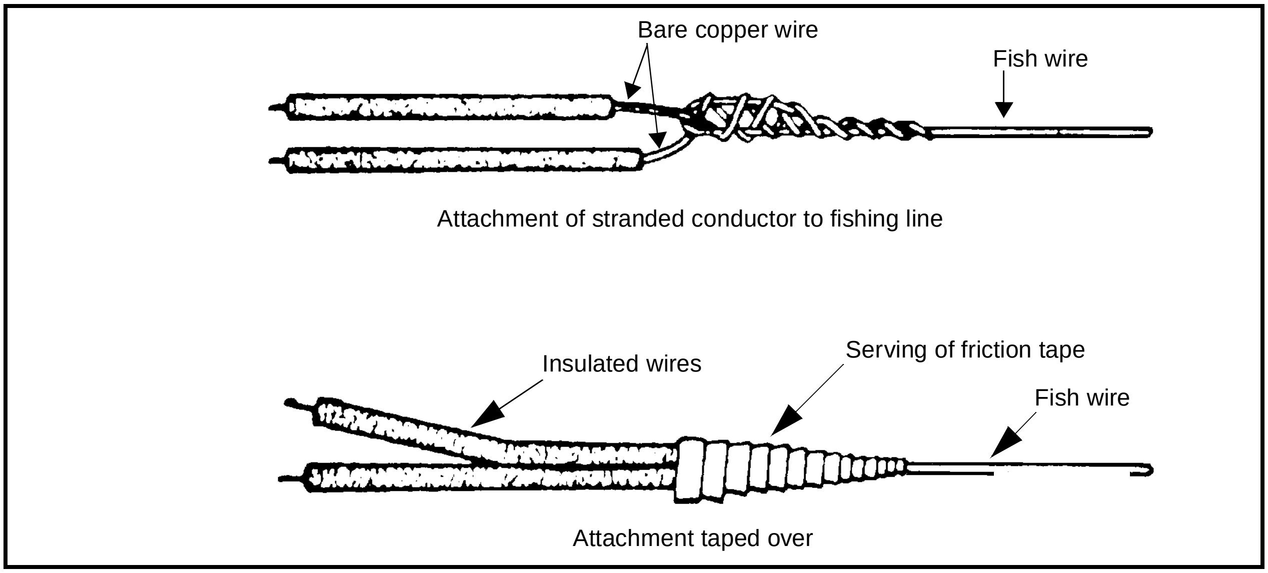


Figure 5-3. Attachment of fish wire

any wire splices that will be concealed in the conduit runs. This requirement is necessary because splices reduce the pulling area in a conduit and could easily be a source of electrical failure.

CIRCUITING

LAYOUT

Follow the directions and procedures in Chapter 3 for layout and circuiting of devices in a conduit installation. The availability of different sizes of conduit, along with their varying conductor capacities, makes the wiring installation for conduit somewhat different from that of the open or cable type. For example, where cable installation requires several runs in a particular location, a conduit installation would use a single conduit with multiple conductors. Consequently, conduit layouts and runs should be planned to use the minimum amount of conduit possible and also to keep the conductor runs to each outlet short enough to maintain a low voltage drop.

CONDUCTOR CONNECTION

No exceptions to the standard color coding of wires, as outlined in the other systems, are permitted in conduit wiring. All load utilization devices (fixtures and receptacles) operating at line-to-neutral voltage in a grounded neutral system must be connected to both a white and a black (or substitute color) wire. The white wire is always the grounded neutral wire. Black wires are the hot leads that are fused and connected to the switch when controlling power to a lamp holder or an outlet. Red, blue, and orange insulated wires can be used as substitutes for black wire when wire combinations are combined in a conduit or a circuit. Never connect the white wire to a black or substitute-color wire. You must not fuse or switch the white wire except in a multipole device that opens all conductors of the circuit simultaneously. A green insulated conductor denotes a wire used to provide an auxiliary equipment ground. As an expedient measure, the ends of the wire insulation may be painted to obtain proper color coding when the colored insulation is not available. They may also be identified by the use of wire code markers.

CONDUIT CAPACITY

Cable wiring, described in Chapter 4, is normally limited to two or three standard combinations of wire sizes. Conduit, however, has the capacity to accommodate several conductors in one run. *Table B-19, page B-18,* lists the maximum number of conductors of a certain gauge that can be inserted in the various sizes of conduit used in interior wiring. For example, the table shows that six No 14 wires would require the installation of a 3/4-inch conduit run. In many installations, it is necessary to use more than one wire size in a conduit run. In such cases, the conductors cannot have a combined or cross-sectional area equal to more than the allowable percent of cross-sectional area of conduit as shown in *Table B-20, page B-18.*

Table B-21, page B-19, lists the percent of conduit cross-sectional area in square inches available for conductor use. For example, if three No 10, Type R, and four No 8, Type R, conductors are to be inserted in a conduit, their combined cross-sectional area obtained from *Table B-22, page B-19,* is 0.4420 square inch (3 x 0.0460 + 4 x 0.0760). The proper size of conduit for this installation is 1 1/4 inches per *Table B-21*. You can find this by first looking for the total area in column 7. You will see that 0.4420 lies between 0.34 square inch (for 1-inch conduit) and 0.60 square inch (for 1 1/4-inch conduit). The 1-inch conduit is too small, so you would use the 1 1/4-inch size.

CIRCUIT WIRING

A fundamental law of electricity generation can be restated for wiring purposes as follows: When a conductor carrying current changes position or the current reverses direction in the conductor, it induces a current in an iron or steel conduit carrying the conductor. Consequently, if this conductor was isolated in an iron or steel conduit, the conduit would be heated by the induced current. This would result in considerable power loss. In an AC system, both wires of a circuit are encased in a single conduit, thereby causing the induced current of each to balance and cancel each other. To eliminate any possibility of induced heating of iron or steel conduit, both wires of a circuit must travel in the same conduit.

ADDITIONS TO EXISTING WIRING

INCREASE OF CIRCUIT AMPERAGE

A standard conduit installation has enough flexibility to accommodate a normal increase in circuit load even if an increase in circuit amperage is required. For example, a 1/2-inch conduit in a standard conduit wiring installation generally carries two No 14 conductors, which have a 15-ampere capacity. From *Table B-19, page B-18*, you can see that the 1/2-inch conduit can also accommodate two No 12 conductors, which have a 20-ampere capacity. Consequently, if you are increasing the load in an existing circuit, you can use two No 12 wires to replace the No 14 wire. When you have replaced all the wires in the circuit, you can safely increase the amperage for the fuse or circuit breaker in the central fuse panel for the circuit from 15 to 20 amperes to accommodate the additional load.

ADDITION OF NEW CIRCUIT

When adding a new load to an existing building with conduit wiring and the circuit analysis indicates the need for a new circuit, you can often use the existing conduit to carry the new circuit most of its distance. Install the new circuit by pulling in an additional wire (red) from the circuit-breaker panel to the existing outlet and then adding the required outlet box beyond this location. The new load is connected to the additional circuit. Use *Table B-19* to determine whether the existing conduit can accommodate an additional wire. The installation of the additional outlet box and conduit should conform to the rules and practices outlined previously. In this type of installation, use a common grounded-neutral wire.

Section II. Thin-Wall Conduit

USES AND ADVANTAGES

Electrical metallic tubing (EMT), commonly called *thin-wall conduit*, is a metallic tubing that can be used for exposed or concealed electrical installations. Its use should be confined to dry interior locations because it has a very thin plating that does not protect it from rusting when exposed to the elements or humid conditions. It is less expensive than rigid conduit and much easier to install. The process of bending requires less effort, and the ends do not have to be threaded. In comparison to the other wiring systems, it ranks behind rigid conduit but ahead of the other types of wiring when considering the quality and durability of the installation. For this reason and because of the decreased cost in materials and labor, it is most generally specified for home-building construction. Install it in the same manner as rigid conduit except use pressure-type couplings and connectors instead of threaded units.

CONDUIT AND FITTINGS

Thin-wall conduit is more easily installed than rigid conduit. This conduit, as its name implies, has a thinner wall than rigid conduit but has the same interior diameter and cross-sectional area. It is available in sizes from 3/8 to 2 inches. Use the 3/8-inch size only for under-plaster extensions. The inside surface is enameled to protect the wire insulation and minimize friction when pulling wire. All couplings and connections to boxes are threadless and are of clamp or compression type. *Figure 5-4* shows thin-wall conduit and the fittings commonly used. Some fittings are similar to sleeves and are secured to the conduit by an impinger tool, which pinches a circular indentation in the fittings to hold them firmly against the conduit. Others have threaded bushings that are tightened to force the tapered sleeve firmly against the tubing.

CONDUCTORS

The same type, capacity, and maximum number of conductors per size of conduit previously given in *Tables B-17 through B-21, pages B-17 through B-19*, for rigid conduit also apply to thin-wall installations.

Figure 5-4. Thin-wall conduit and fittings

BENDS

Use extreme care when bending metallic tubing to avoid kinking the pipe or reducing its inside area. When using thermoplastic-covered conductors, the radius of the curve of the inner edge of any field bend must be at least six times the internal diameter of the tubing. When using lead-covered conductors, it must be at least 10 times the interior diameter of the tubing. *Table B-18, page B-17*, shows the minimum radii for field bends.

CONSTRUCTION

The thin-wall conduit bender (*Figure 5-5*) has a cast-steel head that is attached to a steel pipe handle that is approximately 4 feet long. It is used in the field to form thin-wall conduit into standard and offset bends. Benders are made for each size of conduit; therefore, use them only on those sizes for which they are designed. Each size bends the conduit to the recommended safe radius. Use the projection on the head of the bender, sometimes called a *foot step*, to steady the bender in operation and reduce the pressure required on the handle. The numbers cast on the bender shaft are inch measurements that you can use to check the depths of offset bends.

OPERATION

When making a 90-degree bend, place the conduit on a level surface and hook the end of the proper-size tube bender under the conduit's stub end. Using a steady and continuous force, firmly hold the conduit and bender (with the bending groove over the conduit), push down on the handle, and step on the footstep to bend the conduit to the desired angle. To make a 45-degree bend in this manner, move the bending tool until the handle is vertical. For accurately bending conduit stubs, place the bender at a predetermined distance from the end of the conduit. This distance is equal to the required stub dimension minus an amount commonly called a *take-up height*. The take-up height is based on a constant allowance determined by the bending radii for various-size conduit. The take-up height is 5 inches for 1/2-inch conduit, 6 inches for 3/4-inch conduit, and 8 inches for 1-inch conduit.

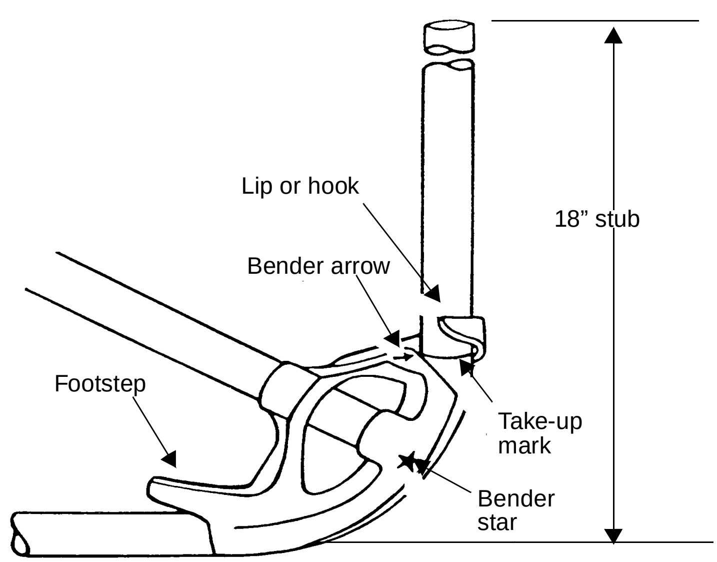


Figure 5-5. Thin-wall conduit bender

INSTALLATION

You may cut thin-wall conduit with a hack-saw or a special thin-wall cutter. As with rigid conduit, you should also ream the sharp edge in thin-wall tubing after cutting to prevent premature wire damage. Exposed thin-wall conduit is supported in a similar manner and with the same type of supports used with rigid conduit. Since there is no positive link between the couplings, box connectors, and thin-wall conduit, ensure that each conduit joint is electrically and mechanically secure. Insert all conduit ends into the fittings until they touch the inner limiting edges. Then, firmly tighten the fit-tings so that they securely grip the conduit walls.

DANGER

Avoid loosening the conduit from the fittings because it could cause a loose connection, a short circuit, or an electrical fire at the point of wire and conduit contact. A mechan-ically loose conduit joint will not maintain the ground continuity required in all electrical wiring installation. This could also create an operating hazard for Army personnel.

Section III. Flexible Conduit

MATERIALS

Flexible metal conduit, generally called *Greenfield*, resembles armored cable in appearance but is more adaptable than cable because various sizes and numbers of wires can be pulled into it after it is installed. You may use plastic-covered Greenfield when the internal conductors are exposed to oil, gaso-line, or other materials that have a deteriorative effect on the wire insulation. This metal conduit has a thermoplastic outer-sheath covering similar to that used on Type T wire, the characteristics and uses of which are detailed in *Table B-2, pages B-2 through B-4*. *Figure 5-6, page 5-12*, shows flexible conduit and the various fittings available.

INSTALLATION

Flexible conduit installation is similar to that for thin-wall conduit except that Green-field must be supported more frequently. Its prohibitive cost limits its use to connections between rigid wiring systems and movable or vibrating equipment such as motors or fans. It may also be installed where the con-struction requires a conduit bend that is dif-ficult or impossible to make.

GROUNDING

Because of restrictions, you must ground most flexible conduit systems by running a separate grounding wire along with the cir-cuit conductors.

BENDING AND SUPPORTING

Despite its flexibility, runs of flexible con-duit between boxes and fittings must not bend more than the equivalent of four quar-ter turns. This conduit must be supported with a conduit strap within 12 inches of every box or fitting and at intervals no longer than 4 1/2 feet.

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 5-6. Flexible conduit and fittings

Section IV. Nonmetallic Conduit

USES

Many types of nonmetallic conduit are available, but schedule 40 polyvinyl chloride (PVC) is the one most electricians use. It is a rigid, heavy-walled, flame-retardant, heat- and sunlight-resistant conduit. It may be used in wet or dry locations, in walls, in ceilings, and above or below the ground. Do not try to substitute PVC irrigation pipe for schedule 40 PVC conduit; look for the insignia of an electrical materials testing laboratory. You can use nonmetallic conduit with metal or nonmetallic boxes, but the nonmetallic boxes are not the same as those used with Type NMC cable.

WIRING

Nonmetallic conduit does not constitute a grounded system, so you must run a separate grounding wire with the circuit conductors.

TRIMMING

After cutting PVC, trim the ends inside and out with a pocketknife to remove any rough edges that might damage conductor insulation.

BENDING

Bends in PVC are made by heating the conduit in a special infrared heater until it is soft. Do not try to heat PVC with a torch because you will char the conduit. Design your runs so that no piece of conduit between fittings bends more than the equivalent of four quarter turns.

JOINING

PVC comes in 10-foot lengths, each one with a coupling. Glue the conduit together with gray conduit cement; do not use water-pipe cement. Male and female adapters are available for transitions to other types of conduit and for box connections.

CHAPTER 6

Foreign Systems

Most foreign wiring systems are not installed according to prescribed standards, so they do not conform to the rigid safety limitations and practices followed in the US. This fact may be attributed largely to material shortages in most foreign countries that have dictated the use and employment of materials at hand. In many instances, these materials would be considered below standard or expedient substitutes in the US. These limitations have been advantageous in some areas, such as the Scandinavian countries, because they have provided an incentive for electrical development that has resulted in more rapid advancement. This chapter acquaints electrical personnel with the major differences to be found and the precautions to be taken when making wiring installations or using equipment purchased or procured in a foreign country. To properly illustrate and discuss the major differences in foreign wiring, US standards are reviewed when necessary.

Section I. Wiring Installations

TYPE OF WIRING

The wiring system generally in use in most foreign countries is similar to open wiring installations because of the low material requirements. Other types of installations, outlined in the preceding chapters, are being installed in urban areas.

VOLTAGES

DOMESTIC

The US uses nominal voltages that range from 120 to 240 volts for single-phase AC low-voltage distribution. Though these voltages are considered to be standard voltage ratings because of their prevalent use, some locations and areas throughout this country still have DC systems or use AC systems with nonstandard voltages.

FOREIGN

Since many countries employ voltages other than those we accept as standard, the electrical equipment in use during occupancy or wartime must be converted, modified, or operated inefficiently when powered by foreign electrical installations. FM 5-422 includes frequency and voltage charts for different parts of the world.

FREQUENCY

The standard frequency of AC distribution in the US is 60 cycles. In most foreign lands, 50-cycle frequency generation is common, but US Army personnel could also encounter such frequencies as 25, 40, 42, and 100 cycles.

MATERIALS

BACKGROUND

The wiring materials commonly used in foreign countries are usually peculiar to the territory's manufacture. In recent years, however, the large export of electrical goods from Germany, England, and the US has been increasingly reflected in the established wiring patterns.

WIRE

The US employs the AWG system, which is peculiar to our installations. However, most foreign wire that Army personnel use differs in size and usage from those given in this manual. *Table B-23, page B-20,* gives the standard and metric diameter of standard AWG sizes.

DEVICES

The receptacles, switches, and plugs used in foreign wiring systems are also peculiar to the installations found in a particular area and normally cannot be mated or used with similar types of receptacles manufactured in the US.

Section II. Additions to Existing Installations

PROCEDURES

During occupancy or wartime in a foreign territory, the Army may commandeer and use all or part of a foreign electrical installation. Though the decision of employment is determined largely by the immediate circumstances, the Army electrician or unit commander will make this decision based on the availability of supplies and time.

SUPPLY

Since the electrical components of a foreign and domestic electrical system cannot be interchanged, the problem of supply is a major factor. The problems of installation and use of foreign power equipment should be compared to the necessary modification of US electrical items to meet the standards required in the foreign territory.

MODIFICATIONS

If time is a factor, consider using standard electrical items made in the US and modify the plugs or connections so that they may be used with the foreign installation. Though this method usually results in decreased operating efficiency, the ease of adaptability and abundance of supply usually outweigh the reduction in performance.

EFFECTS OF VOLTAGE DIFFERENCES

All equipment should be operated at its rated voltage. To expedite the use of a foreign system, items built to operate at standard US voltages may have to operate at different voltages. Though they may not be operated efficiently, their availability for use may be an important military advantage. Some effects of voltage differences on common electrical devices are—

- When fluorescent lamps are operated at voltages higher than standard, both the lamp and ballast life are shortened. Line voltages below the minimum of the operating ranges of 110 to 240, 199 to 216, or 220 to 250 volts will cause uncertain starting, short lamp life, and reduced lighting efficiency.

- When incandescent lamps are used and operated at voltages higher than their normal ratings of 115, 120, and 125 volts, they have a shortened lamp life and their light output is increased. Conversely, if the line voltage of operation is below standard, the life of the lamps is increased and the lighting efficiency is reduced approximately 3 percent for each 1 percent drop in rated voltage.
- Rotating equipment, such as motors and fans, is usually manufactured to operate with a permissible voltage variation of 10 percent within their prescribed rating. The combined voltage and frequency variation is also limited to 10 percent. Higher voltages give increased torque, efficiency, and starting temperature. A lower operating voltage results in decreased torque, decreased efficiency, and increased running temperature. Operation at voltages differing from the rated voltage by more than 10 percent may be permitted only in an extreme emergency because the equipment could be damaged or destroyed by such operation.

EFFECTS OF FREQUENCY DIFFERENCES

Electrical operating items that are based on resistance characteristics such as heaters, hot plates, and electric stoves operate efficiently over all ranges of distribution frequencies used throughout the US and foreign territories. Rotating equipment and items such as lights and transmission or receiving equipment are adversely affected by variations in frequency. Some effects of frequency changes on this type of equipment are—

- Fluorescent lights rated to operate at nominal 60-cycle current can be used at 50 cycles, but they will have a shorter ballast life. At lower than 60-cycle frequencies, a noticeable flicker in the light output can be seen. This is undesirable in areas where painstaking and meticulous work is being performed. Operation at lower frequency is not satisfactory and should be avoided.
- Incandescent lights, because of their resistance design, will operate satisfactorily at all of the frequencies encountered overseas.
- Motors should not be connected to power-distribution systems with frequencies that vary more than 5 percent from their rated limits of operation. Some motors are built to function at either 50 or 60 cycles. Their shaft speed is directly proportional to the frequency of the power supply. Consequently, if a motor is nominally rated to run at 1,800 revolutions per minute at 60 cycles and is operated at 50 cycles, its output speed will be 1,500 revolutions per minute. Special motors with considerably larger frames must be obtained for the same power outputs at lower frequencies.
- All receiving and transmitting equipment or other items that have transformers included in their wiring will not operate satisfactorily either below or above their rated line frequency and should be used only in an emergency.

EFFECTS OF MATERIAL DIFFERENCES

Dissimilar metals should never be used together except in an emergency expedient installation. Interchangeable use of dissimilar materials in a power-distribution system can create problems. The close association of dissimilar metals can cause galvanic corrosion at the joints, which would eventually destroy the usefulness of the equipment. This is a particular concern when aluminum and copper are joined; however, new materials that have no adverse effects are available specifically for connection to copper or aluminum. These new materials are marked for easy identification. If aluminum is used exclusively in a system, a special joint compound must be applied to all connections or joints. This compound protects the connection against excess surface oxidation because, unlike copper oxide, the oxide of an aluminum conductor adds a high contact resistance to the wire.

CHAPTER 7

Switches and Fuses

Manual and automatic switches are used to open and close circuits. They must be designed to carry their rated current continuously without overheating and must have clearances and insulation for the normal voltage of the circuit. Fuses and circuit breakers provide a simple, comparatively inexpensive method of automatic overcurrent protection, as well as a means of controlling the location of breakdowns.

DISCONNECTS

Disconnect switches are generally used in a primary circuit where opening the circuit is necessary under voltage with little or no load current. They must interrupt only the charging or exiting current of lines or apparatus connected. These switches are ordinarily used to disconnect branch lines, off-circuit breakers, and transformers where the load current may otherwise be broken.

TYPES

Disconnect switches are available in various types, ratings, and classes. The switch shown in *Figure 7-1* is used at switch structures and out on the line. If the mounting height is not too great, the switch can be operated from the ground with a long-handled switch stick. The switches shown in *Figure 7-2, page 7-2,* are used for line sectionalizing. They are generally installed on the crossarms carrying the primary circuit and are operated by a switch stick that can be fastened to the lineman's belt.

BYPASS SWITCHES

Bypass switches may be used at booster and regulator installations to provide a quick, reliable means of taking such apparatus in and out of service without de-energizing the feeder circuits and to prevent winding burn-outs from open-circuit windings.

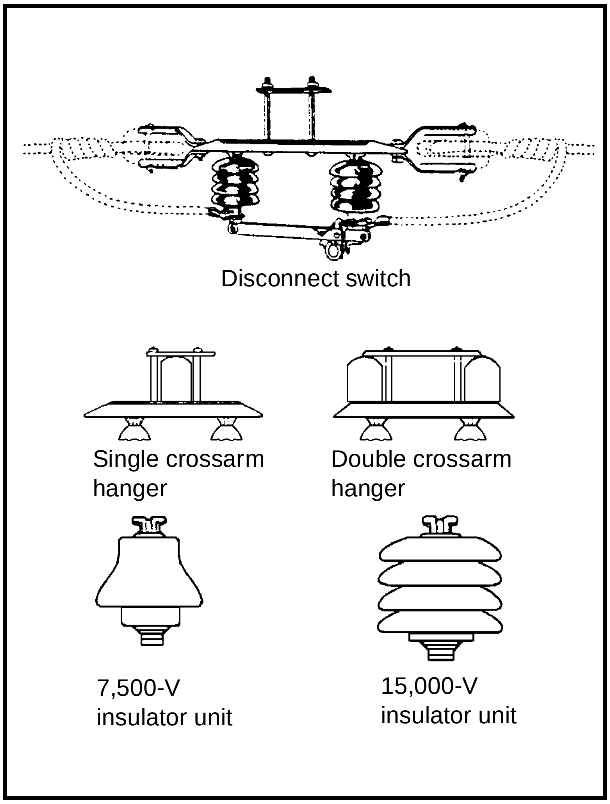


Figure 7-1. Open-type disconnect switch and components

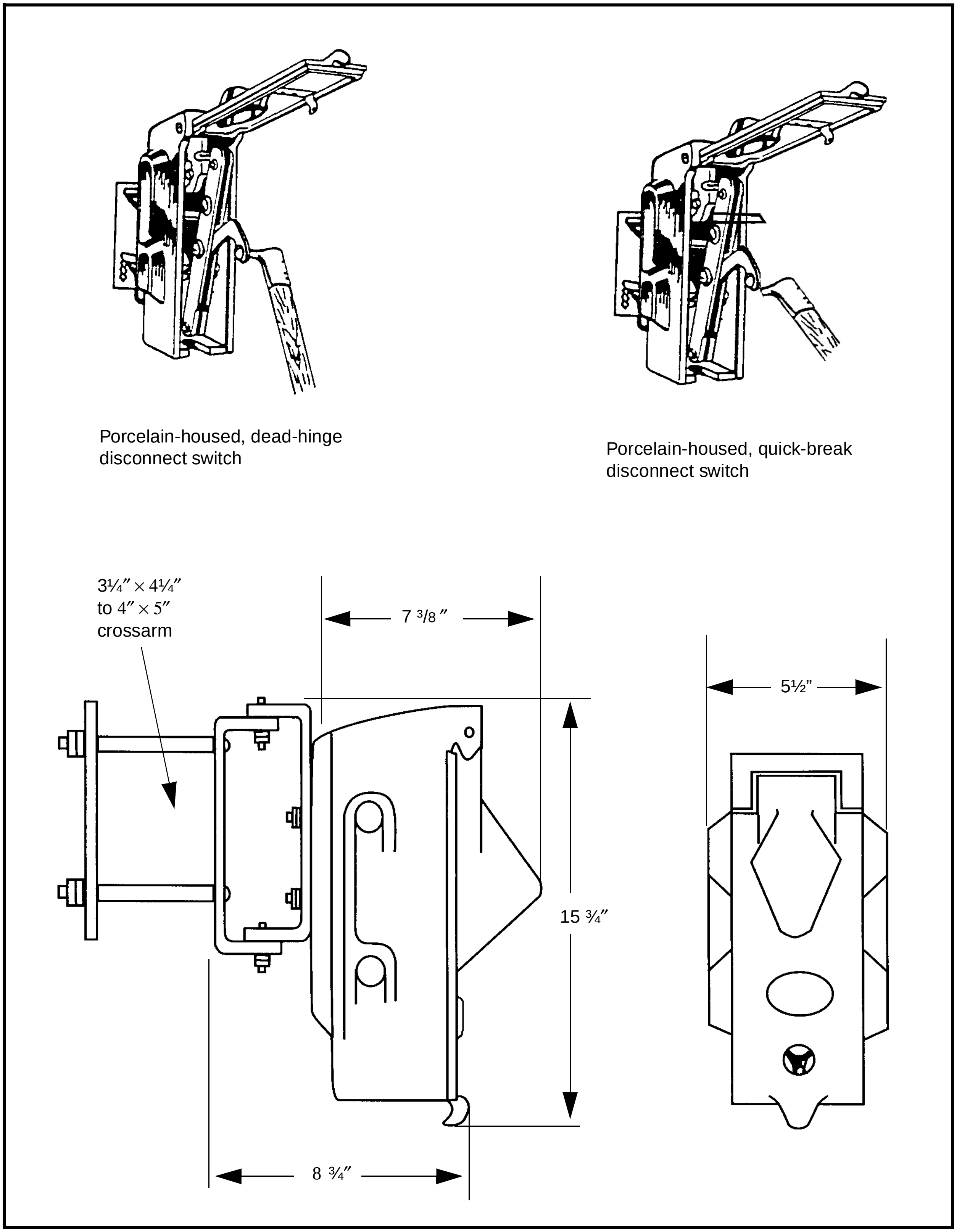


Figure 7-2. Enclosed-type disconnect switches

GANG-OPERATED DISCONNECTS

Gang-operated disconnects are used where more than one phase of a circuit must be opened simultaneously. The most common gang-operated disconnect switches are the air-brake type manufactured in 200-, 300-, and 400-ampere ratings in all voltage classes from 5,000 volts up. They are used at substations, switching structures, and on the lines for energizing and de-energizing transformer banks and other apparatus. They are also used for sectionalizing. Although they can be motor-operated, they are more commonly provided with a switch handle for hand operation. This type of switch is ideal because it lends itself to operation from the ground, often permitting service to be restored to sections of the network without pole climbing.

MAINTENANCE

Contacts of disconnects must stay smooth and covered with a thin film of nonoxide grease. The bearing must be well lubricated, and the blades should move freely yet be rigid enough for proper alignment with contacts. Locate broken or defective insulators during inspections and replace them immediately. Ensure that all bolts and nuts are tight.

CAUTION

Always ground the switch handle by connecting it to the counterpoise or ground plate, below the topsoil, directly beneath the operating handle.

OIL CIRCUIT BREAKERS

Oil circuit breakers open a circuit automatically under load. They are generally designed and connected for one or more automatic reclosings to restore service quickly when a fault has cleared itself. Their use is generally confined to substations or switching stations where either high interrupting capacity or high-grade service is required.

Pole-mounted oil circuit breakers are also called *reclosers, sectionalizing oil circuit breakers*, or *interrupters*. They are adaptable for use on the low side of step-down substations, on branch circuits that are connected to important feeders, and for protecting important loads and isolating line trouble. Reclosers are available with ratings up to 50 amperes and 15,000 volts; the 50-ampere breaker has an interrupting rate of about 1,200 amperes.

The recloser is connected in the line and is normally closed. The trip coil is in series with the contacts and derives energy from fault current, which may lift the armature and the movable contact of the interrupting element by magnetic attraction. When a fault occurs, the circuit promptly opens and then automatically recloses in about three seconds. If the fault is not cleared on the first interruption, the recloser opens the circuit a second and possibly a third time. If the fault is cleared after the second or third interruption, the recloser mechanism automatically resets. If the fault persists after the third interruption, the recloser opens a fourth time and locks open. It must then be reset manually.

The recloser contains one pair of contacts—the lower (stationary) contact is in the bottom of the unit, and the upper (movable) contact is connected to one end of the operating or trip coil. The contacts are normally held in the closed position by positive pressure, but when a short circuit occurs, the movable contact rises rapidly, drawing an arc in the oil. The heat of the arc forms a gas bubble, which sets up pressure in the oil-blast chamber. This pressure in the chamber forces a blast of cool air between the contacts, preventing the arc from reestablishing itself after an early current zero. The butt-type contacts automatically compensate for burning caused by repeated operation. They can be replaced if renewal eventually becomes necessary. *Figure 7-3* shows a single-phase installation, including a bypass switch and a lightning arrester. The use of bypass switches is optional. Some types of breakers include internal lightning protective devices so external lightning arresters are not required.

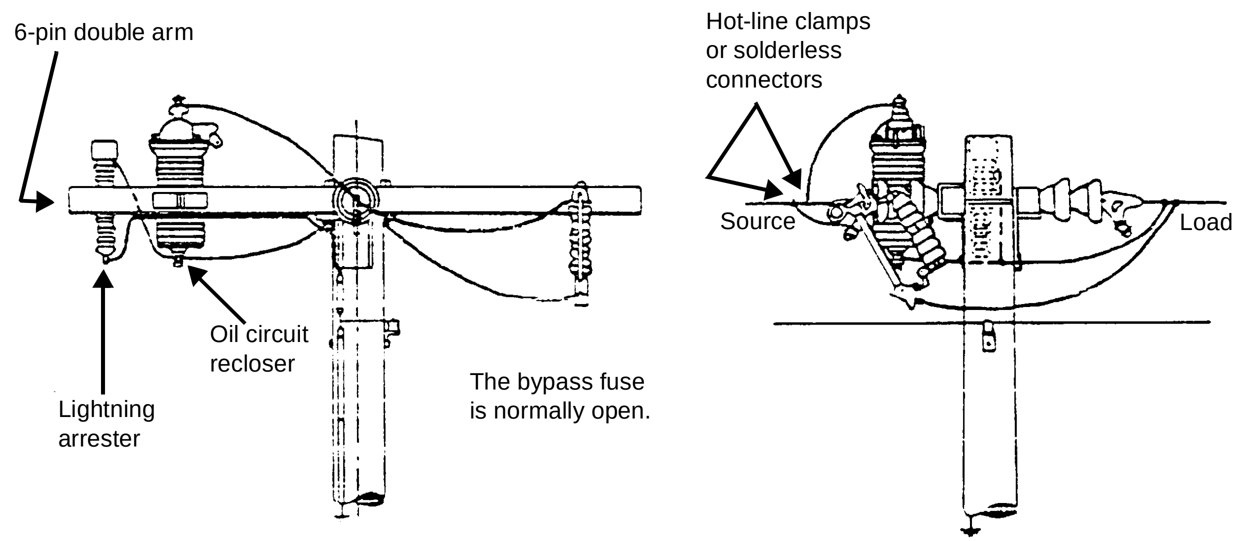


Figure 7-3. Pole-mounted oil circuit breaker, single-phase, Y-primary

OIL FUSE CUTOUTS

Oil fuse cutouts are most commonly used on underground systems. They are also used on overhead systems that have voltage ratings up to 7,500 volts, where intermediate interrupting capacity is required and automatic restoration of service is not essential.

CIRCUIT-RECLOSING FUSE CUTOUTS

Circuit-reclosing fuse cutouts (multiple-shot) are either porcelain-housed or open. Porcelain-housed cutouts are manufactured in 50- and 10-ampere ratings and in 5,000- and 500-volt classes. Open cutouts are available in higher voltage classes and mounted on either standard pin-and-cap insulators or one-piece, post-type insulators. Open types are available in sizes up to 100 amperes in voltage classes up to 46 kilovolts and in sizes up to 200 amperes, limited to 7,500- and 15,000-volt ratings.

Cutouts frequently permit quick restoration of service where frequent temporary faults may be caused by lightning or high winds. Although the open type is more commonly used, both types are applicable for use on feeder or branch circuits. Their use should be confined to remotely located and unattended substations or at remote locations on the distribution circuits.

OPERATION

When the fuse link blows, the first holder drops out. The dropping of the holder or cartridge, either by pressure or spring action, closes the circuit through the next cartridge. If the cutout is a three-shot type, this performance is repeated. Three faults on a three-shot cutout cause all three fuses to blow, and all three barrels should be found in the dropout indicating position. Cartridges can be replaced in any sequence without momentary service interruptions.

FUSES

Fuses for distribution systems are manufactured in various styles for similar and varying applications. Some manufacturers place the fuse element in a tube that is filled with powder or granular material to absorb the vaporized fuse metal and to extinguish the arc. In other types, the element is placed in a tube; and the arc is extinguished by a dielectric, using either high or low interrupting capacity. Both initial and replacement costs of these fuses are high, and application is usually limited to circuits having 13,200 volts or more. *Figures 7-4 and 7-5, page 7-6,* show two types of circuit-reclosing fuse cutouts.

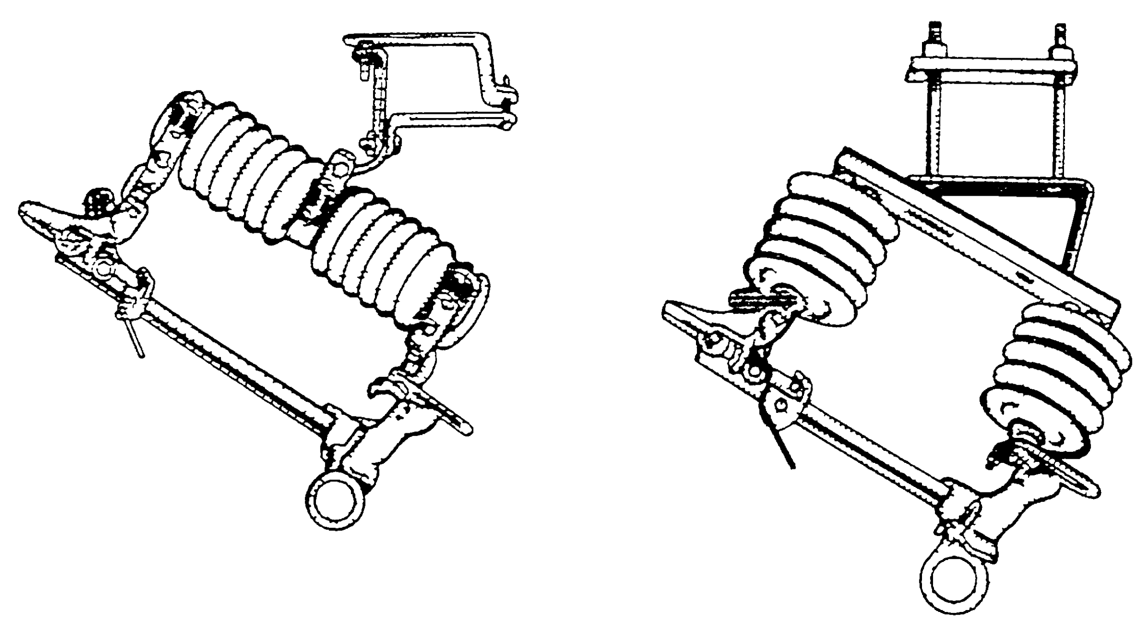
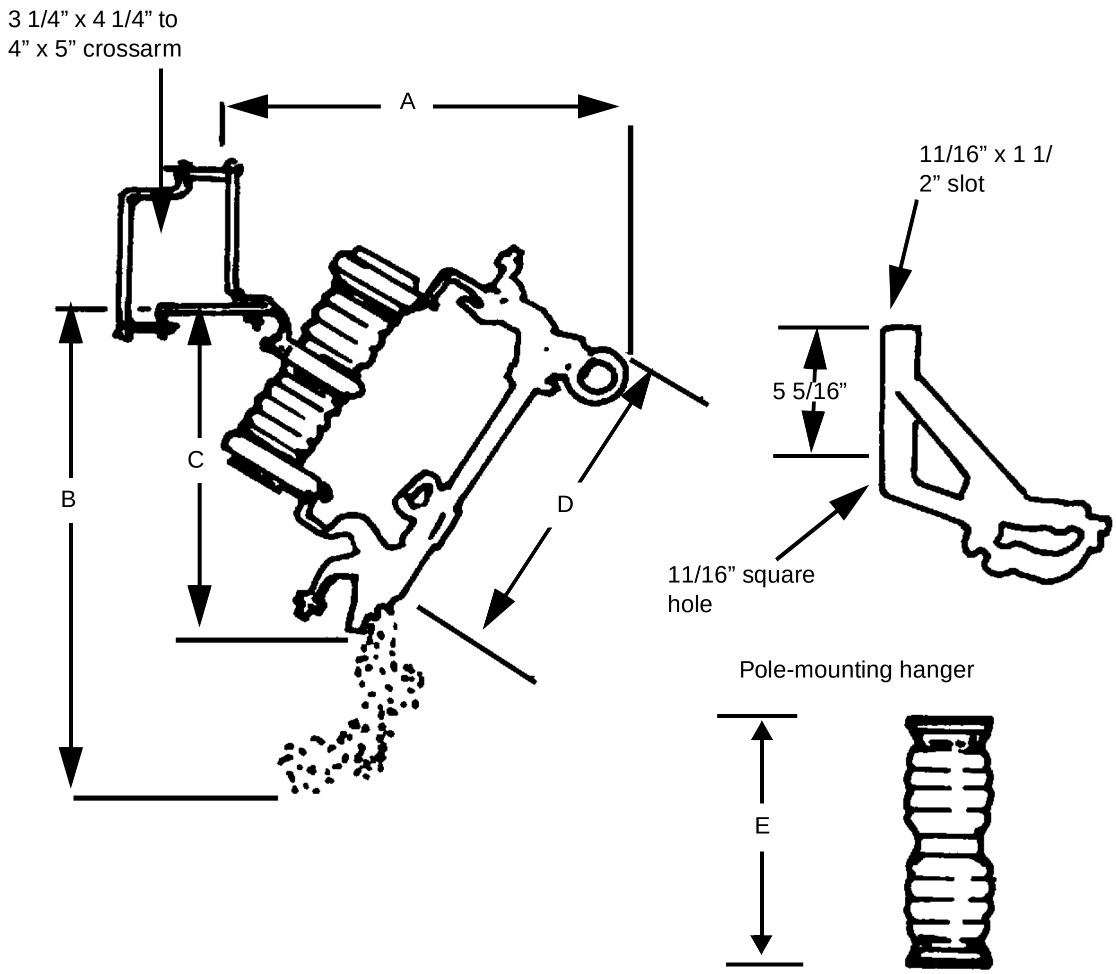


Figure 7-4. Fused disconnect switches



Voltage	A	B	C	D	E
7,500/12,500	17 3/8”	26 7/8”	15”	14 1/4”	11”
15,000	18 3/8”	31 5/8”	16 1/2”	17 1/2”	16 1/4”

Figure 7-5. Typical open-type fuse

Part Three. Power Generation

CHAPTER 8

Generators

The demands for electricity in military field operations are numerous and varied. Electricity powers equipment ranging from rock crushers to missile launchers. It services aircraft, ships, and land vehicles. Electricity is required for command and control operations, medical support, and other facilities. The Department of Defense (DOD) uses a *family* of generator sets to produce the electrical power needed by military field units. This family was developed in the 1960s to reduce the variety of generator sets and repair parts required by all services. This chapter describes the generators in this family and provides instructions for their use.

Section I. Mobile Generator Sets and Electric Distribution Systems

MOBILE GENERATOR SETS

A mobile electric generator set converts mechanical energy to electrical energy by using an engine to drive the generator. An internal fuel supply makes the set independent and mobile. When equipped with accessories such as an electric distribution system, this set produces all the power needed by military forces in the field. The elements of an electrical power-generating site in the field are shown in *Figure 8-1, page 8-2*.

Table 8-1, page 8-3, lists the characteristics of generator models found in the DOD inventory and shows kilowatts, frequency rating (in cycles per second), and voltage output. The rated current of DC generators is shown in the output column. The characteristics in the table must match the requirements for the equipment that is being connected to the generator set.

Table 8-2, page 8-4, shows the generator models separated by the type of engine that drives the generator, the application (use) for each model, and the TM that provides additional information about it.

Electric generator sets are driven by gasoline or diesel engines and produce AC or DC. AC changes in value and reverses its direction of flow at regular intervals; DC is constant in value and flows in only one direction.

AC GENERATOR SETS

The lighting and power loads of most field units require voltages and frequencies supplied by AC systems. While 60-cycle AC is used much of the time, loads with specific voltage, frequency, and power requirements may use up to 400-cycle AC. Radar, fire-control sets, communication controls, and guided-missile systems are examples of equipment that require 400-cycle AC. Some equipment can operate with either 60- or 400-cycle AC.

AC generator sets are designed to operate at various voltages, frequencies, and power levels. To meet a particular power demand, an operator must choose a set with the proper characteristics. If a large set is needed but is unavailable, several small sets, each located near the load to be supplied, may be used. Additional operators and maintenance personnel may be required if several small sets replace a large one.

Mobility is a factor in selecting generator sets for field use. Sets that produce 60 kilowatts of electricity are often used in the field because they can be transported in 2 1/2-ton trucks. Sets that produce more than 60 kilowatts of power must be transported in 5-ton trucks. Therefore, a field unit may make parallel connections between several 60-kilowatt generator sets to produce an amount of power equivalent to one large set.

Small

Small AC generator sets are driven by gasoline engines and produce 0.5 or 1.5 kilowatts of electricity. The output is delivered in 120 or 240 volts, with a single-phase distribution system, at a frequency of 60 cycles. Sets that produce 0.5 kilowatts are available at a frequency of 400 cycles; sets that produce 1.5 kilowatts are available at a frequency of 60 cycles.

The 1.5-kilowatt, 60-cycle generators are the most versatile and widely used small sets in the DOD inventory. They satisfy the communications and lighting needs of small field units.

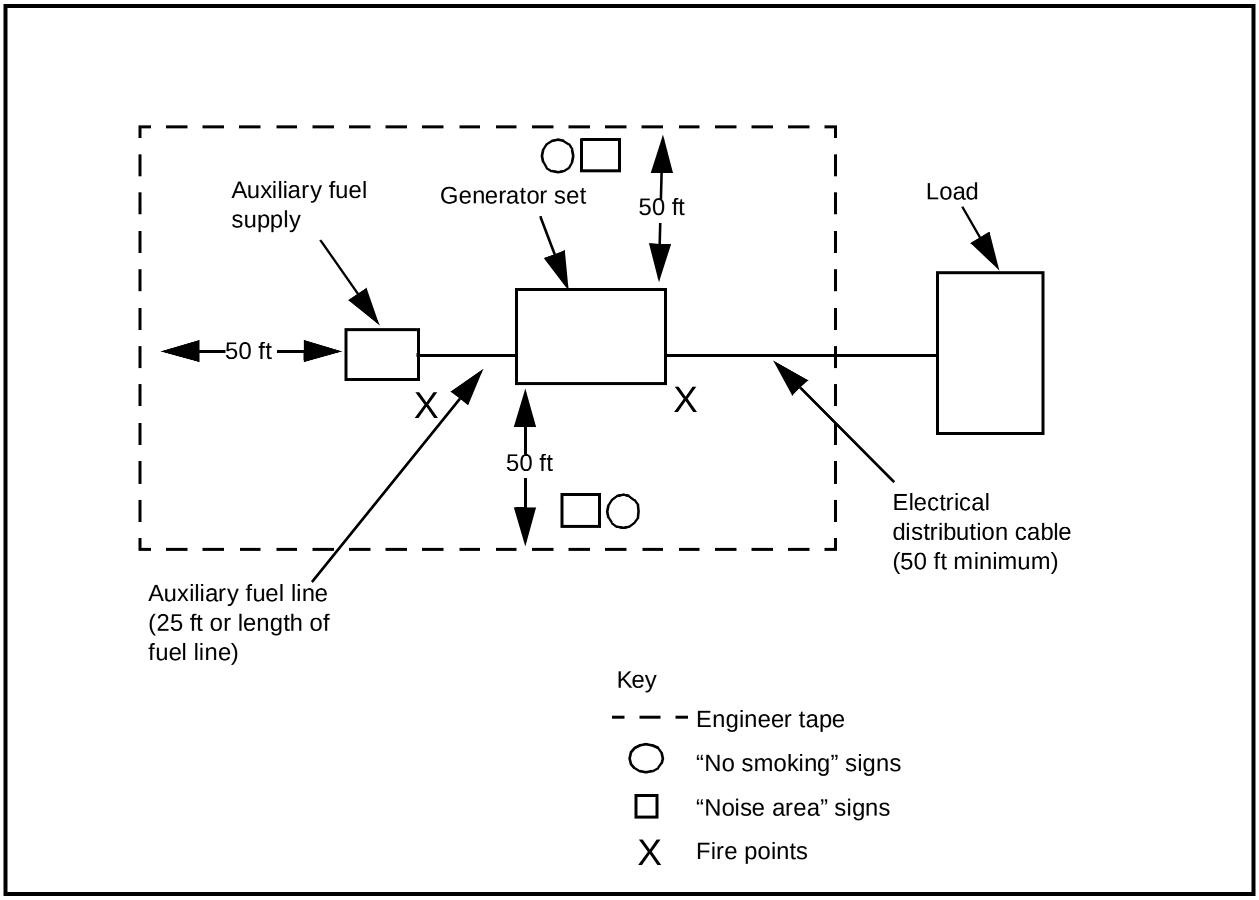


Figure 8-1. Typical electrical power-generating site

Table 8-1. Generator set characteristics

Model	Kilowatts	Frequency (Cycles per Second)	Voltage Output
MEP-014A	0.5	60	120/240 V, single-phase, three-wire
MEP-024A	0.5	DC	28 V, 17 amps
MEP-019A	0.5	400	120/240 V, single-phase, three-wire
MEP-015A	1.5	60	120/240 V, single-phase, three-wire
MEP-025A	1.5	DC	28 V, 53 amps
MEP-016A	3	60	120 V, three-phase 120/240 V or 120/208 V, three-phase, four-wire
MEP-021A	3	400	120 V, three-phase 120/240 V or 120/208 V, three-phase, four-wire
MEP-026A	3	DC	28 V, 103 amps
MEP-002A	5	60	120 V, three-phase, three-wire 120/240 V or 120/208 V, three-phase, four-wire
MEP-017A	5	60	120 V, three-phase, three-wire 120/240 V or 120/208 V, three-phase, four-wire
MEP-022A	5	400	120 V, three-phase, three-wire 120/240 V or 120/208 V, three-phase, four-wire
MEP-018A	10	60	120 V, three-phase, three-wire 120/240 V or 120/208 V, three-phase, four-wire
MEP-023A	10	400	120 V, three-phase, three-wire 120/240 V or 120/208 V, three-phase, four-wire
MEP-003A	5	60	120 V, three-phase, three-wire 120/240 V or 120/208 V , three-phase, four-wire
MEP-112A	10	400	120 V, three-phase, three-wire 120/240 V or 120/208 V, three-phase, four-wire
MEP-004A	15	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-103A	15	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-113A	15	400	120/208 V or 240/416 V, three-phase, four-wire
MEP-005A	30	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-104A	30	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-114A	30	400	120/208 V or 240/416 V, three-phase, four-wire
MEP-006A	60	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-105A	60	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-115A	60	400	120/208 V or 240/416 V, three-phase, four-wire
MEP-404B	60	400	120/208 V or 240/416 V, three-phase, four-wire
MEP-007A	100	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-007B	100	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-106A	100	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-116A	100	400	120/208 V or 240/416 V, three-phase, four-wire
MEP-009A	200	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-108A	200	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-029A	500	50/60	120/208 V or 240/416 V, three-phase, four-wire
MEP-029AHK	500	50/60	120/120 V or 120/208 V, three-phase, four-wire

Table 8-2. Mobile electric generator sets

Model	Kilowatts	Application	Voltage	Technical Manual
Gasoline-Engine Driven				
MEP-014A	0.5	Utility	AC	TM 5-6115-329-14
MEP-019A	0.5	Utility	AC	TM 5-6115-329-14
MEP-024A	0.5	Utility	DC	TM 5-6115-329-14
MEP-015A	1.5	Utility	AC	TM 5-6115-323-14
MEP-025A	1.5	Utility	DC	TM 5-6115-323-14
MEP-016A	3	Utility	AC	TM 5-6115-271-14
MEP-021A	3	Utility	AC	TM 5-6115-271-14
MEP-026A	3	Utility	DC	TM 5-6115-271-14
MEP-017A	5	Utility	AC	TM 5-6115-332-14
MEP-022A	5	Utility	AC	TM 5-6115-332-14
MEP-018A	10	Utility	AC	TM 5-6115-275-14
MEP-023A	10	Utility	AC	TM 5-6115-275-14
Diesel-Engine Driven				
MEP-002A	5	Utility	AC	TM 5-6115-584-12
MEP-003A	10	Utility	AC	TM 5-6115-585-12
MEP-112A	10	Utility	AC	TM 5-6115-585-12
MEP-005A	30	Utility	AC	TM 5-6115-465-12
MEP-104A	30	Precise	AC	TM 5-6115-465-12
MEP-114A	30	Precise	AC	TM 5-6115-465-12
MEP-006A	60	Utility	AC	TM 5-6115-545-12
MEP-105A	60	Precise	AC	TM 5-6115-545-12
MEP-115A	60	Precise	AC	TM 5-6115-545-12
MEP-007A	100	Utility	AC	TM 5-6115-457-12
MEP-007B	100	Precise	AC	TM 5-6115-457-12
MEP-106A	100	Precise	AC	TM 5-6115-457-12
MEP-116A	100	Precise	AC	TM 5-6115-457-12
MEP-009A	200	Utility	AC	TM 5-6115-458-12
MEP-108A	200	Precise	AC	TM 5-6115-458-12
MEP-029A	500	Utility	AC	TM 5-6115-593-12
MEP-029AHK	500	(with options)	AC	TM 5-6115-593-12
Turbine-Engine Driven				
MEP-404B	60	Precise	AC	TM 5-6115-603-12

Medium

Medium AC generator sets are driven by gasoline or diesel engines and produce between 3 and 10 kilowatts of electricity. These generator sets can deliver 60- or 400-cycle AC. A reconnection switch enables the operator to connect any of the following distribution systems at the rated kilowatt output:

- Single-phase, two-wire, 120 volts.
- Single-phase, two-wire, 240 volts.
- Three-phase, three-wire, 120 volts.
- Three-phase, four-wire, 210/208 volts.

Generator sets that produce 60-cycle AC are used for general power requirements because they are versatile and their power output ranges considerably. Sets that produce 10 kilowatts at 60 cycles are the most versatile because their output is adequate for small maintenance shops and other relatively large loads. These generators are usually mounted on skids to increase mobility.

Large

Large AC generators are driven by diesel engines and produce between 15 and 500 kilowatts of electricity. These generators can deliver 50/60- or 400-cycle AC. They can deliver three-phase, four-wire power at 120/208 or 240/416 volts. An output delivered at 50 cycles is 82 percent of the rated power; an output delivered at 60 cycles is 100 percent of the rated power.

Large generator sets produce electricity for lighting and power in buildings and other general loads. They can produce enough output to supply several kinds of loads simultaneously over a relatively wide area. Standard-frequency generator sets are rated at 50/60 cycles; high-frequency generator sets are rated at 400 cycles.

DC GENERATOR SETS

DC generator sets provide power for specific pieces of equipment. For example, they are used to charge batteries, operate communications equipment, and provide power to some missile equipment. Thus, the need for DC generator sets in the field is less than the need for AC generator sets. The three DC generator sets listed in *Tables 8-1 and 8-2, pages 8-3 and 8-4*, are basic AC generators that use rectifiers to convert the AC voltage to DC voltage.

DATA PLATES

Three data plates located on the generator provide pertinent information about output, capabilities, and performance characteristics. Refer to the description and data section in the appropriate TM for information about a specific generator that is not on the plates.

- Alternator Data Plate. Specifies the alternator ratings for 50-, 60-, and 400-cycle outputs. It provides the serial number, kilowatt rating, DC excitation requirement, date of manufacture, voltage and ampere outputs, power factors, model number, and revolutions per minute (rpm). On most models, this plate is attached to the main generator housing.
- Equipment Identification Plate. Specifies the model number, serial number, horsepower rating, date of manufacture, number and firing order of cylinders, national stock number, contract number, and occasionally, the applicable TM. A typical equipment identification plate is shown in *Figure 8-2*.

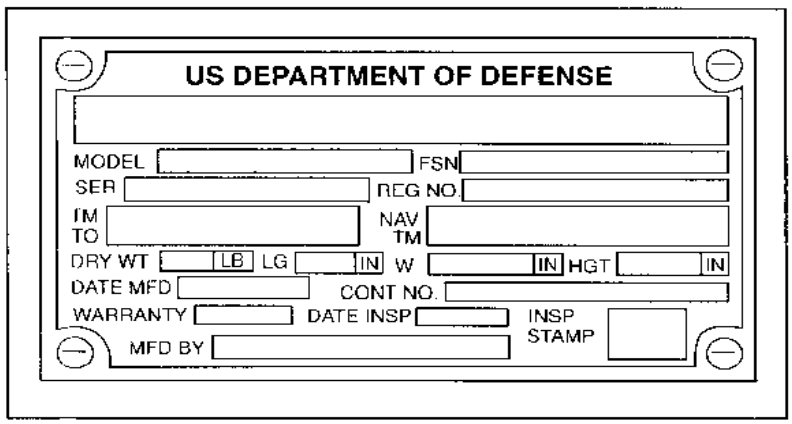


Figure 8-2. Typical equipment identification plate

- Starting and Stopping Instruction Plate. Specifies starting and stopping and/or paralleling and synchronizing procedures and is frequently called the *paralleling and synchronizing instruction plate*. It may also show preliminary positioning of controls and procedures for using the dark-lamp method of synchronizing and paralleling generators. This plate is located inside the main control-panel cover.

ELECTRIC DISTRIBUTION SYSTEMS

A distribution system transfers electricity from its source in the generator to loads such as heaters, motors, or lights. The system is identified by the number of phases, number of wires, and voltages between wires. Operators must check the data plates on the equipment before connecting a distribution system to the load.

Distribution systems are classified according to the voltage used to carry the power from the power source to the distribution transformers or to the loads.

> **WARNING**
>
> **Any attempt to operate equipment at other than its rated frequency will damage it.**

Military field units commonly use one of four systems:

SINGLE-PHASE, TWO-WIRE

A single-phase, two-wire distribution system (*Figure 8-3*) has one of the two wires from the generator set connected to the neutral wire. The neutral wire is called the *grounded wire* or the *grounded circuit conductor*. The second wire, called the *live wire* or *ungrounded conductor*, is connected to the load. Usually, there is a difference of 120 volts between these two wires. Any single-phase, two-wire, 120-volt load can be connected to both the live wire and the grounded wire. This system supplies electricity for light bulbs, portable tools, and most equipment requiring low power.

SINGLE-PHASE, THREE-WIRE

A single-phase, three-wire distribution system (*Figure 8-4*) has one grounded wire and two live wires. It is called a single-phase system because there is no phase difference between the two available voltages. The difference in voltage between either of the two live wires and the grounded wire is usually 120 volts. The difference in voltage between the two live wires is 240 volts. This system supplies power directly to small loads such as lighting in barracks.

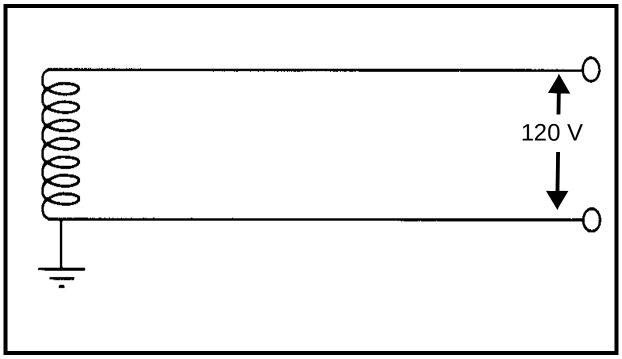


Figure 8-3. Single-phase, two-wire distribution system

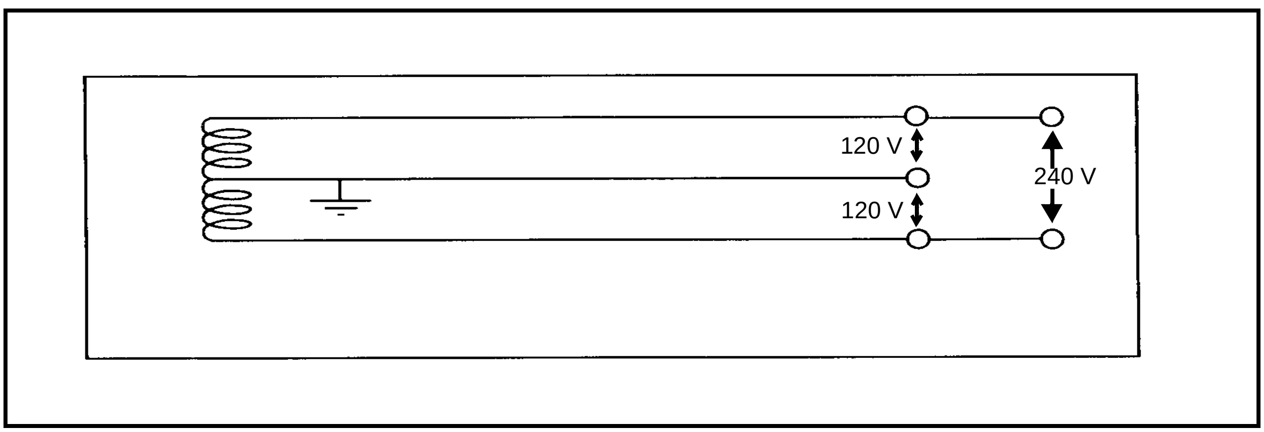


Figure 8-4. Single-phase, three-wire distribution system

THREE-PHASE, THREE-WIRE

All three wires in a three-phase, three-wire distribution system (*Figure 8-5*) are live wires. Thus, a three-phase, three-wire, 120-volt load can be connected to all three wires. This system requires a generator set designed to produce three-phase voltage. Because only one magnitude of voltage is available from this kind of generator, the loads must require the same voltage. This system supplies power to loads in structures where the three-phase power load is larger than the single-phase lighting load. The single-phase lighting load in such a structure is supplied from a separate single-phase service or by a step-down transformer.

THREE-PHASE, FOUR-WIRE

A three-phase, four-wire distribution system (*Figure 8-6, page 8-8*) may be designed to produce single-phase or three-phase voltages. For example, the generator could produce 120 and 208 volts or 240 and 416 volts. A 240/416 voltage connection is common on generator sets that produce from 15 to 500 kilowatts of electricity. This system, which is more flexible than the single-phase systems, supplies power to structures that require substantial amounts of power and lighting, such as shops and hospitals.

Generator sets are designed so that the ratio of the higher (line) voltage to the lower (phase) voltage is always the same and cannot be changed (1.73 times the phase voltage equals the line voltage). Thus, any—

- Single-phase, two-wire, 120-volt load can be fed power by making a connection between any live wire and the grounded wire.
- Single-phase, two-wire, 208-volt load can be fed between any two live wires.
- Single-phase, three-wire, 120/208-volt load can be fed by making a connection to two live wires and the grounded wire.
- Three-phase, three-wire, 240-volt load can be fed by repositioning the tap change board and the connection to the three live wires.
- Three-phase, four-wire, 120/208-volt load can be fed power by making a connection to all four wires.

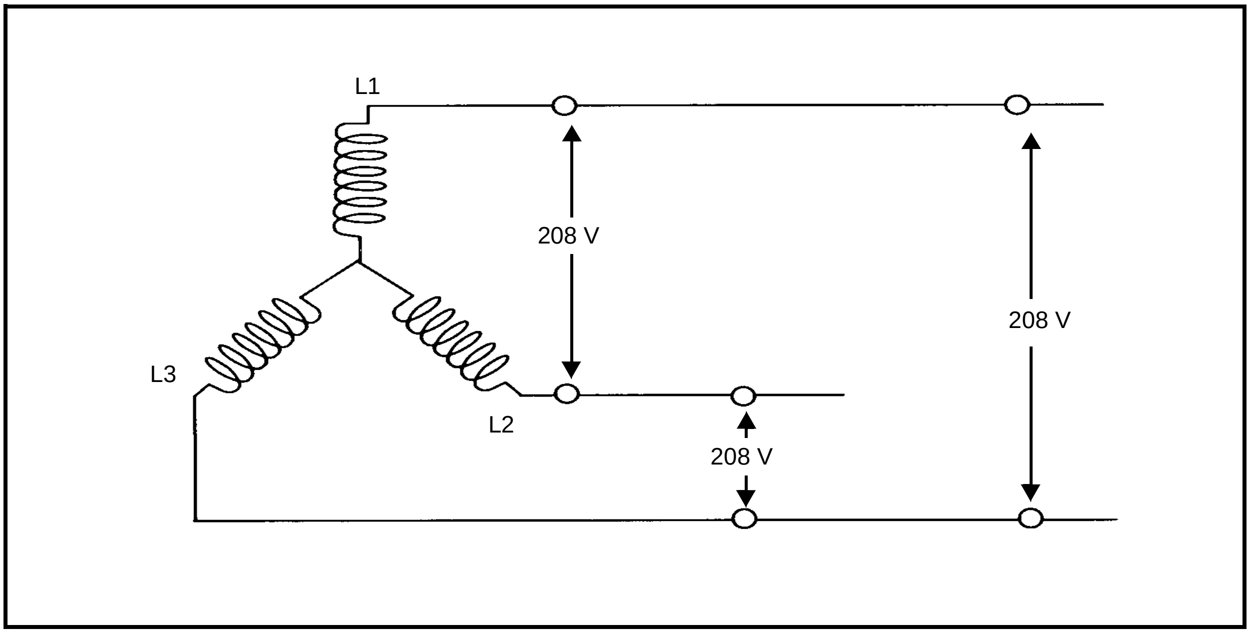


Figure 8-5. Three-phase, three-wire distribution system

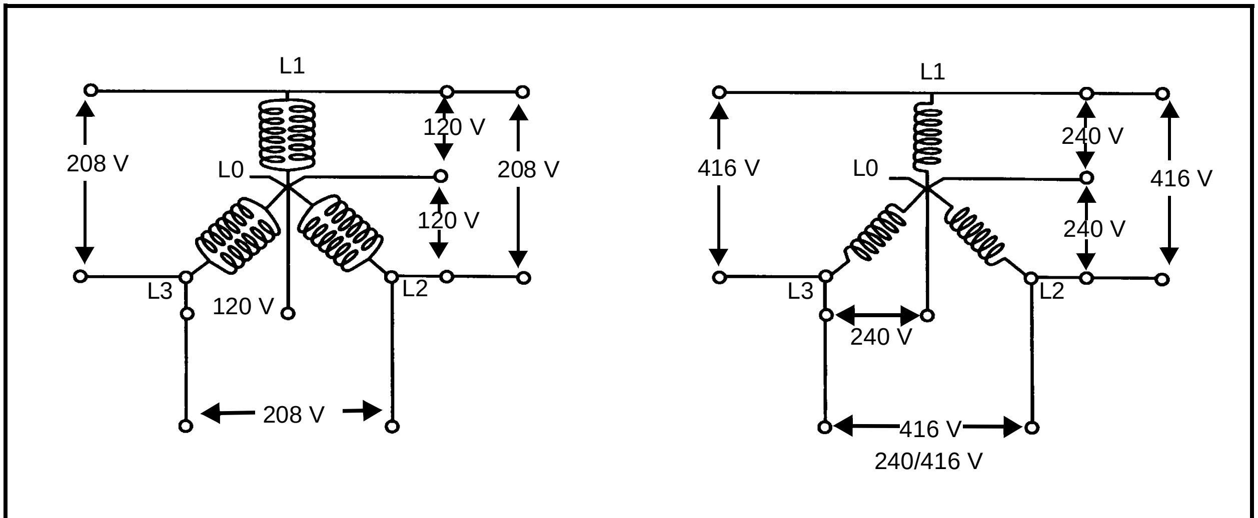


Figure 8-6. Three-phase, four-wire distribution system

Section II. Generator Selection and Operation Principles

SELECTING THE GENERATOR

Selecting generators that can produce the power required by a field unit is an important function. The operator or person responsible for this function must select the number and types of generators that can best meet the unit's needs. Preliminary tasks that must be completed before selecting power-generating equipment are computing the load, computing the cable size, and balancing the load required for the field unit.

COMPUTING THE LOAD

You need an accurate estimate of the load requirement before you can properly design a field unit's power distribution system. The estimated load is determined from the size and location of the load. Complete the following steps to determine the field unit's load requirement:

Step 1. Map the field unit. Locate all structures that require electrical power and mark them on a map. Identify each structure as shown in *Figure 8-7*.

Step 2. Determine the electrical load for each area. Electrical loads are usually measured in amperes, kilowatts, or kilovolt-amperes. The total electrical load fluctuates constantly as equipment starts and stops.

Step 3. Compute the connected load for each structure. The connected load, computed from the electrical load and usually measured in kilowatt-amperes, should total the wattage required for all lights and electrical devices plus the total horsepower of all motors.

Step 4. Compute the demand load. The demand load, computed from the connected load, is the maximum demand required to serve a connected load. The demand load is usually less than the connected load because all equipment in a building seldom operates at one time. The ratio between the estimated maximum demand load and the connected load is the demand factor. Note that the demand load is never greater than the connected load, but the demand and connected loads may be the same if the mission of a tactical shop requires that all electrical equipment be operated simultaneously. The demand factors established for the design of several types of military structures are

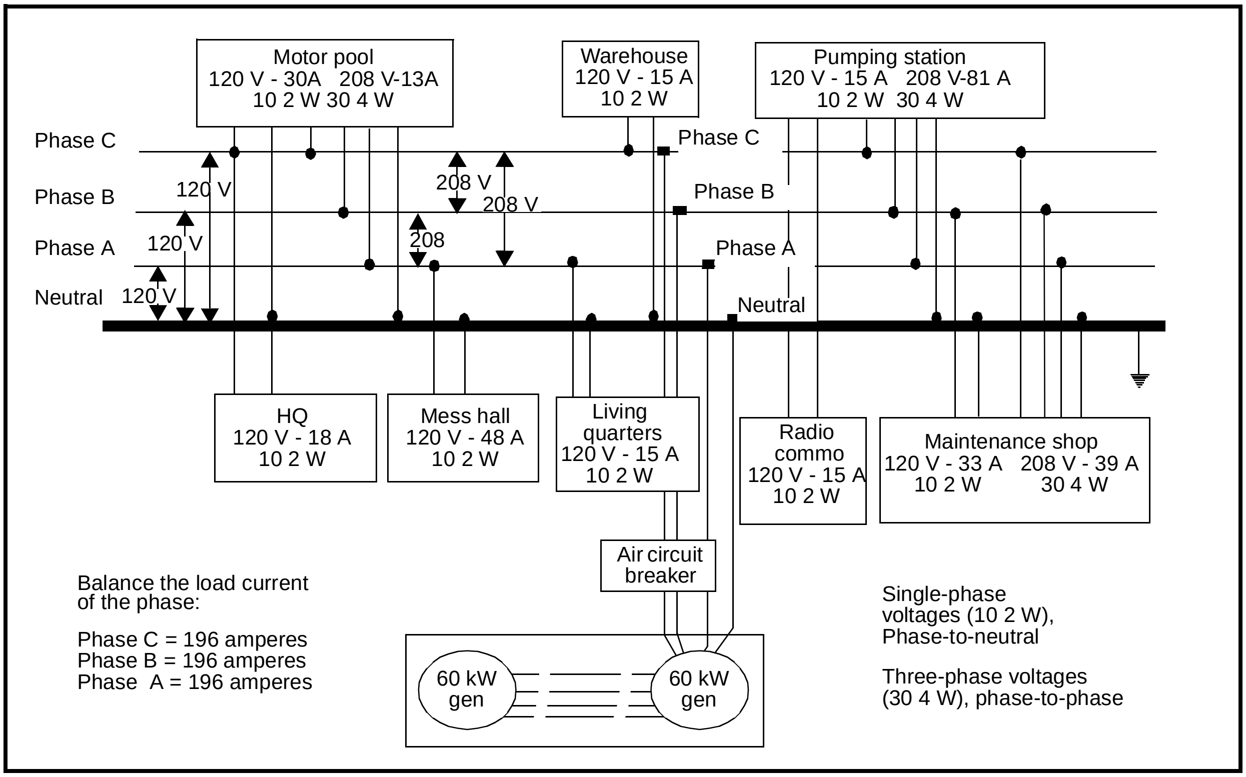


Figure 8-7. Load requirements of a military field installation

listed in *Table 8-3*. Use the following formula to determine the demand load when you know the demand factor:

Demand load = connected load x demand factor

Table 8-3. Demand factors

Structure	Demand Factor
Housing	9
Aircraft maintenance facilities	7
Operation facilities	8
Administrative facilities	8
Shops	7
Warehouses	5
Medical facilities	8
Theaters	5
Navigational aids	7
Laundry, ice plants, and bakeries	10
All others	9

Step 5. Compute the diversity factor. Measured at the point of supply, the diversity factor is the ratio of the sum of the maximum power demands for the component parts of a system to the maximum demand of the entire system. The diversity factor is similar to the demand factor except that it deals with the actual demand load rather than the potential demand load. For example, a generator set may serve three demand sites, each with a maximum demand of 30 kilowatts, as shown in *Figure 8-8, page 8-10*. In this example, the potential demand load is 90 kilowatts. Because maximum demands at the three sites do not occur simultaneously, the maximum demand load on the generator set is only 60 kilowatts, not 90 kilowatts.

Demand and diversity factors are used to plan the design of electrical facilities and determine the type and size of generator sets required for a field unit. Demand factors are also used to rearrange existing facilities. For example, additional equipment may greatly increase the connected load of a structure, but it may or may not require a change to the serving generator set.

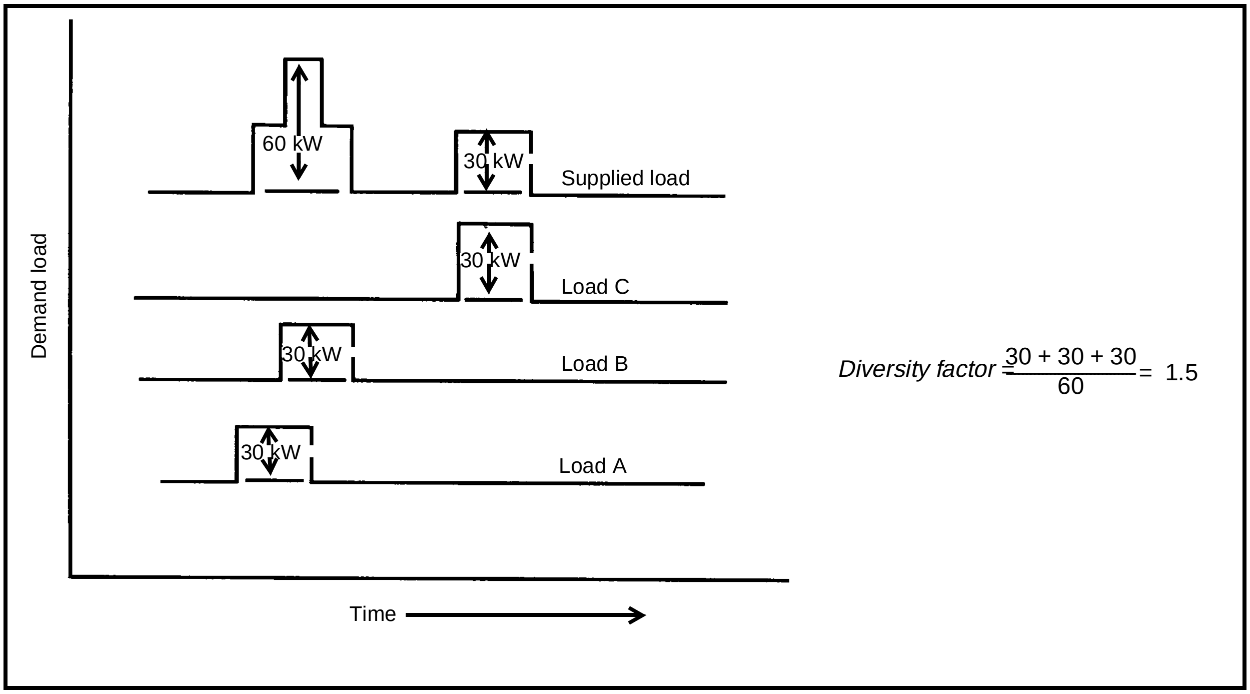


Figure 8-8. Diversity factor

Diversity factors of significant loads must be considered when they contribute to peak loads. Loads that occur during peak times may affect the capacity required for a generator set, while loads that occur during nonpeak times may not. For example, a dining facility may contribute about 25 percent of its actual electrical load to the peak load of the system.

Step 6. Compute the power factor. You must determine the power factor of an anticipated load before you can accurately estimate the amount of power required for an area. All AC power estimates are calculated using equipment power-factor ratings whenever possible. Noninductive loads such as lights, heaters, and soldering irons are computed at a power factor of 1.0. Inductive loads such as partially loaded transformers and induction motors produce a power factor less than 1.0 because they introduce inductive reactance. The sum of the inductive and noninductive loads is the connected load for the entire installation. The power factor of an AC circuit is the ratio of the true power (watts) to the apparent power (volt-amperes), as shown in the following formula:

$$\textit{Power factor} = \frac{\textit{watts}}{\textit{volt-amperes}}$$

The power (in watts) delivered by a DC generator set is the product of the current multiplied by the voltage. There is no inductive reactance in a DC circuit regardless of the character of the load.

Step 7. Compute the voltage drop. The voltage drop, sometimes called the *line loss*, is the difference between the amount of voltage at the input and output ends of a transmission line and is caused by the resistance of the line. A voltage drop is expressed either as a percentage of the voltage required at the receiving end or as a percentage of the voltage applied by the generator to the line.

The example in *Figure 8-9* shows a generated voltage of 231, a receiving end voltage of 220, and a voltage drop of 11. The voltage drop expressed as a percentage of the voltage at the receiving end is 11/220 or 5 percent. The voltage drop expressed as a percentage of the voltage from the generator end is 11/231 or 4.8 percent of the sending end voltage. The voltage drop is usually shown as a percentage of the voltage required at the receiving end.

The maximum allowable voltage drop for lighting and power loads is 5 percent. This allows no more than a 3 percent loss in the branch lines and no more than a 2 percent loss in the main and feeder lines.

To increase the voltage at the receiving end of the distribution system, increase the voltage output from the generator set. However, the output should never exceed the voltage rating of the generator set. Operators must periodically monitor the voltage throughout the distribution system to identify and correct malfunctions in electrical equipment that is connected to the lines.

A calculated voltage drop is used to plan a distribution system. A system that does not produce enough voltage may cause unexpected results. For example, the heat produced by resistive heating equipment varies as the voltage varies. Thus, a system operating at 10 percent below the rated voltage will produce 19 percent less heat. The heat loss is absorbed by the conductors supplying the power and may cause conductor failure.

Step 8. Allow for growth. Expect the power demands on an electrical circuit to increase in the future. Allow a growth of at least 50 percent of the initial load. When installing a wiring system for electrical power, ensure that the circuit can accommodate at least 50 percent more than the actual connected loads.

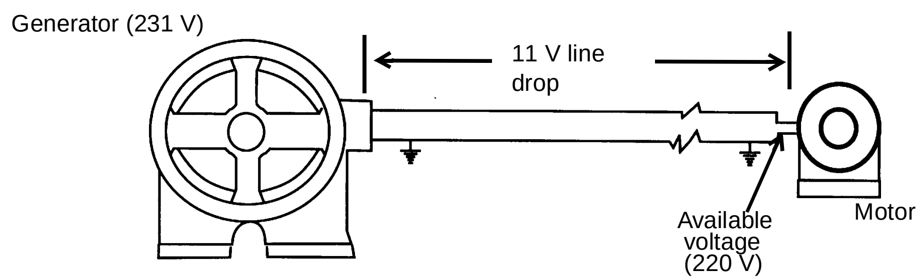


Figure 8-9. Typical line voltage drop

COMPUTING THE CABLE SIZE

A cable connects the generator set to the load. The size of this cable affects the efficiency of the generator. Power losses will occur along the transmission line if the cable is too small. The load current carried by the cable and the distance between the generator set and the load are used to determine the correct cable size.

When a conductor is too small in diameter to carry the current demanded, the cable may overheat and cause the insulation to burn. If the cable wires melt, the circuit will break. The amount of resistance to current flow that occurs along the cable is determined by the distance between the generator set and the load.

Complete the following steps in sequence to determine the cable size required:

Step 1. Use *Table 3-1, page 3-2, and Tables 8-4 and 8-5, page 8-12 through 8-14,* to compute the total current demand for each phase.

Step 2. Use *Table 8-6, page 8-15,* to determine the wire size capable of carrying the total current. If the wire size determined is not available, use parallel runs of smaller wires or use the next larger size. Substitute sizes based on the current-carrying capacities of the wires as listed in *Table 8-7, page 8-16*. The wire substitutions should not produce excessive voltage drops along the distribution line; however, operators must monitor the voltage at the receiving end to ensure that the substituted wire carries the current efficiently.

Table 8-4. Load conversion factors

To Find	Direct Current	Alternating Current	
		Single-Phase	Three-Phase
Amperes when horsepower is known	$\frac{HP \times 746}{E \times Eff}$	$\frac{HP \times 746}{E \times Eff \times PF}$	$\frac{HP \times 746}{1.73 \times E \times Eff \times PF}$
Amperes when kilowatts are known	$\frac{kW \times 1,000}{E}$	$\frac{kW \times 1,000}{E \times PF}$	$\frac{kW \times 1,000}{1.73 \times E \times PF}$
Amperes when kilovolt-amperes are known		$\frac{kVA \times 1,000}{E}$	$\frac{kVA \times 1,000}{1.73 \times E}$
Kilowatts when amperes are known	$\frac{I \times E}{1,000}$	$\frac{I \times E \times PF}{1,000}$	$\frac{I \times E \times 1.73 \times PF}{1,000}$
Kilowatts when horsepower is known	$\frac{HP \times 746}{1,000 \times Eff}$	$\frac{HP \times 746}{1,000 \times Eff}$	$\frac{HP \times 746}{1,000 \times Eff}$
Kilovolt-amperes when amperes are known		$\frac{I \times E}{1,000}$	$\frac{I \times E \times 1.73}{1,000}$
Kilovolt-amperes when horsepower is known		$\frac{HP \times 746}{1,000 \times Eff \times PF}$	$\frac{HP \times 746}{1,000 \times Eff \times PF}$
Horsepower output when amperes are known	$\frac{I \times E \times Eff}{746}$	$\frac{I \times E \times Eff \times PF}{746}$	$\frac{I \times E \times 1.73 \times Eff \times PF}{746}$
Load power factor when rated horsepower and kilovolt-amperes are known		$\frac{HP \times 746}{100 \times kVA \times Eff}$	$\frac{HP \times 746}{100 \times kVA \times Eff}$

I = amperes; E = volts; Eff = efficiency (as a decimal); PF = power factor (as a decimal); kW = kilowatts; kVA = kilovolt-amperes; HP = horsepower.

NOTE: Three-phase, AC lines are assumed to be feeding balanced, three-phase loads. For three-phase loads, input current is per phase.

Step 3. Use *Table 8-8, page 8-17,* to determine the total resistance of the cable when it is connected between the generator set and the load. Ampacity affects the size of wire required for a distribution cable. Ampacity is the current-carrying capacity of a cable or wire expressed in amperes. If the ampacity load is great and the wire length from the generator set to the load is short, ampacity considerations will require a larger wire size than that normally required. When power requirements are low and the length of the line is long, the voltage-drop criteria will require a larger wire size than that normally required. The criteria resulting in the larger size wire governs the design of the distribution system.

NOTE: When installing a cable overhead, use a minimum size of No 8 AWG. An overhead cable must meet the voltage-drop requirement and be strong enough to support its own weight plus any additional weight caused by fallen branches, ice, or snow.

Table 8-5. Full-load currents of motors

HP	120-Volt	240-Volt
1/4	2.9	1.5
1/3	3.6	1.8
1/2	5.2	2.6
3/4	7.4	3.7
1	9.4	4.7
1 1/2	13.2	6.6
2	17	8.5
3	25	12.2
5	40	20
7 1/2	58	29
10	76	38
15		55
20		72
25		89
30		106
40		140
50		173
60		206
75		255
100		341
125		425
150		506
200		675

NOTE: These values of full-load current are average for all speeds and are in accordance with the National Electrical Code.

HP	115-Volt	230-Volt
1/8	4.4	2.2
1/4	5.8	2.9
1/3	7.2	3.6
1/2	9.8	4.9
3/4	13.8	6.9
1	16	8
1 1/2	20	10
2	24	12
3	34	17
5	56	28
7 1/2	80	40
10	100	50

NOTES:

1. These values of full-load current are in accordance with the National Electrical Code and are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

2. For full-load currents of 208- and 200-volt motors, increase the corresponding 230-volt motor full-load current by 10 and 15 percent, respectively.

Table 8-6. Table 8-5. Full-load currents of motors (continued)

HP	Induction-Type Squirrel-Cage and Wound Motor Amperes				Sychronous-Type Unity Power-Factor Amperes*				
	110-Volt	220-Volt	440-Volt	550-Volt	2,300-Volt	220-Volt	440-Volt	550-Volt	230-Volt
1/2	4.0	2.0	1.0	0.8					
3/4	5.6	2.8	1.4	1.1					
1	7.0	3.5	1.8	1.4					
1 1/2	10.0	5.0	2.5	2.0					
2	13.0	6.5	3.3	2.6					
3		9.0	4.5	4.0					
5		15.0	7.5	6.0					
7 1/2		22.0	22.0	9.0					
10		27.0	14.0	11.0					
15		40.0	20.0	16.0					
20		52.0	26.0	21.0					
25		64.0	32.0	26.0	7.0	54.0	27.0	22.0	5.4
30		78.0	39.0	31.0	8.5	65.0	33.0	26.0	6.5
40		104.0	52.0	41.0	10.5	86.0	43.0	35.0	8.0
50		125.0	63.0	50.0	13.0	108.0	54.0	44.0	10.0
60		150.0	75.0	60.0	16.0	128.0	64.0	51.0	12.0
75		185.0	93.0	74.0	19.0	161.0	81.0	65.0	15.0
100		246.0	123.0	98.0	25.0	211.0	106.0	85.0	20.0
125		310.0	155.0	124.0	31.0	264.0	132.0	106.0	25.0
150		360.0	180.0	144.0	37.0		158.0	127.0	30.0
200		480.0	240.0	192.0	48.0		210.0	168.0	40.0

*For 90 and 80 percent power factor, the above figures should be multiplied by 1.1 and 1.25, respectively.

NOTES:

1. These values of full-load current are in accordance with the National Electrical Code and are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

2. For full-load currents of 208- and 200-volt motors, increase the corresponding 230-volt motor full-load current by 10 and 15 percent, respectively.

Table 8-7. Allowable current capacities of conductors, in amperes, for not more than three conductors in a raceway or cable

A	B[1]	C	D	E	F	G
AWG	Rubber Types R, RW, RU, RUW (14-2) Type RH-RW[2] Thermoplastic Types T, TW	Rubber Types RH, RH-RW[2], RHW	Paper Thermoplastic asbestos Type TA Var-Cam Type V Asbestos Var-Cam Type AVB MI Cable	Asbestos varnished-cambric Types AVA, AVL	Impregnated asbestos Types AI (14-8), AIA	Asbestos Types A (14-8), AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
1/0	125	150	155	190	200	225
2/0	145	175	185	215	230	250
3/0	165	200	210	245	265	285
4/0	195	230	235	275	310	340

[1]Insulation type and description.

[2]If type RH-RW rubber-insulated wire is used in wet locations, the allowable current-carrying capacities will be that of column C; and if used in dry locations, the current-carrying capacities will be that of column D.

Type	Description
R	Code-grade rubber compound
RW	Moisture-resistant rubber compound
RU	Latex-rubber compound
RUW	Latex-rubber, moisture-resistant compound
RH-RW	Heat- and moisture-resistant rubber compound
RH	Heat-resistant rubber compound
RHW	Heat- and moisture-resistant compound
T	Thermoplastic-covered for dry locations
TA	Thermoplastic- and asbestos-covered for switchboard wiring
TW	Thermoplastic-covered for moist locations
MI	Mineral-insulated, copper-sheathed for general use and special high-temperature locations
A	Nonimpregnated, all-asbestos, without asbestos outer braid
AA	Nonimpregnated, all-asbestos, with asbestos outer braid
AI	Impregnated, all-asbestos, without asbestos outer braid
AIA	Impregnated, all-asbestos, with asbestos outer braid
AVA	Impregnated-asbestos and varnished-cambric with asbestos braid
AVB	Impregnated-asbestos and varnished-cambric, flame-resistant cotton braid
AVL	Impregnated-asbestos and varnished-cambric, outer asbestos braid, lead-sheathed
V	Varnished-cambric

Table 8-8. Substitute wire sizes

AWG or MCM	Current Carrying Capacity (Amps)	Number and Size of Wires That can be Substituted for a Single Wire of the Size Shown in the First Column				
		2	3	4	5	6
1,000,000	455	300,000	3/0	1/0	2	3
900,000	435	300,000	2/0	1	2	3
800,000	410	250,000	2/0	1	2	4
750,000	400	250,000	2/0	1	3	4
700,000	385	4/0	2/0	1	3	4
600,000	355	4/0	1/0	2	3	4
500,000	320	3/0	1	3	4	6
400,000	280	2/0	2	4	-	6
300,000	240	1/0	3	4	6	8
250,000	215	1	3	6	-	8
4/0	195	1	-	6	8	-
3/0	165	2	6	-	8	10
2/0	145	3	6	8	10	-
1/0	125	4	6	8	10	-
1	110	6	8	10	-	12
2	95	6	8	10	12	-
3	80	8	10	12	-	14
4	70	8	10	12	14	-
6	55	10	12	14	-	-
8	40	12	14	-	-	-
10	30	14	-	-	-	-

BALANCING THE LOAD

The final task before selecting generator sets for a field unit is to balance the load among the phases. When balancing a load, ensure that each phase carries an equal share of the load.

Loads may be connected between a power-carrying conductor (live wire) and a ground wire or between several live wires. When you connect a load between a live wire and a ground wire, any unbalanced current (power) in the line conductors is supplied through the ground wire. A load connected between two or more live wires is distributed equally among the live wires.

An installation fed by a three-phase, four-wire generator set can have a single-phase load attached to each of the three phases. Regardless of the number of loads supplied or how the loads are arranged, the generator supplies the total load on each phase. The generator attempts to supply the power required to satisfy the load in each phase. To ensure that the power is balanced, connect the loads so that each phase receives an equal load of current from the generator set. An unbalanced load has two adverse effects:

- Unbalancing causes high voltage on the lightly loaded phase and low voltage on the other phase(s). This causes poor voltage regulation throughout the system.
- A load that is unbalanced for a long time damages the generating equipment.

Table 8-9. Physical and electrical properties of conductors

Standard Rubber Conductor		IPCEA Class B Stranding	At 77°F (25°C)	
AWG	Circular Mils	No of Wires	Bare Copper	Tinned Copper
18	1,624	7	6.64	7.05
16	2,583	7	4.18	4.43
14	4,107	7	2.63	2.69
12	6,530	7	1.65	1.72
10	10,380	7	1.04	1.08
9	13,090	7	0.824	0.856
8	16,510	7	0.654	0.679
7	20,820	7	0.519	0.538
6	26,250	7	0.410	0.427
5	33,100	7	0.326	0.339
4	41,740	7	0.259	0.269
3	52,640	7	0.205	0.213
2	66,370	7	0.162	0.169
1	83,690	19	0.129	0.134
1/0	105,500	19	0.102	0.106
2/0	133,100	19	0.0811	0.0842
3/0	167,800	19	0.0642	0.0668
4/0	211,600	19	0.0509	0.0525

SINGLE-PHASE SYSTEMS

A single-phase, two-wire, 120-volt system (*Figure 8-10*) cannot be unbalanced because the two wires are connected to one load. When you connect this basic load-carrying circuit, half of the total load is supplied by one live wire while the other live wire supplies the other half of the load.

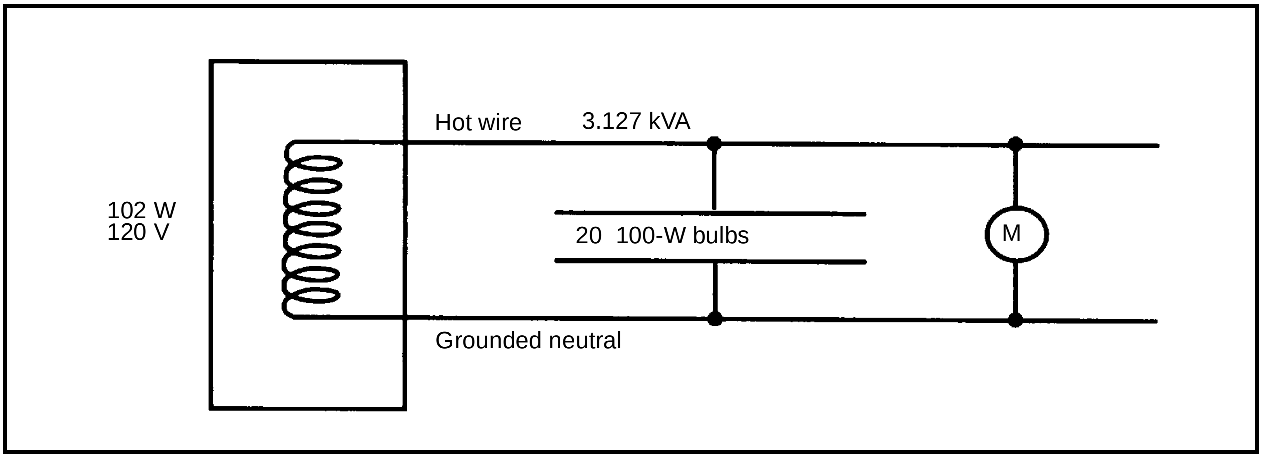


Figure 8-10. Balanced single-phase, two-wire system

A single-phase, three-wire, 120/240-volt system (*Figure 8-11*) has two live wires and one ground wire. It can supply power for two single-phase, 120-volt loads and one single-phase, 208/220-volt load group.

THREE-PHASE SYSTEMS

A three-phase, three-wire, 208-volt system (*Figure 8-12*) has three live wires. It can supply three single-phase, 208-volt loads or one three-phase, 208-volt load. For a single-phase connection, divide the total load equally between the three live wires.

A three-phase, four-wire, 120/208-volt system (*Figure 8-13)* has three live wires and one ground wire. This system can supply power for a single-phase, 120-volt load; a three-phase, 208-volt load; and a single-phase, 208-volt load.

When the total load is balanced, mark on a site diagram the voltage and the number of phases needed. The voltage and phase requirements are marked plainly on most AC and DC motors.

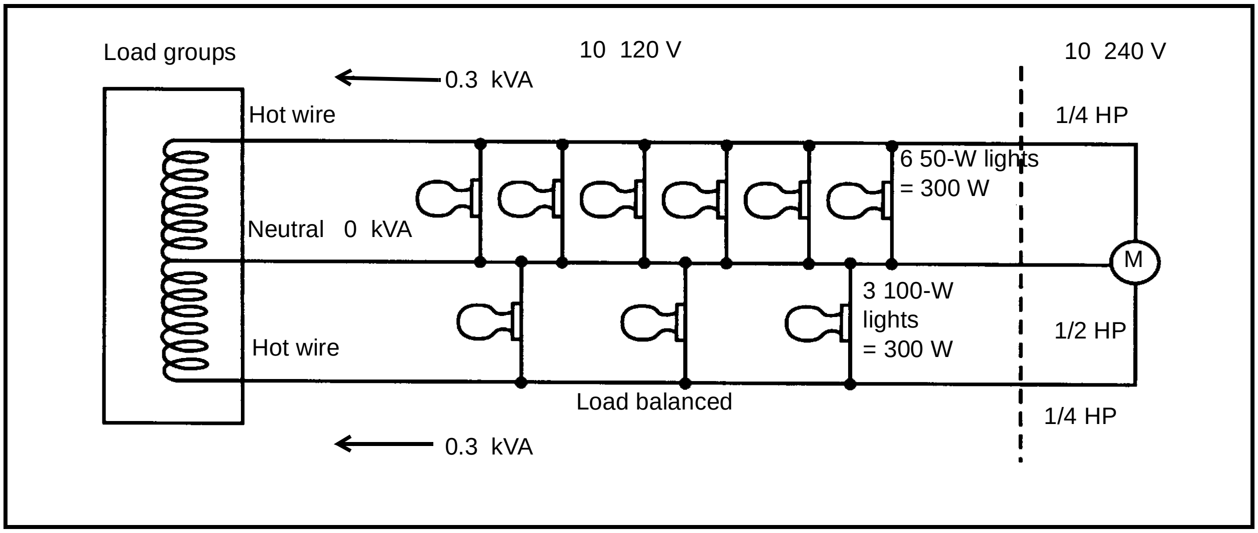


Figure 8-11. Balanced single-phase, three-wire system

SELECTING THE GENERATOR

After you have designed the distribution system and balanced the load, you can select the generating equipment to produce the power needed for the field unit. The electrical systems at most military field units supply power day and night for various lighting, heating, and power equipment. The annual load factor of a well-operated, active field unit is 50 percent or more of the capacity of the generator sets. The annual load has a power factor of 80 percent or more of the average power factor. The following criteria govern the generator selection process:

- Electrical loads to be supplied.
- Kilowatt rating requirements.
- Operating voltages required.
- Number of phases required.
- Frequency requirements.

Other considerations when selecting generating equipment for a field unit include—

- Availability of fuels.
- Expected life of the field unit.
- Availability of skilled maintenance personnel.
- Probable load deviation.

The layout of the field unit is also an important consideration when selecting generating equipment. For example, if the load is more than a few hundred feet from the generator set, you may need a high-voltage distribution system. If the power plant serves a primary distribution system, the generator set must be rated at the distribution system's voltage. This eliminates the need for a transformer at the sending end. Also, the number of phases required by the load may differ from that of the generators on hand. Because most loads can be divided and balanced between phases, most medium- and large-sized generator sets are designed for three-phase operation.

Most electrical loads in the US require a frequency of 60 cycles. Although equipment operators try to maintain a constant frequency throughout the electrical system, deviations sometimes occur. Most electrical equipment operates satisfactorily when the frequency drifts approximately 5 cycles above or below 60 cycles. Some types of equipment, such as teletypewriters and clocks, are sensitive to frequency changes. Consider frequency drift when selecting generator sets that supply power to sensitive equipment.

You must select generator sets that are the proper size and type for the field unit's needs. If a central generating station is needed but there is not enough time to build one, install a generator set at each work site that requires power. The size of the generator set selected for each work site depends on the needs of the site. For example, the electrical load at a headquarters building that consists of lights and single-phase motors can be supplied by a small, single-phase generator set. A maintenance shop that uses large amounts of single-phase and

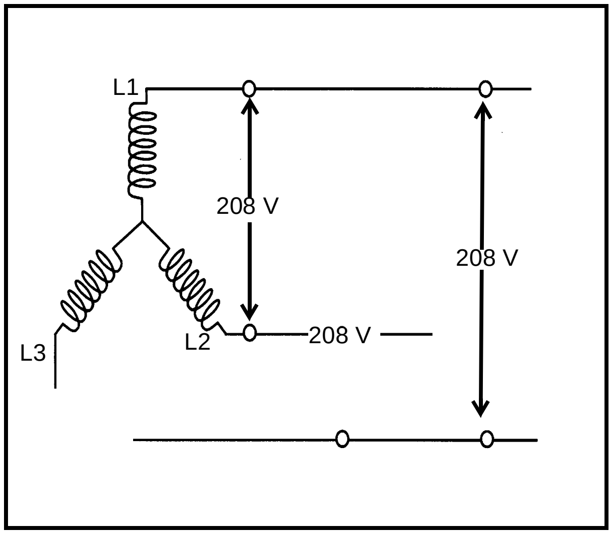


Figure 8-12. Balanced three-phase, three-wire system

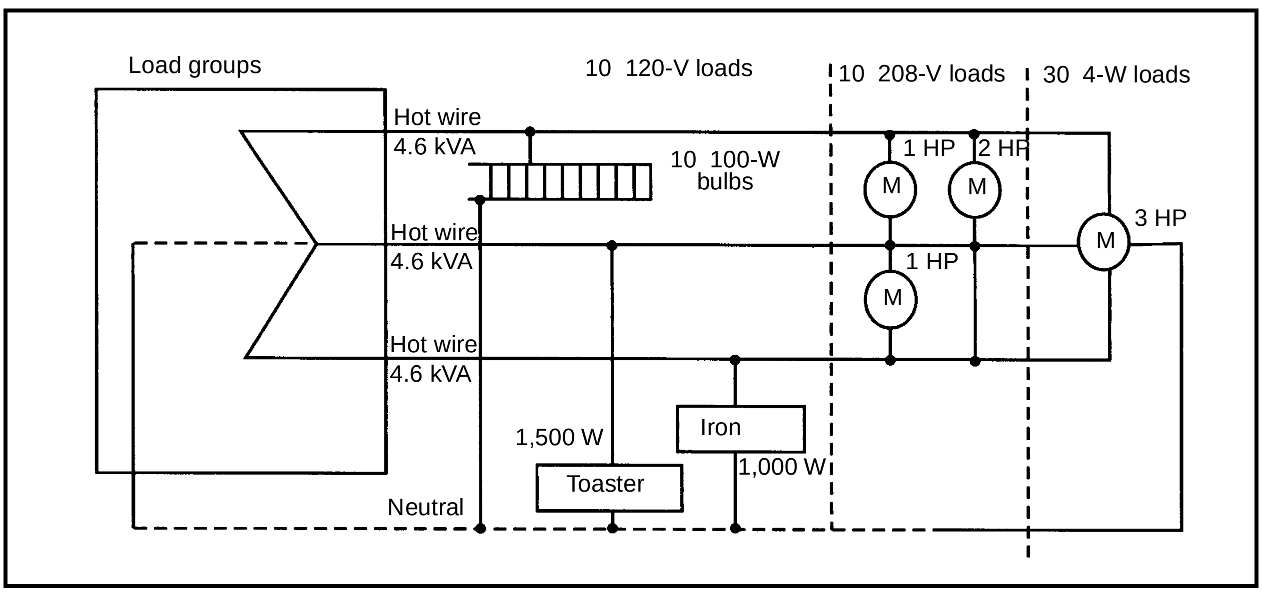


Figure 8-13. Balanced three-phase, four-wire system

three-phase power requires a three-phase generator set.

Coordinate your choice of generator set with the maintenance and supply facilities at the field unit. Maintenance skills and the necessary tools and spare parts required for the selected generator must be available at the field unit.

POWER AND VOLTAGE REQUIREMENTS

The power and voltage requirements of the load determine the size of the generator set used. For example, a two-wire, 120-volt generator set with an output rating of 1.5 kilowatts produces enough electricity for equipment rated at 120 volts, single-phase, with a combined power load of less than 1.5 kilowatts. A 5-kilowatt, AC generator set produces enough electricity for equipment requiring between 1.5 and 4.5 kilowatts.

If motors are part of the load, increase the capacity of the generator set above the capacity normally required. The increased capacity is required to compensate for reduced terminal voltage when large motors are started and when frequency surges occur during motor acceleration. These power drains may adversely affect the performance of electronic systems and other equipment fed from the same generator set. Also, motors already running may stall when large motors are started. You can avoid these and similar problems by removing the existing load when starting a large motor and then placing the small loads back on the generator set after the large motor has reached its required speed.

Some single-phase loads contain equipment rated at both 115 and 230 volts. These loads require a generator set with a single-phase, three-wire, 120/240-volt output.

The size of the load is a primary consideration when selecting a generator set. Determine the capacity needed to support the load before selecting a generator set. Sets with capacities ranging from 0.5 to 500 kilowatts are available.

SELECTION GUIDES

Use the following guides to select a generator set:

- Single-phase equipment provides power for small lighting, AC and DC motors, special equipment such as radial (arc) electrical welders, and some furnace loads. You may use a two- or three-wire system, depending on the size of the load and the area serviced.
- Three-phase equipment provides power for almost everything except small loads. The generation and transmission lines are usually three-wire systems, but the distribution circuits may be three- or four-wire. When single-phase power is obtained from three-phase circuits, operators must balance each phase at the generator set.
- To determine the voltage required for a generator set, consider the distribution circuits; the size, character, and distribution of the load; the length, capacity, and type of transmission lines; and the size, location, and connection of the generator sets.
- Lighting is universally rated at 120 volts in the US. The voltage required for lighting can be obtained from a single-phase, two-wire, 120/240-volt circuit or a three-phase, four-wire, 120/208-volt circuit. Using both lighting and small-motor circuits increases the load requirements for general power applications.
- Small motors (less than 5 horsepower [HP]) are supplied by DC or single-phase AC systems at 120 volts. Large three-phase motors (5 HP or more) usually operate satisfactorily between 200 and 240 volts.
- DC generator sets are used for specific tasks, and selection is based on the task to be performed. Battery charging is the main use of DC generators. A practical wiring diagram of a two-wire, DC generator set is shown in *Figure 8-14*.

- A single generator set is the least desirable method for obtaining continuous electricity. This set is used when it is isolated from the distribution system and when equipment failure will not seriously affect the field unit's mission. A single generator set is sometimes used to power extremely large loads that cannot be tied into a limited distribution system.

Generator sets have gasoline or diesel engines. Consider fuel availability when selecting a generator set because it may limit the choice of engines in advanced or isolated areas. Use the following guides to select the type of engine for a generator set:

- Most gasoline-engine generator sets are similar to small automotive engines. Therefore, maintenance problems on these sets may be easier to correct than maintenance problems on other, less-common engines.
- Diesel-engine generator sets usually operate for longer periods and under greater strains than the gasoline-engine generator sets. Also, diesel engines usually require less maintenance than gasoline engines because of their construction and lack of an ignition system.

LOAD CLASSIFICATION REQUIREMENTS

You must properly match the load to the generator set at the field unit. Loads are classified as *inductive* or *resistive*. The load classification partly determines the amount of load a generator can support. The rating information is in amperes, kilovolt-amperes,

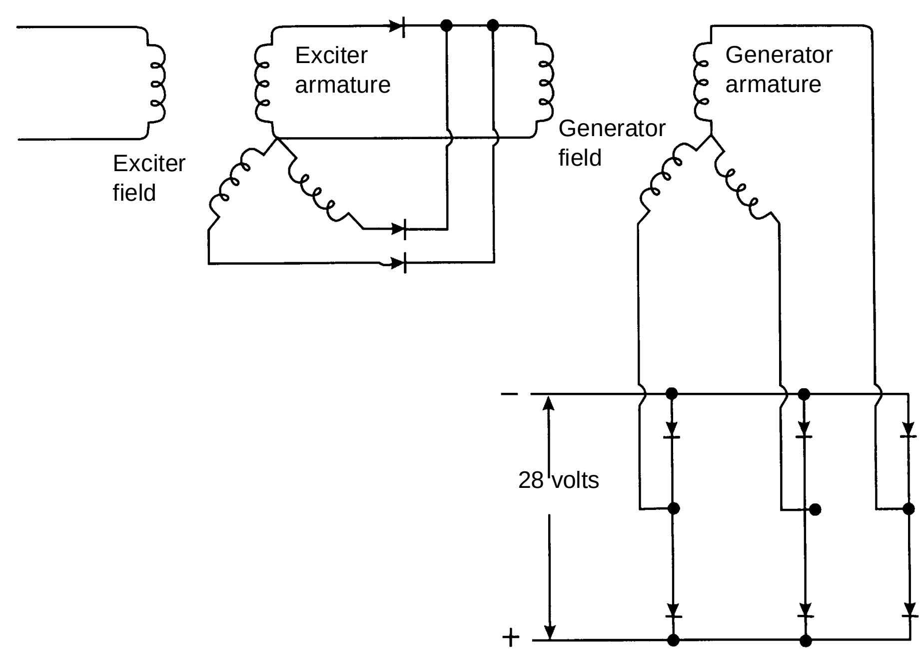


Figure 8-14. Typical wiring diagram of a two-wire, DC generator set

kilowatts, and/or power factors. If the only information you know about a generator set is the kilovolt-amperes, power factor, and voltage-output rating, you must determine the load classification.

A generator can support its kilovolt-amperes rating if the major portion of a load is inductive. For example, a model MEP-017A generator set rated at 6.25 kilovolt-amperes can support a 6.25-kilovolt-ampere inductive load. A generator with a load that is entirely resistive may be overloaded easily because it can support only 80 percent of its kilovolt-ampere rating. For example, a model MEP-017A generator set rated at 6.25 kilovolt-amperes can support only a 5-kilowatt load (6.25 x 0.80 = 5). A generator set with a rating of 0.8 power factor cannot support that rating in kilovolt-amperes if the load is purely resistive (a power factor of 1.0). If the ampere rating is known, calculate the total amperes required to support the load but do not exceed the rating of the generator set.

Many generator sets are designed so that you can select one of several voltages. The ampere rating changes as the voltage output changes. Thus, a model MEP-018A, 5-kilowatt generator set can supply any of the voltages and amperes in *Table 8-9*.

Rating information is on the alternator data plate and in the tabulated data section of the TM for each generator set.

Table 8-10. Voltage and ampere output

Phase	Voltage	Amperes
Single	120	104
Single	240	52
Three	120	34.7 (per phase)
Three	208	17.3 (per phase)

PARALLELING THE GENERATOR SETS

Sometimes a field unit with only small- and medium-sized generator sets needs a large quantity of power. This can be done by connecting and operating two or more generator sets in parallel. When generator sets are connected in this manner, their combined kilowatt rating is equal to the sum of the kilowatt rating for each set. Parallel-connected generator sets are shown in *Figure 8-15*.

Generator sets are connected in parallel to provide continuous power and to allow shutdown time for servicing the equipment. Installations that require continuous power, such as surgical hospitals, use parallel-connected generator sets to avoid power outages. Generator sets are shut down and serviced periodically. When they are connected in parallel, one set can be shut down and serviced while the others continue to operate. Thus, an installation can receive continuous power with no time lost for maintenance and repair.

You must synchronize the parallel generator sets before connecting them to the load. Complete the following steps in sequence to synchronize a base set and an incoming set:

Step 1. Close the main circuit breaker on the base set.

Step 2. Ensure that the voltmeter indicates the frequency required for the load.

NOTE: During the synchronizing process, the base (operating) generator set may be connected to the load and operating or it may be disconnected from the load and operating. After steps 1 and 2 are completed, the incoming generator set may be synchronized with the base unit.

Step 3. Open the circuit breaker on the incoming generator set.

Step 4. Ensure that the voltage and frequency outputs of the incoming generator set are the same as those of the base set.

Step 5. Place the paralleling switch on the control panels of the base and incoming generator sets in the ON position. When the

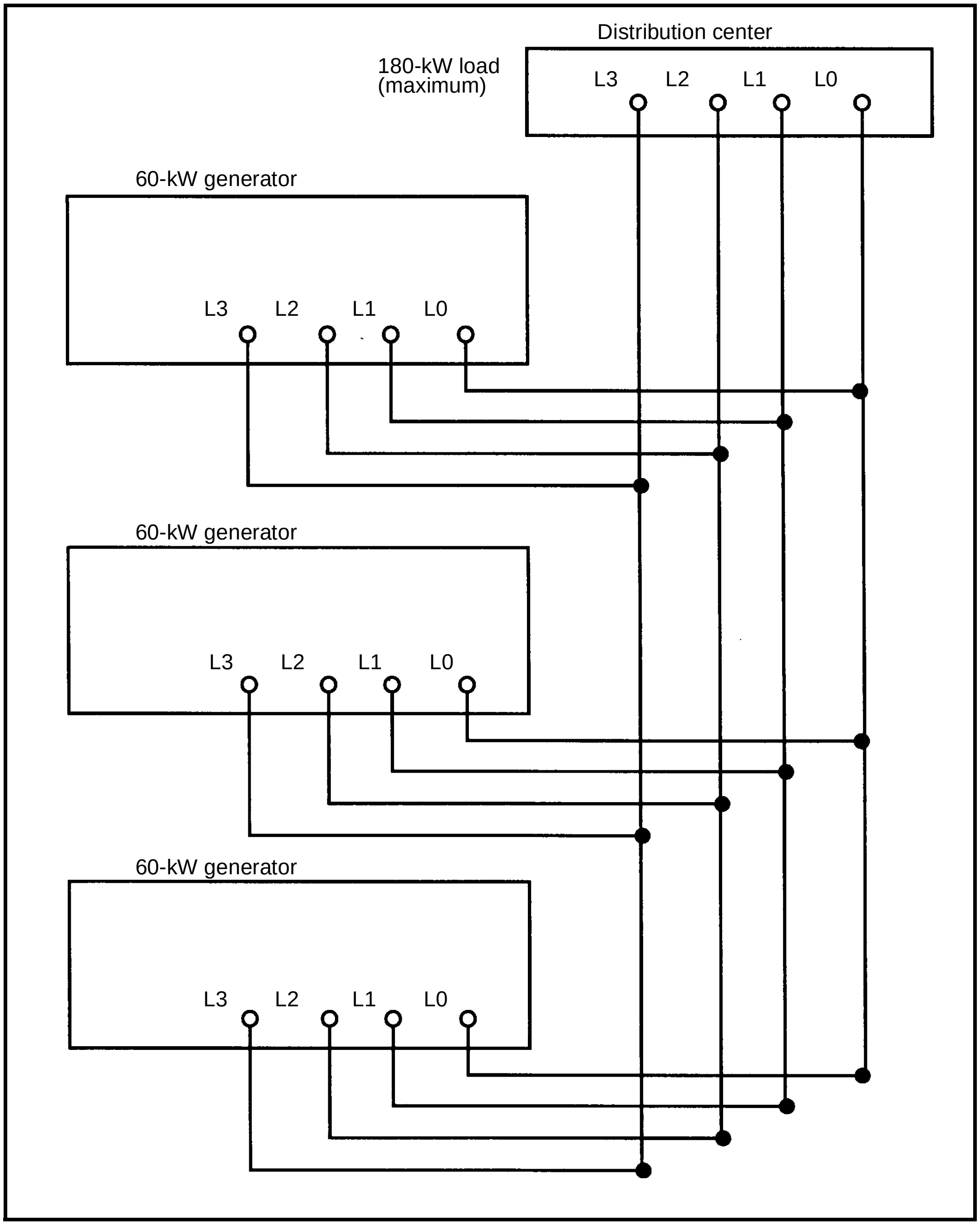


Figure 8-15. Parallel-connected generator sets

paralleling switches are on, the two paralleling lamps on the control panel of the incoming set will begin to blink on and off. Both lights will blink on and off at the same time if the generator sets are connected properly.

NOTE: The following measures should be taken only if the lights do not blink in unison. Turn all power off before reconnecting the generator sets.

Ensure that the lights blink in unison. If the base set is under a power load, observe the kilowatt meter (percent-of-power meter) on the base set. Then go back to the incoming set and observe the paralleling lamps. Adjust the throttle (on utility sets) or the frequency adjust rheostat (on precise sets) until the lamps go on and off at 3- to 5-second intervals. When the lights are completely dark, close the main circuit breaker on the incoming set. Adjust the frequency rheostat of the incoming set until the kilowatt meter indicates one-half of the power of the base set. Adjust the voltage rheostats on both sets, if necessary, to eliminate crosscurrents.

When the synchronizing lamps blink in unison, the two sets are operating in parallel as one base unit.

Step 6. Complete steps 3 through 5 for each additional incoming set. The percent-of-power meter on the third set should indicate one-third of the load on the base set.

CAUTION

If the current meter on either set indicates excessive current and the voltage rheostat will not balance the current, do not operate the generators in parallel. Refer to the next higher level of maintenance.

Step 7. After all generator sets are operating in parallel, divide the load equally among them. To do this, adjust the voltage and frequency outputs of each set. This step completes the paralleling process.

DETERMINING THE GROUNDING SYSTEM

Electrical power-generating equipment must be grounded. In the field, portable power-generating equipment may be grounded with a grounding rod, pipe, or plate. *Figure 3-3, page 3-9,* shows the methods of grounding.

DANGER

If electrical power-generating equipment is not grounded, stray electrical current within the generator set or in the distribution system can injure or kill the operator and damage the equipment.

GROUNDING ROD

The standard grounding rod used by military units is a 5/8-inch copper rod with three 3-foot sections. To install a grounding rod, drive it at least 8 feet into the soil. The rod must be buried below the moisture level. If you cannot do this, replace the grounding rod with an 8-foot electrode. Bury the electrode in a horizontal trench that is at least 2 1/2 feet deep, and place the electrode below the moisture level.

If one grounding rod does not produce a good grounding system, you can form a network with three or more rods. Install the rods about 6 feet apart. If three rods form the network, place them in a straight line or in a triangular pattern. If more than three rods are used, install them in a straight line and connect the grounding cable from the generator set to each grounding rod so they are in series.

GROUNDING PIPE

Use a clean, metallic pipe of 3/4-inch trade size or larger to make a grounding pipe. Pipes made of iron or steel must be galvanized or coated for corrosion protection. Drive the pipe at least 8 feet into the soil. If you cannot do this, replace the pipe with an 8-foot-long electrode. Bury the electrode in a horizontal trench that is at least 2 feet deep and place it below the moisture level.

GROUNDING PLATE

You may use a buried grounding plate (plate electrode) as a ground. The plate must be at least 36 inches wide and 36 inches long (9 square feet). An iron or steel plate may be substituted for a plate electrode if it is at least 1/4-inch thick and coated for corrosion protection. Grounding plates must be buried below the moisture level.

Attach the grounding system with a No 6 AWG or larger cable. Connect one end of the cable to the grounding terminal of the generator set. Tighten the nut securely, as described in the appropriate TM. Connect the other end of the cable to the grounding electrode with a special grounding clamp.

SOIL CONDITIONS

Contact with the earth does not guarantee a good grounding system. The soil type, moisture content, and temperature affect the efficiency of the grounding system. *Table 8-10* describes the characteristics of four types of soils.

Table 8-11. Soil characteristics

Type of Soil	Quality of Ground
Fine soil granules with high moisture content	Very good
Clay, loam, shale	Good
Mixed (clay, loam, shale mixed with gravel or sand)	Poor
Gravel, sand, stone	Very poor

Soil is divided into two distinct layers. Topsoil, the first layer, usually ranges from 1 to 6 inches deep. Because it is often dry and loosely packed, topsoil is not a good electrical conductor. Subsoil, the second layer, is usually tightly packed, retains moisture, and provides the best electrical ground. Wet soil passes electrical current better than dry soil and allows the grounding system to work efficiently.

A chemical solution is used on soils to improve a poor grounding system. To make this solution, mix 5 pounds of sodium chloride (common table salt) with 5 gallons of water (1 pound of salt to 1 gallon of water). Dig a hole that is about 1 foot deep and 3 feet wide. Pour the solution into the hole and allow it to seep into the soil. Install the grounding rod in the hole, connect the grounding strap, and fill the hole with soil. Keep the soil around the rod moist at all times.

Frozen soil is a poor conductor of electrical current. When the soil temperature drops below 32°F and the soil moisture freezes, the effectiveness of the grounding system decreases. To compensate for low soil temperatures, place the grounding system near a source of heat such as a generator set or vehicle exhaust. When it is difficult to install an effective grounding system because the soil is frozen, connect the grounding strap to something that is already grounded, such as a metal building or an underground pipe. If possible, attach the strap with a grounding clamp; if not, attach it with a bolt.

Another alternative is to drive several grounding stakes into the soil at different locations to form a grounding network. Drive the stakes to the greatest depth possible. If necessary, drill, dig, or blast a hole in the soil and use the salt solution described previously. You may also be able to make a temporary ground by driving a spike deep into a large tree.

Geographical locations are important considerations when establishing grounding systems.

- Deserts. The extremely dry and loosely packed desert soils provide a very poor electrical grounding system. Increase the efficiency of the grounding system with the salt solution. Keep the soil around the grounding system moist at all times. Place the equipment near an oasis or subterranean water if possible.
- Mountainous areas. In the rocky terrain typical of mountainous areas, site selection is the key to providing a good grounding system. Try to place the equipment near a streambed.
- Packed, rocky, or frozen soil. Use a slip hammer to drive a grounding rod into this soil. You can make a slip hammer (*Figure 8-16, page 8-26*), or you can order one through normal supply channels.

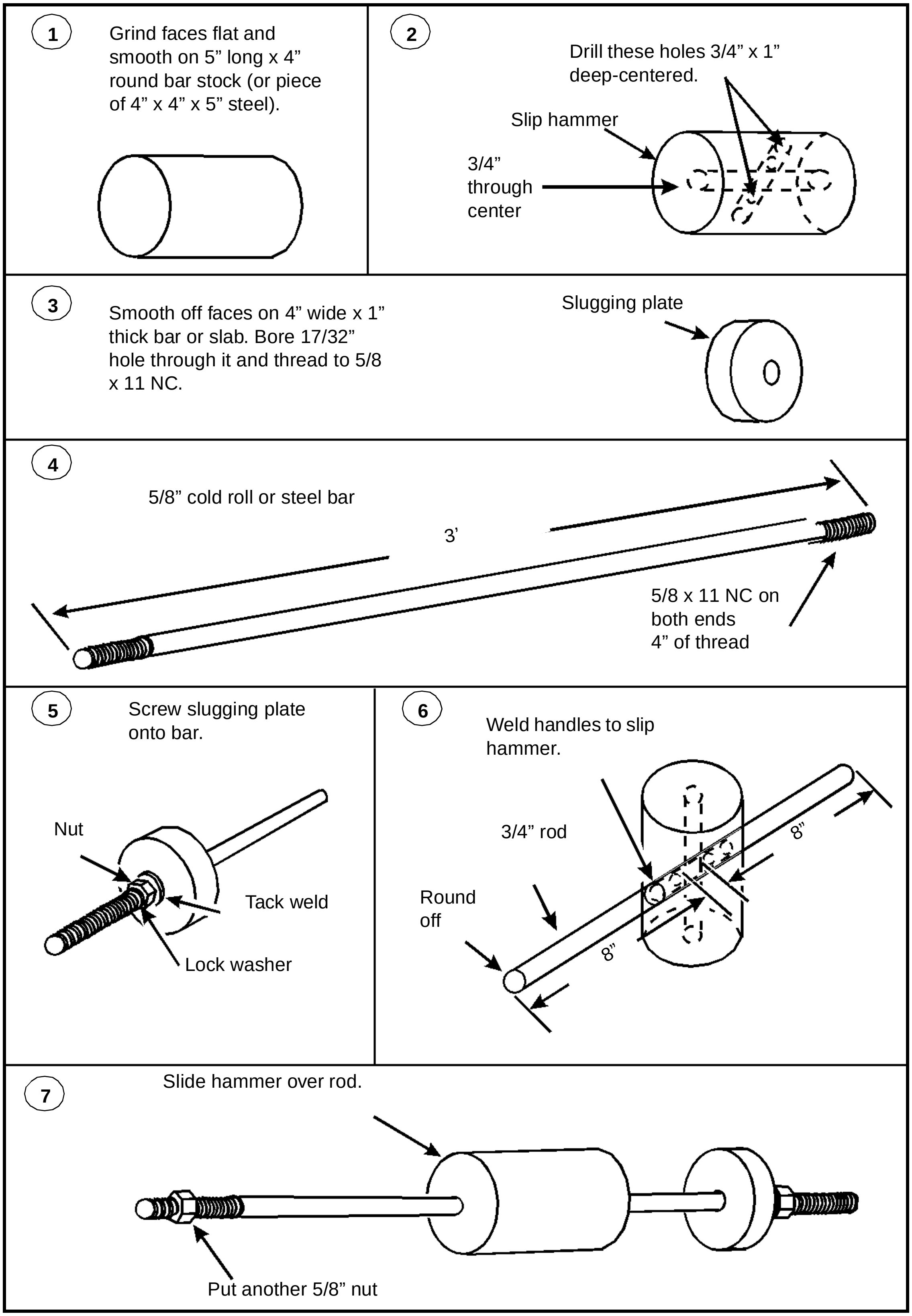


Figure 8-16. Procedures for making a slip hammer

- Tropical areas. Soils in jungles and rain forests provide good electrical ground for the grounding-rod assembly issued with the generator set. You can install grounding rods easily in these moist soils. The fast buildup of corrosion is a problem in the tropics. To ensure a good electrical path, apply waterproof tape at the connection of the grounding strap and keep the grounding rod clean and dry.

Perform the following checks and services to establish a good grounding system:

- Remove paint, oil, and grease from the grounding rods, straps, and connections.
- Keep grounding rods and straps clean.
- Ensure that grounding rods are as straight as possible.
- Keep the points of grounding rods sharp enough to penetrate the soil.
- Ensure that the straps and cable are the proper lengths.
- Use the proper clamps and connections for the grounding system selected.
- Properly tighten the terminal screw and the grounding-clamp screws.

SELECTING THE GENERATOR SITE

The location of the generator set affects the efficiency of the power system. The individual demands for electrical power and the area to be serviced govern the site selected. Generator sets are usually located near the large demands.

You must determine where the large demands are located. To do this, study the map where the individual demands are plotted. If you need additional sets for parallel operations, plot them on the map. All the power demands must be plotted on the map before you select the site and prepare it for the generator set.

Place the generator sets near the largest loads. This practice reduces the size of wire cable required, minimizes the line voltage loss, and provides voltage control at the demand end of the line.

Provide shelter for the generator set. Although the equipment is weather-resistant, it needs protection from inclement weather and enemy fire. A revetment-type shelter provides protection from weather and enemy fire and controls noise levels. Revetment shelters are used for air-cooled generator sets that produce from 0.5 to 10 kilowatts of electricity. The shelter should provide ventilation to maintain a reasonable temperature around the generator and allow heated air and exhaust fumes to escape. If the generator set operates in a closed structure, the exhaust gases must be piped outside.

The pipe used to remove exhaust gases must be installed properly. It should be as short as possible and have no more than one 90-degree bend. Keep combustible materials at lease 6 inches away from the exhaust pipe. Wrap the pipe with insulation if personnel can accidentally touch it.

Use the following guides to select a site for power-generating equipment:

- Provide enough clearance around the generator set to perform maintenance procedures.
- Place the generator set away from areas where noise may be a problem. Most mobile generator sets produce high noise levels.
- Mount the generator set in an area that is clean, level, dry, well-ventilated, and well-drained. Use planks, timbers, logs, ammunition boxes, or other materials to prevent the skids or frame from sinking into soft earth. Keep the set level, preferably within 5 degrees, for proper lubrication. Never tilt the set more than 15 degrees in any direction. You may use cargo trucks for mounting generator sets, but two-wheeled trailers are more common because they offer greater

maneuverability and ease of maintenance. When the set is mounted on a trailer, it is called a *power unit* (*Figure 8-17).*

- Mount the generator set on a surface that can support the weight of the equipment.
- Provide a supply of clean fuel that is sufficient for all requirements planned for the life of the installation. For a long-term installation, consider placing the fuel tanks underground.
- Place the auxiliary fuel tanks for generator sets that produce less than 10 kilowatts as near the shelter as possible. The bottoms of the tanks must be less than 4 feet below the fuel pump on the installed generator set. The fuel tanks for sets producing 15 kilowatts or more must be placed less than 12 feet below the fuel transfer pumps. Connect the fuel line between the auxiliary fuel tank and the fuel selector valve. Ensure that no dirt or moisture gets into the fuel lines.
- Enclose auxiliary fuel supply tanks that are above ground with engineer tape to rope off the area. Place *No Smoking* signs at each entrance to the fuel supply area, at least 50 feet from the fuel supply and the generator set. If possible, construct a shelter to protect the auxiliary fuel supply from rain and direct sun rays. Install a fire point that includes a Class A fire extinguisher, a shovel, and a pickax.

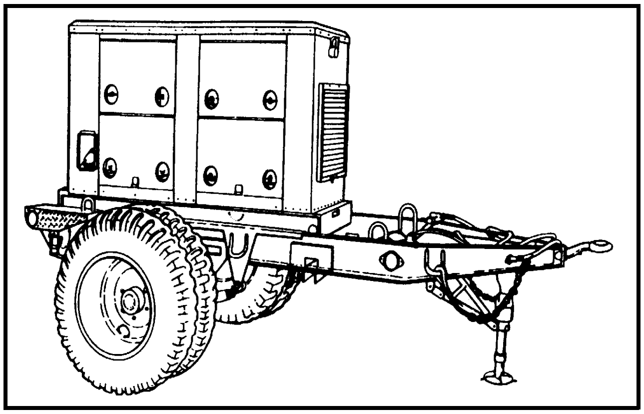


Figure 8-17. Trailer-mounted generator set

- Provide adequate shelter for generators that will be in service at one location for a long period of time. Use noncombustible material for the shelter if possible. Allow a clearance of 4 to 6 feet if you use combustible materials. A lean-to, a shack, or a shed can adequately shelter generating equipment.
- Provide a suitable foundation so the generator set can be bolted to the floor. This will eliminate unnecessary vibrations. Do not use the portable, totally enclosed, and winterized type of generator set in a permanent, indoor installation.

CONSTRUCTING A REVETMENT

Air-cooled, engine-driven generator sets are designed to operate in the open with unrestricted ventilation. However, you may need a revetment (*Figure 8-18*) to protect the equipment from extreme weather and enemy attack. The revetment described in this section is designed to shelter one generator set. Install only one generator set within each revetment. Also, do not place other heat-generating equipment in a revetment with a generator set. Anything that creates heat inside a revetment will adversely affect the cooling of the set.

NOTE: Use revetments only for air-cooled, engine-driven generator sets.

DIMENSIONS

The minimum allowable inside dimensions for a revetment for generator sets rated from 1.5 through 10 kilowatts are 7 1/2 feet long, 5 1/2 feet wide, and 4 feet high. The height includes 1-foot openings around the top of walls that are 3 feet high. The entrance into the revetment should be 2 feet wide. The height of the sill at the bottom of the entrance should be 1 foot or less. A revetment with these dimensions is also suitable for generator sets that produce 0.5 kilowatts of electricity. To economize, however, the width and length can be reduced to 4 feet and 5 feet, respectively.

The above minimum dimensions are based only on engine cooling and ventilation considerations. They allow the minimum space required for servicing and maintaining equipment.

FOUNDATION AND DRAINAGE

Generator sets require an adequate foundation. If the generator set is attached to a shipping pallet, the pallet provides an adequate foundation. If the set is not attached to a pallet, use planks, timbers, logs, ammunition boxes, or other materials to prevent the skids of the frame from sinking into soft earth. The foundation must be less than 6 inches high.

A drainage system is required to ensure that the runoff flows away from the generator set and out of the revetment. Place all drain holes at the inside ground level. Install a sump and drainage trench for each drain hole if the water does not drain away from the revetment naturally. Place a sump and drainage trench outside the revetment.

WALL CONSTRUCTION

The walls of a revetment may be constructed with sandbags, ammunition boxes filled with sand or dirt, or any other materials.

ROOF CONSTRUCTION

The roof can be supported by any means possible, but it must be at least 1 foot above

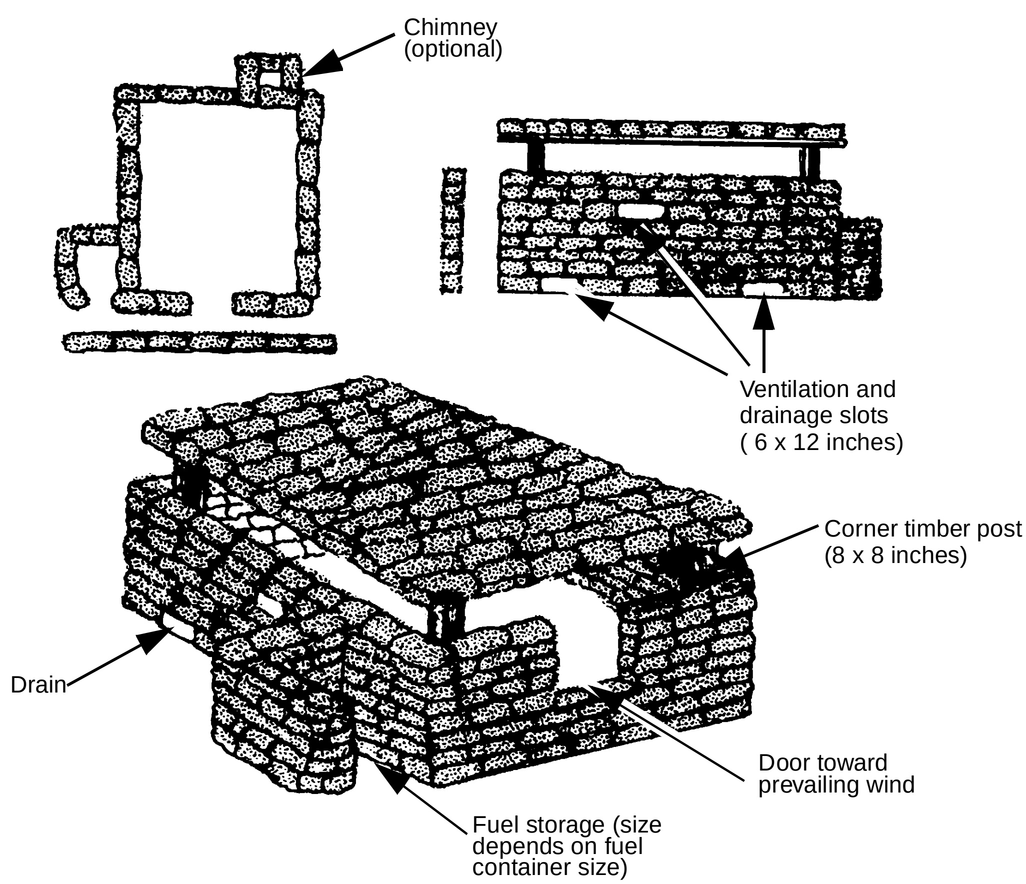


Figure 8-18. Revetment construction

the wall of the revetment. Allow as much open space between the top of the walls and the roof as possible for ventilation. Roof construction usually consists of two pieces of lumber (4 inches by 4 inches) or logs (4 inches in diameter), about 10 feet long, and enough cross pieces of lumber, logs, or steel planking to cover the entire roof. The cross pieces should be about 8 feet long. If the above materials are not readily available, use any available material. The amount and type of protection desired determines the thickness of the roof. When adding roof protection, be sure the roof can support the additional weight. **NOTE: The roof shown in *Figure 8-18, page 8-29,* is covered with sandbags for additional protection.**

WARNING

Never operate an air-cooled, gasoline-engine generator set inside a closed building unless forced ventilation can remove the engine heat and exhaust gases outside. Exhaust gases contain carbon monoxide, which is a poisonous, odorless, and colorless gas.

MISCELLANEOUS CONSTRUCTION

Construct a compartment outside the revetment for fuel storage. The size of this storage area depends on the size of the fuel containers. The fuel supply is stored outside the revetment to minimize the hazards associated with fuels at high temperatures. Air temperatures within the revetment increase considerably above the ambient temperature outside when the generator set operates. Some generators are equipped with integral fuel tanks. Do not use the integral fuel tanks in a revetment because of the hazards associated with fuels at high temperatures.

The exhaust from the engine may or may not be ducted out of the revetment. This decision is left to the commander. Install a flexible pipe (chimney) similar to the one shown in *Figure 8-18* if the exhaust is ducted outside. If a flexible pipe is not available, use a piece of exhaust pipe or similar material. The point where the exhaust discharges through the revetment wall depends on the type of generator set and the exhaust pipe. The exhaust may or may not be discharged into an external exhaust chimney. However, a chimney is preferable because it helps duct the exhaust gases away from the revetment and reduces the noise level.

Construct a revetment doorway shield that is similar to a revetment wall. The shield is a wall that prevents projectiles and fragments from entering directly into the revetment. The doorway shield must be 3 feet high and 7 1/2 feet long.

ALIGNMENT INSTRUCTIONS

When constructing a revetment, align the structure so that the door faces into the direction of the prevailing wind. Install the generator set so that its long axis is parallel with the long axis of the revetment. Center the set within the revetment walls. Use the information in *Table 8-11* to orient the generator set.

Table 8-12. Engine-driven generator-set orientation

Generator Set Output (kW)	Orientation
1.5	Generator end toward the door
3.0	Engine end toward the door
4.0	Generator end toward the door
10.0	Generator end toward the door

CHAPTER 9

Controls and Instruments

A complex set of controls and instruments monitors the operation of an electric generator set. Equipment operators must understand what these controls and instruments monitor and how they work. Information about many controls and instruments is included in this chapter. Additional information about the controls and instruments for a specific generator set is in the manual issued with the set.

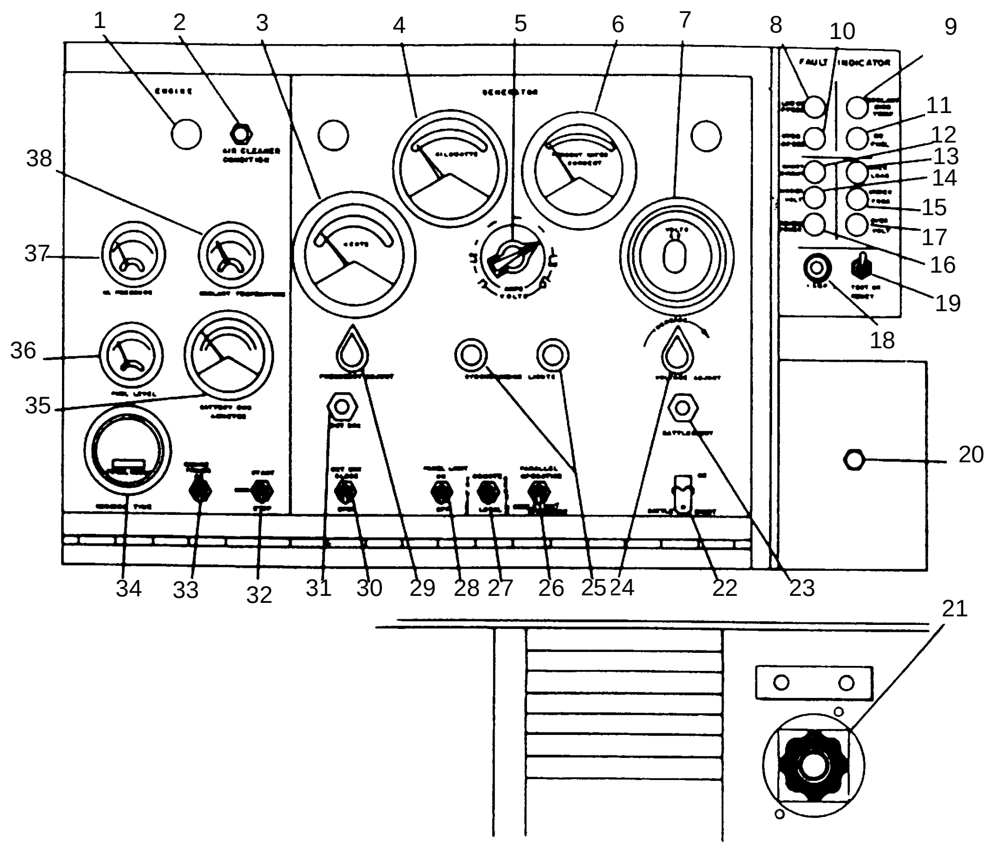
ENGINE CONTROLS

The controls and instruments used to operate a generator set are installed in a control panel similar to the one in *Figure 9-1, page 9-2*. **NOTE: In this chapter, the number in parentheses after the control name corresponds to the callout in *Figure 9-1*.**

The *DC circuit breaker* (20) protects DC circuits against shorts and emergency stops. When pressed in the start position, the *start-run-stop switch* (32) completes the battery circuit to start the motor. The switch is released and returns to the run position after the generator starts. The switch remains in the run position until it is placed in the stop position. The *manual speed control* (21) regulates the speed of the engine. The *heater controls* (*Figure 9-2, page 9-3*) operate the engine's heater. The control set includes a circuit breaker, a heater-on indicator light (press-to-test light), and an on-off switch. The press-to-test light is on when the heater is operating. The *three-way fuel valve* (*Figure 9-3, page 9-3*) directs the flow of fuel from the source of supply to the fuel pump. The valve has three positions—auxiliary fuel tank, set fuel tank, and off. The first two positions indicate the fuel source. For example, when the valve handle is in the *set fuel tank* position, fuel is drawn from the tank on the generator set.

SAFETY CONTROLS

Most generator sets have a safety-control system similar to the one in *Figure 9-4, page 9-4*. The system consists of relays, overspeed safety devices, and pressure-temperature controls. The generator shuts down when a safety device actuates. Safety devices stop the engine or trip the circuit breaker in cases of overspeeding, low fuel level, low oil pressure, or high coolant temperature. The *low oil-pressure indicator* (8) illuminates when the oil pressure drops enough to actuate the low oil-pressure safety device. The *coolant high-temperature indicator* (9) illuminates when the coolant temperature rises enough to actuate the coolant high-temperature safety device. The o*verspeed indicator* (10) illuminates when the engine speed exceeds the rated rpm and the overspeed safety device (*Figure 9-5, page 9-5*) actuates. The *no-fuel indicator* (11) illuminates when the fuel in the tank is low enough to actuate the no-fuel protective device.



1. Panel-illumination light
2. Air-cleaner condition indicator
3. Frequency meter
4. Kilowatt meter
5. Volts-amps selector switch
6. AC ammeter
7. AC voltmeter
8. Low oil-pressure indicator
9. Coolant high-temperature indicator
10. Overspeed indicator
11. No-fuel indicator
12. Short-circuit indicator
13. Overload indicator
14. Under-voltage indicator
15. Under-frequency indicator
16. Reverse-power indicator
17. Over-voltage indicator
18. Fault-location indicator fuse
19. Test or reset switch
20. DC circuit breaker
21. Manual speed control
22. Battle-short switch
23. Battle-short indicator
24. Voltage-adjust rheostat
25. Synchronizing lights
26. Parallel-lights switch
27. Voltage-sensing switch
28. Panel-light switch
29. Frequency-adjust rheostat
30. Circuit-breaker switch
31. Circuit-breaker indicator
32. Start-run-stop switch
33. Engine-primer switch
34. Hour meter
35. Battery-charge ammeter
36. Fuel-level gauge
37. Oil-pressure gauge
38. Coolant-temperature gauge

Figure 9-1. Typical generator control panel

The *battle-short switch* (22) permits emergency operation of the generator. This four-pole, on-off switch prevents the generator from starting after a safety device actuates by locking out the starter circuit. It bypasses all protective device circuits except the overspeed and short circuits. During normal operations, the battle-short switch is in the off position.

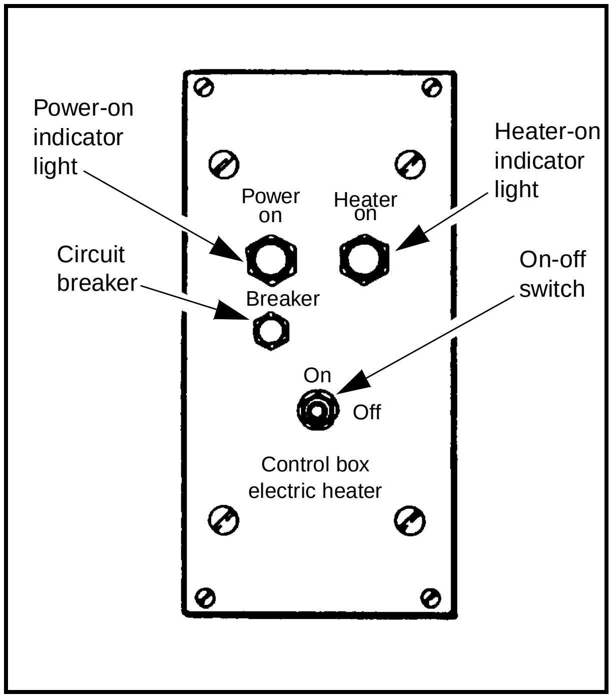


Figure 9-2. Typical heater controls

ENGINE INSTRUMENTS

Several instruments monitor the engine's operation. The *oil-pressure gauge* (37) indicates the amount of oil pressure maintained in the engine. The *coolant-temperature gauge* (38) indicates the temperature of the engine coolant. The *fuel-level gauge* (36) indicates the amount of fuel in the main tank. The *battery-charge ammeter* (35) indicates the condition of the batteries and the charging system. The *hour (time-totalizing) meter* (34) indicates the amount of time the generator set has operated.

AC GENERATOR CONTROLS

Several controls monitor the operation of an AC generator. The *volts-amps selector switch* (5) provides current and voltage readings for each generator phase. A meter is connected to each phase of the main generator. Most switches have six positions that are plainly marked on the face of the selector plate. The *phase-selector switch* (*Figure 9-6, page 9-5*) changes the output of a generator to match the voltage and phase requirements of the load. This rotary-type switch is used on generators that produce as much as 10 kilowatts of electricity; changeover boards are used for generators that produce 15 or more kilowatts. The *parallel-lights switch* (26) closes the synchronizing-lights circuit in preparation for paralleling two or more power units. It is usually a two-position, rotary or toggle switch. The *voltage-adjust rheostat* (24) adjusts the value of the output voltage. The rheostat is a small, variable resistor. The *circuit-breaker*

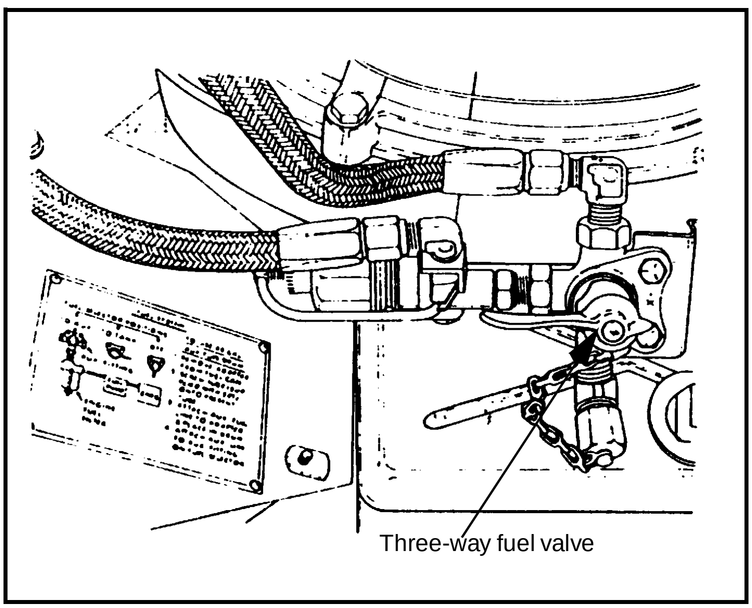
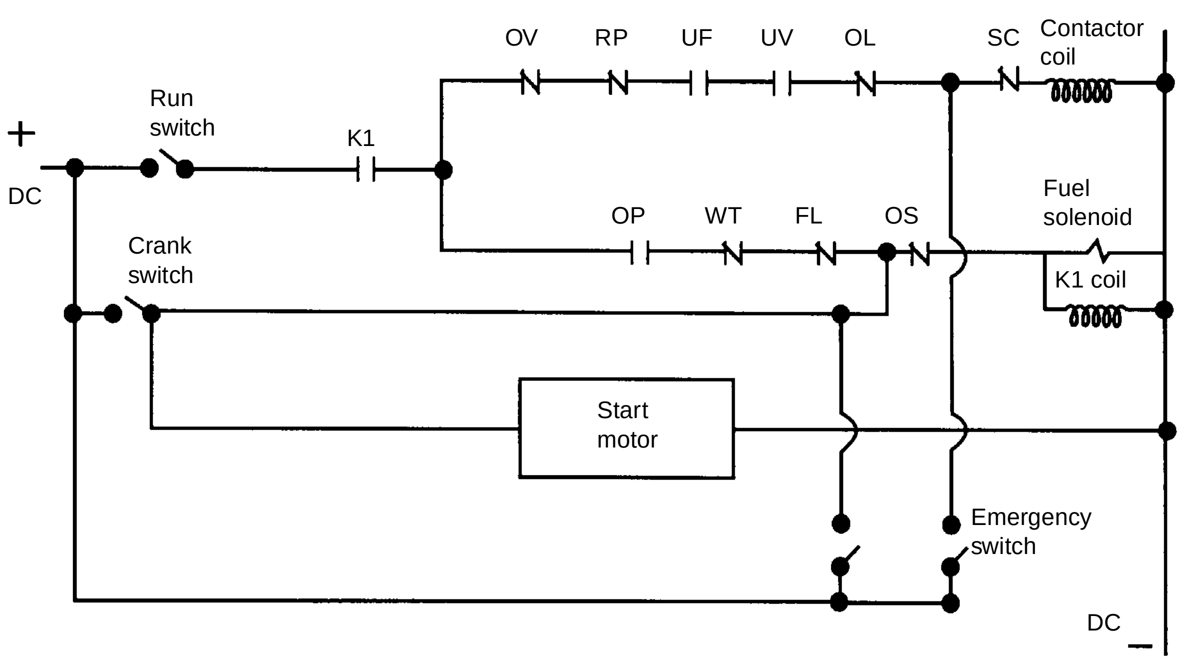


Figure 9-3. Three-way fuel valve

switch (30) disconnects and connects the load lines from the generator set. This switch acts as a main switch and an overload protective device. The circuit breaker automatically disconnects the load from the generator in case of overload, short circuit, or ground on the load lines or within the equipment being powered.

AC GENERATOR METERS

Various meters monitor the output from an AC generator. The *AC ammeter* (6) indicates the current output of the generator. The output is usually a percentage of the rated load. The *AC voltmeter* (7) indicates the voltage of the output terminals and, therefore, the voltage output of the generator. The *frequency (hertz) meter* (3) indicates the line frequency of the generator output in cycles per second. This dial-type meter is used for 50-, 60-, and 400-cycle generators. The *kilowatt meter* (4) indicates output from the generator. The output reading, in percent of kilowatts, must not exceed the rated capacity of the power plant. The operator must reduce the load if the output reading exceeds the rated capacity of the power plant.



1. K1 Run relay
2. OV Over voltage
3. RP Reverse power
4. UF Under frequency
5. OL Overload
6. SC Short circuit
7. OP Oil pressure
8. WT Water temperature
9. FL Fuel level
10. OS Overspeed
11. UV Under voltage
12. DC Direct current

Figure 9-4. Practical wiring diagram of a safety control system

CONVENIENCE OUTLET

The generator contains a 120-volt AC convenience outlet that provides outlets for lights around the generator set. Fuses or a circuit breaker protect the outlet from overloads.

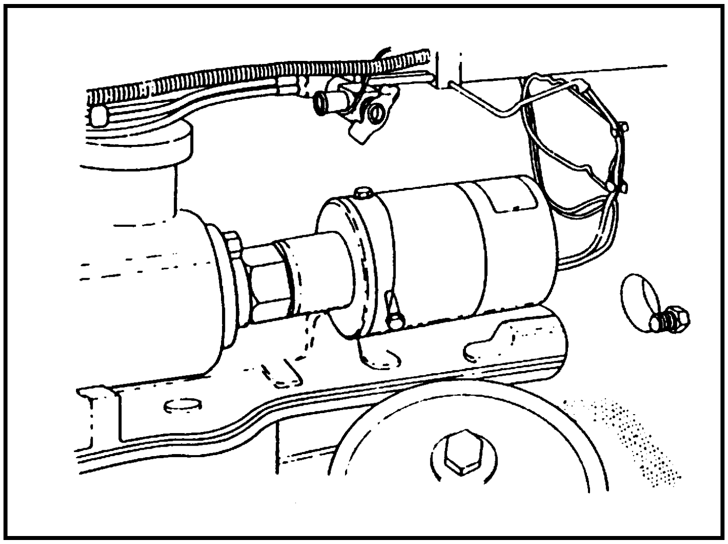


Figure 9-5. Overspeed safety device

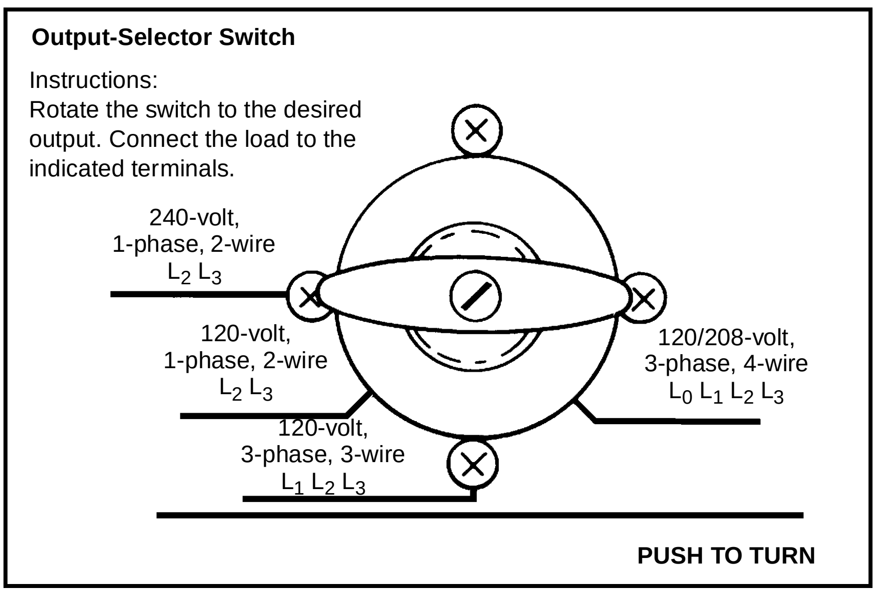


Figure 9-6. Phase-selector switch

CHAPTER 10

Setup, Installation, and Operation Procedures

Equipment operators must be able to set up and install an electric generator set in the field and to determine locations for the fuel supply and maintenance facilities. If performed properly, this function helps ensure safe and efficient equipment performance throughout the field of operations. This chapter describes the tasks required to set up and install an electric generator set and support facilities in the field.

Section I. Setup and Installation

PRELIMINARY INSTRUCTIONS

An electric generator set may arrive in the field completely operational and ready for use. However, if the equipment was shipped from a supply or maintenance point, the fluids have been drained out of the set and it is not in an operational-ready status. Several preliminary tasks are required to set up the equipment and support facilities for a field unit.

INSPECT THE EQUIPMENT

The operator must carefully inspect all incoming equipment.

- Inspect the identification plate. Ensure that the information on the plate matches the equipment.
- Inspect the generator set for damage. Document all damage on DA Form 2404 and submit the form to the next echelon of maintenance.
- Compare the equipment with the packing list to ensure that all items shipped are present and serviceable.
- Inspect the entire unit carefully for loose and missing hardware. Tighten loose hardware and replace missing items.
- Turn the engine over by hand to ensure that all moving parts in the engine and the generator move freely.
- Ensure that all tags, tape, cloth, and barrier materials are removed.

SERVICE THE EQUIPMENT

Perform daily preventive maintenance checks and services (PMCS) after the equipment is inspected.

- Lubricate the generator set's engine according to the instructions in the current lubrication order.
- Correct as many deficiencies as you can and report uncorrectable deficiencies to organizational maintenance.

INSTALL THE FUEL SUPPLY

One of the equipment operator's most important tasks is to properly install the fuel supply and storage tanks required for the generator set. Gasoline, diesel fuel, or jet fuel (JP-4) may be used to power the generator set. Consider the following when planning installation of the fuel storage area:

- Planned duration of the field installation.
- Security requirements.
- Potential fire and safety hazards.
- Potential sources of contamination.

Planned Duration

The length of time the field unit will be in operation partly determines how the fuel storage facilities are installed. For a long-term field unit, use the proper fittings to install the fuel tanks underground. Ensure that the tanks comply with the manufacturer's instructions. Select a location that is convenient to the using equipment. Proper installation and a convenient location minimize the hazards of fuel contamination, vapor lock, and fire.

For a short-term field unit, place the auxiliary tanks or drums above the ground, as far from the using equipment as the auxiliary line allows. If you are using a metal pipeline, place the tanks about 25 feet from the generator set. Keep the auxiliary fuel line as straight as possible.

Security Requirements

Follow the unit's standing operating procedures to perform the proper security measures.

Potential Fire and Safety Hazards

Fire and safety hazards are critical elements in the design of a fuel storage area. The following safety practices will help eliminate many fire and safety hazards:

- Clearly mark the entire fuel storage area with *NO SMOKING* and *OPEN FLAME* signs to indicate that it is a hazardous area.
- Dig an open trench 4 feet wide and 6 inches deep around the area to contain any fuel leaks or spills. Pile the earth in a mound around the trench. Place crushed rock or sand inside the trench to absorb spilled fuel. Immediately cover any small spills with dry sand or earth.
- Prohibit burning of trash within 200 feet of any fuel storage area.
- Do not place any electrical wires above or near the fuel tanks.
- Direct hot exhaust from operating engines away from the fuel supply.
- Bury or cover fuel lines leading away from fuel tanks to protect them from the sun and physical damage.
- Avoid using a rubber hose for fuel delivery except as a temporary measure. To make the hose safe, attach or clamp a light, flexible copper wire to the end fittings of the hose. Twist a ground wire around the hose to prevent breakage and to provide a path for static electricity to flow to the ground. Attach one electrical grounding wire to the auxiliary tank and another to the generator set.
- Avoid using a long, nonconductive hose for fuel delivery except as a temporary measure. Static electricity builds up when fuel flows through a long pipe or hose.
- Maintain adequate fire-extinguishing equipment near the auxiliary fuel-tank area and the generator set. The fire point must include a shovel, a pickax, and a fire extinguisher. Include buckets of sand in the fire point if they are available.

Potential Sources of Contamination

The fuel supply for an electric generator set must be free of contamination. The equipment operator can help ensure a pure fuel supply by identifying potential sources of contamination and planning around them.

Place the fuel storage area at least 50 feet from all work areas and equipment that does not require fuel. The storage area must be at least 50 feet from heavily traveled roads but be easily accessible by the fuel supply trucks. Place the storage area in such a manner that any fuel leaks flow away from the equipment, personnel work areas, and housing. You may need to emplace a shelter or cover to protect the fuel from contamination.

MAINTAIN THE FUEL SUPPLY

The operator must maintain a fuel supply that is adequate for all needs. To help ensure that the proper fuel is on hand—

- Ensure that the type and grade of fuel used in the generator match the specifications.
- Never mix different fuels. Label each storage tank clearly with the type and grade it contains. Ensure that only that type of fuel is put in the tank.
- Clean the tank thoroughly before changing the grade and type of fuel stored in it. Drain all the old fuel and remove the sediment and condensation. This procedure prevents improper operation or damage to the generator set.
- Ensure that fuel does not spill on any engine parts when draining an engine-mounted fuel tank. Connect a flexible hose between the petcock and the container if the fuel cannot drain directly into the container.

PERFORM BEFORE-OPERATION PMCS

Equipment operators must perform PMCS before starting an electric generator set. Refer to the manual issued with the set to ensure that all required PMCS for a specific set are performed properly. **NOTE. Use the equipment manual to obtain the correct operating data.**

- Check the fuel lines for leaks. Check the fuel level in the tank and refill it as needed. If winterization equipment is used, check the heater for fuel leaks. The heaters in some generator sets use diesel fuel from the main tank. Check the fuel level in the auxiliary tanks. Drain condensation from the tanks and clean the fuel filters before operating the equipment.
- Inspect the plenum drain fitting before starting a gas turbine, engine-driven generator set. Ensure that it is clear and that no fuel has accumulated in the plenum chamber. Use only clean fuel. Drain the sediment from the filter into a small container and dispose of the sediment. Check the fuel control valves for proper positioning.
- Check the radiator coolant level and add coolant if necessary. Allow room for expansion when filling a cold radiator. If cold weather is anticipated, add antifreeze according to the instructions in *Table 10-1, page 10-4*.
- Ensure that all required tools, TMs, and basic issue items on the inventory list are on hand and serviceable. Included in the basic-issue items are an auxiliary fuel hose, grounding rods and cables, a fire extinguisher, paralleling cable, a load-terminal wrench, and grounding-wire clamps. Most generator sets have a storage compartment for the tools, TMs, and basic-issue items.
- Check the electrolyte level in the batteries, and add distilled water as necessary. Ensure that the level is about 3/8 inch above the battery plates. Never add water to the batteries from a metal container. Refer to TM 9-6140-200-14 for additional battery services.
- Check the engine's oil level and add oil if necessary. Lubricate all other parts according to the lubrication order issued with the equipment.
- Carefully check the fuel tank, the radiator, oil covers, and the oil pan for leaks. Check all lines and connections for leaks.

- Ensure that all generator and engine instruments are securely mounted, properly connected, and undamaged. Check all gauges when the generator is operating to ensure that they work properly.
- Inspect the entire generator set for cracks, breaks, and loose or missing hardware. Inspect all wires and terminals for damage and loose connections. On gas-turbine units, inspect the air-inlet screen assembly and remove obstructions. Inspect the changeover board (*Figure 10-1)* and the phase selector switch (*see Figure 9-6, page 9-5*) for the correct link connections or positioning for the desired voltage. Set the frequency selector switch for the desired frequency output on the 50/60 cycle, precise Class 1 sets. Place the circuit breaker (main switch) in the open (off) position. Connect the output service cable to the load-panel terminal connections.

WARNING

Never attempt to start a generator set with the circuit breaker closed (on). A closed circuit breaker will cause a power surge and damage the equipment.

- Ensure that the grounding connections on the equipment and the grounding rod are tight. Use No 6 AWG or larger wire for the ground.

Table 10-1. Freezing points, composition, and specific gravities of military antifreeze materials

<table>
<tr><th>Lowest Expected Ambient Temperature (°F)</th><th>Pints of Inhibited Glycol per Gallon of Coolant[1]</th><th>Compound Antifreeze Arctic[2]</th><th>Ethylene Glycol Coolant Solution Specific Gravity at 68°F[3]</th></tr>
<tr><td>+20</td><td>1 3/4</td><td rowspan="10">Issued full strength and ready mixed for 0°F to 65°F for both initial installation and replenishment of losses. DO NOT DILUTE WITH WATER OR ANY OTHER SUBSTANCE.</td><td>1.022</td></tr>
<tr><td>+10</td><td>2</td><td>1.036</td></tr>
<tr><td>0</td><td>2 3/4</td><td>1.047</td></tr>
<tr><td>-10</td><td>3 1/4</td><td>1.055</td></tr>
<tr><td>-20</td><td>3 3/4</td><td>1.062</td></tr>
<tr><td>-30</td><td>4</td><td>1.067</td></tr>
<tr><td>-40</td><td>4 1/4</td><td>1.073</td></tr>
<tr><td>-50</td><td rowspan="3">Arctic antifreeze preferred</td><td>NA</td></tr>
<tr><td>-60</td><td>NA</td></tr>
<tr><td>-75</td><td>NA</td></tr>
</table>

[1]Maximum protection is obtained at 68 percent by volume, that is 5.4 pints of ethylene glycol per gallon of solution.

[2]Military Specification MIL-C 11755 Arctic type, nonvolatile antifreeze compound is intended for use in the cooling system of liquid-cooled internal combustion engines for protection against freezing primarily in Arctic regions where the ambient temperature remains for extended periods of time close to -40°F or drops below, to as low as -90°F.

[3]Use an accurate hydrometer. To test the hydrometer, use 1 part ethylene glycol-type antifreeze to 2 parts water. This should produce a hydrometer reading of 0°F.

NOTE: Fasten a tag near the radiator filler cap indicating the type of antifreeze.

CONNECTION INSTRUCTIONS

After the preliminary tasks are completed, the operator must install and connect the distribution cables.

INSTALL THE DISTRIBUTION CABLE

A distribution cable connects the generator set to the load. The cable may be installed overhead, buried underground, or laid on the ground. Two types of distribution cables are used in military distribution systems:

- Cable that is supplied in predetermined lengths and sizes and equipped with quick-disconnect connector plugs.
- Building wire that is supplied in rolls.

The operator must decide how the distribution cable is installed. The decision to install the cable overhead, underground, or on the ground depends on the type of material available and the conditions at the field unit.

Overhead

When conditions dictate the use of an overhead line, you must construct the line properly. Utility poles, the most convenient method of supporting the lines, are seldom available in the field. Pieces of wood 6 inches by 6 inches may be substituted for poles if they are long enough to set rigidly in the ground and provide safe clearance for the wires. As a last resort, you may use trees for support if the proper weatherproof cable is available. Use the following guides when installing an overhead distribution system:

- Allow a minimum height of 20 feet for vehicle clearance when crossing over roads.
- Space the poles so that the quick-disconnect joints are supported by the pole as shown in *Figure 10-2*.
- Tie the cable together with the quick-disconnects.
- Use the proper plug connections when installing multiphase cables equipped with quick-disconnects. This type of cable has male and female receptacles that must be properly aligned to prevent a reverse-power condition in the system. Match the cable marking or apply markings before installing the cable to ensure the proper alignment. Most cables are marked by the manufacturer. The marks are countersunk circular or triangular depressions or raised buttons in the insulation on each receptacle. Receptacles usually have one pin and one jack larger than the other pins and jacks. The large pin and large jack represent a grounding (neutral) conductor. Match the large pin and large jack to ensure that the receptacles are connected properly if there are no other markings. If you mark the cable at the field unit, paint a color code on the receptacle.

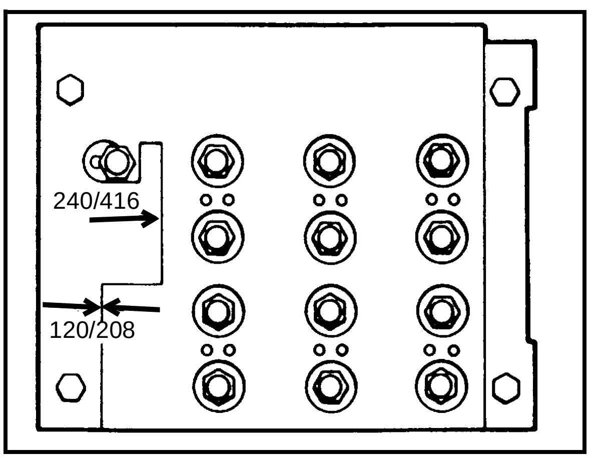


Figure 10-1. Typical changeover board

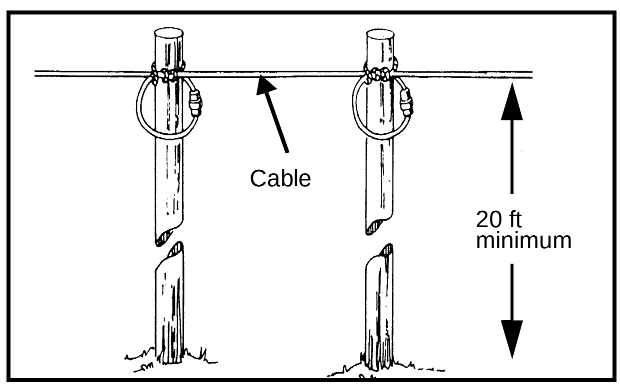


Figure 10-2. Overhead distribution system

Underground

Sometimes the cable must be buried underground. Use the following guides to ensure proper cable installation:

- Dig a trench that is at least 18 inches deep to prevent the cable from being disturbed by surface digging.
- Use only moistureproof cable. Lay the cable in the trench on a cushion of sand. If sand is not available, loosen the trench base and remove all rocks and stones.
- Ensure that the joints are moistureproof if the cable is equipped with quick-disconnects.
- Separate the cables uniformly to protect the circuits. Allow at least 6 inches between the cable centers for mechanical and electrical protection.
- Cover the cable with earth that has no rocks or stones. This procedure should protect the cable if the surrounding earth is disturbed by flooding or frost heaving.

On the Ground

Most cables are laid on the ground to save time. Because many mobile generator sets can be moved almost to the point of use, it may be necessary only to lay the cable over the ground to the load. Protect the cable from mechanical damage by laying planks or logs on both sides of it. This prevents vehicles from driving directly on the cable. Lay the cable where it will have the least interference from personnel operations and install warning signs indicating the cable location. Use only moistureproof cable that can withstand inclement weather.

CONNECT THE DISTRIBUTION CABLE

Electrical power is either distributed to the load in a direct line from the generator set or processed through a load-terminal board. A direct line is used when relatively few items make up the load and when the phase requirement is fairly constant. A load-terminal board is used when many items make up the load, the loads are scattered, and the phase and voltage requirements differ. In either case, the load must be balanced between the phases as explained in Chapter 8.

All AC generator sets are equipped with a load-terminal board (*Figure 10-3*). The board has four terminals that are marked L_0, L_1, L_2, and L_3. The terminals simplify the process of connecting the distribution cable at the generator.

When a generator set that is large enough to supply the total electrical load is unavailable, a field unit may use a distribution center. In this situation, it is necessary to make parallel connections between two or more sets and distribute their total load through a bus-bar distribution center (*Figure 10-4*). A bus-bar distribution center is also used when the equipment requiring power is so widely scattered that two or more branch feeder lines are required. Power to the branch feeder lines is controlled from the bus-bar distribution center.

Perform the following PMCS before connecting a distribution system:

- Ensure that all equipment is securely mounted, securely supported, and properly insulated.
- Select the proper size of wire to connect the load. The size of wire used depends on the load current. Refer to *Tables 8-7 and 8-8, pages 8-16 and 8-17*, to select the proper wire size.
- Ensure that the current rating of the fuses or trip elements provides adequate protection against overloads and short circuits on the branch feeder lines. Two types of switches control the output to each branch feeder line—the circuit breaker and the fused-knife switch. The operator must ensure that the components of the circuit breaker (contact points) or fused-knife switch (switch-

blades) can carry the rated current and voltage of the branch feeder lines.

- Protect the switch gear and bus bar from inclement weather. A weatherproof canopy provides adequate protection.

The layout of a typical distribution system is shown in *Figure 10-5, page 10-8*. Shielded cables of various lengths connect the loads in four central areas to the power equipment. The shielding on each cable must be grounded at one end as a safety precaution. Power distribution in the central areas usually requires three-conductor, stranded copper cable. Use *Tables 8-7 and 8-8* to compute the proper wire size. Operators must use three-phase voltage that ranges from 120 to 208 volts.

WARNING

Equipment damaged by rain or snow can injure personnel if they contact the electrical distribution devices.

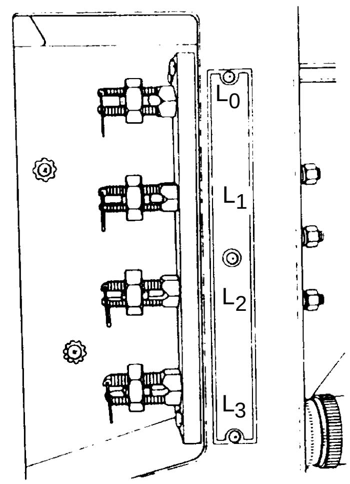


Figure 10-3. Load-terminal board

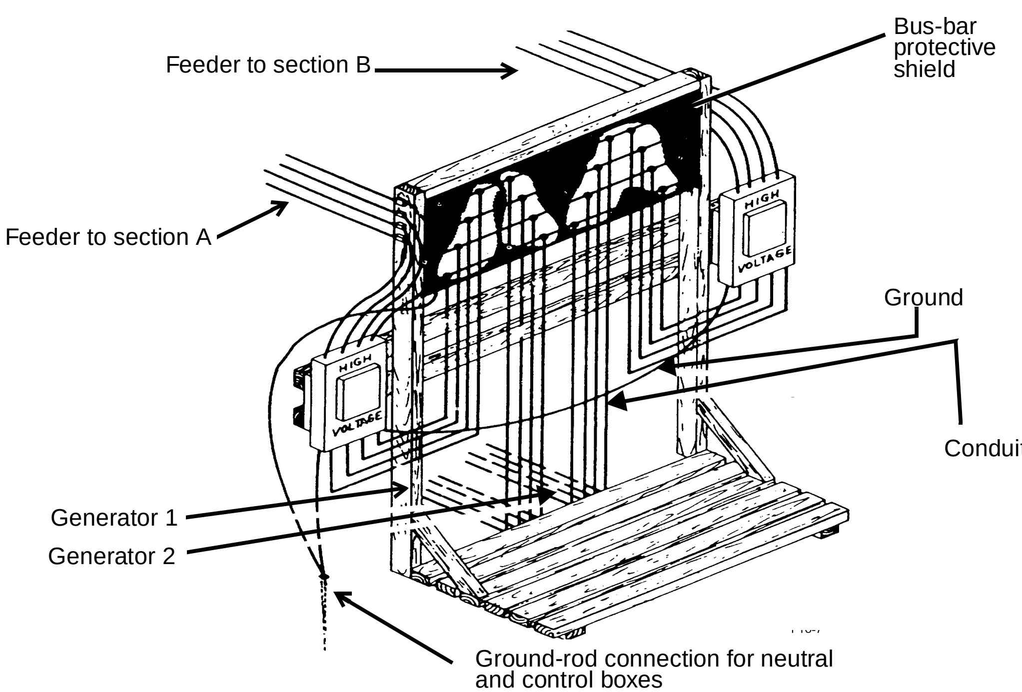


Figure 10-4. Typical bus-bar distribution center

Section II. Operation

WEATHER CONDITIONS

EXTREME COLD

Generator sets can start and operate at temperatures as low as -25°F without a winterization kit. When the ambient temperature is lower than -25°F, most engines require preheating before they are started. The engine type determines the method used. The two basic types of cooling systems used on power-generating equipment are air-cooled and liquid-cooled. A blowtorch is used to preheat most air-cooled engines. Most liquid-cooled engines are equipped with a winterization kit that contains a preheater. Refer to the manual issued with the generator set for preheating and cold-weather starting instructions.

Checks

Some general PMCS for starting equipment in cold weather follow:

All equipment—

- Check the equipment manual for installation instructions before installing a generator set in extreme cold.
- Check the antifreeze solution. Ensure that it will protect the equipment at the lowest temperature expected. Use the information in *Table 10-1, page 10-4,* to mix antifreeze.
- Ensure that the coolant in the radiator is kept at the proper level.
- Inspect the cooling system frequently for leaks. Check all gaskets and hose connections.
- Check the thermometer (water-temperature gauge) during operation for abnormally high readings.
- Ensure that all shutters, shutter controls, and thermostats function properly.
- Ensure that the shutters and the baffle rods on air-cooled systems are positioned for cold-weather operation.
- Report all uncorrectable faults to organizational maintenance.

Electrical system—

- Ensure that the batteries are fully charged to prevent freezing.
- Inspect the electrolyte level daily. The electrolyte level must be 3/8 inch above the battery plates.

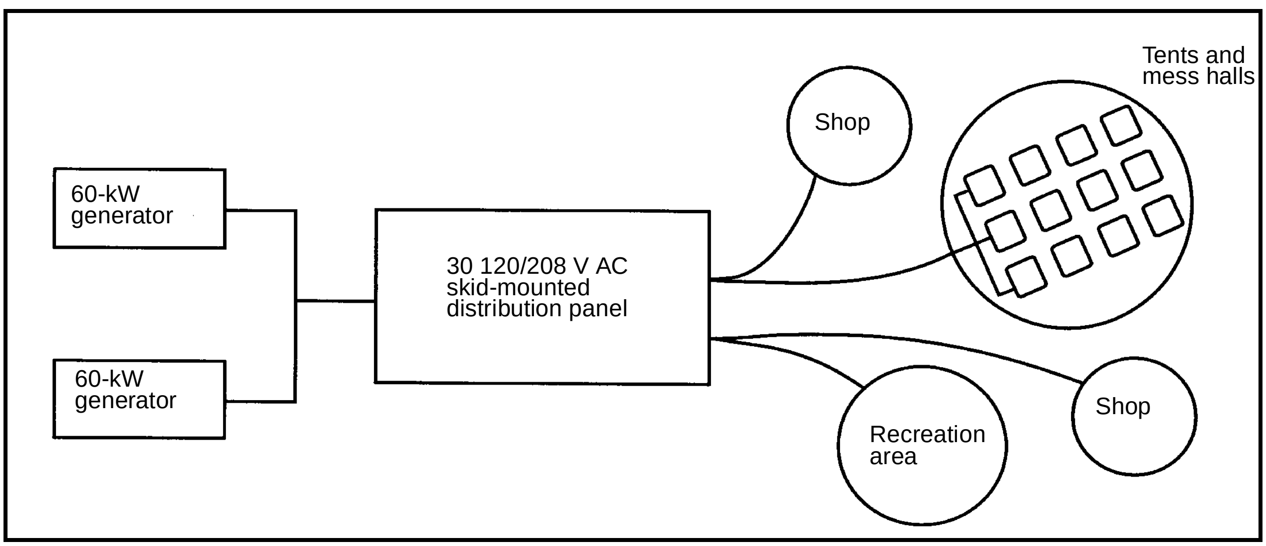


Figure 10-5. Layout for a distribution system

- Keep the batteries clean and free of ice, moisture, and corrosion.

> **CAUTION**
> Water added to a battery may freeze unless it is immediately mixed with electrolyte by charging. Do not add water unless the engine is immediately operated for 1 hour or longer.

- Ensure that the battery connections are clean, lightly greased, and tightly secured.
- Ensure that the battery-cap vent holes are open.
- Inspect all electrical wiring insulation for cracks, frays, and breaks.
- Tighten loose connections. Report all defective wiring to organizational maintenance.

> **CAUTION**
> Disturb the wiring as little as possible because insulation becomes brittle and breaks easily in extreme cold.

Fuel system—

- Keep the fuel tank as full as possible to reduce condensation.
- Ensure that the proper grade of fuel is used for existing temperatures.
- Service the fuel filters more frequently than usual to remove water from the fuel system.
- Keep the fuel-tank cap and filler neck free of ice, snow, and moisture during operation and when refueling.
- Drain the fuel tank if the fuel becomes contaminated and refill it with clean fuel. Drain sediment from the fuel tank daily.

Lubrication

Lubricate the generator set for cold-weather conditions according to the current lubrication order.

Cleaning

Remove ice, snow, moisture, and other foreign material from the generator set before each period of operation.

Generator Warm-Up Period

Warm the generator set to the operating temperature before applying the load. Some generator sets are damaged when the engines operate at low rpm.

EXTREME HEAT

Operating electric generators when ambient temperatures are high requires efficient equipment cooling and adequate lubrication. The following PMCS are required when operating equipment in extreme heat:

- Provide maximum ventilation for the cooling system at all times. Keep the equipment clean, especially the engine shrouds and cooling fins and the generator blower cover. Ensure that all air passages are free of obstructions. Move all shutters and baffle rods to the proper position.
- Inspect the coolant level frequently, and add clean coolant as needed. To keep the cooling system free of rust and scale, add an approved rust inhibitor and flush the cooling system regularly. Do not use alkaline or salt water as a coolant. Ensure that the radiator core fins and screens are free of obstructions. Ensure that the fan-drive V-belt tension is adjusted properly. Ensure that the radiator shutter operates properly. If the automatic shutter control (thermostat) fails, open and close the shutter manually and report the failure to organizational maintenance. Refer to the appropriate TM to determine whether the panel doors should be opened or closed.
- Inspect the electrolyte level of the batteries daily, and add distilled water as needed. The electrolyte level must be 3/8 inch above the battery plates. Keep the batteries clean and free of corrosion. Frequently inspect the terminals for corrosion and loose connections. Corroded and loose connections generate heat during

operation, and extreme heat causes the wiring insulation to swell and soften. Chafing and fraying of the wires due to vibration are more frequent during extreme heat than in other conditions. Frequently inspect the wiring for damaged insulation and report damaged insulation to organizational maintenance.

- Lubricate the generator set according to the current lubrication order.
- Provide ample air circulation around the generator set if it operates in an enclosed shelter. Allow air from the outside to circulate within the shelter. Keep the main generator's ventilation screen and louvers free of obstructions. Frequently inspect the instruments on the control panel for overloads. Overloads cause the main generator to overheat and may cause the main circuit breaker to open. Do not fill the fuel tank completely; instead, allow room for fuel expansion. Before an operating set is shut down, run it without the load to cool the engine.

GEOGRAPHICAL AREAS

DUSTY/SANDY

Perform the following PMCS when operating electric power-generating equipment in dusty/sandy areas:

- Erect a protective shield to provide wind protection for the generator set. Dust and sand cause mechanical failures and shorten the life of the equipment. Natural barriers can form a wind shield. For example, locate the generator set in the prevailing windward side of dusty areas, roadways, and construction sites.
- Frequently clean the generator set with an approved cleaning solvent. Keep the unit clean, especially the screens and grilles. When water is plentiful, wet the terrain surrounding the immediate operating area.
- Keep all equipment clean. Keep the main generator free of grease and oil. Clean obstructions from the ventilation screens. Blow dust from electrical components with low-pressure, dry, compressed air.
- Frequently inspect the cooling system for leaks. Ensure that the radiator and shutter operate properly and are free from obstructions. Keep the radiator cap tightly closed. Drain and flush the cooling system more frequently than required for normal conditions. When adding coolant, take any precautions needed to keep dust and sand from entering the cooling system.
- Maintain lubrication. Lubricate the generator set according to the current lubrication order. Keep all lubricant containers tightly sealed, and store them in an area free from dust and sand. Service the engine oil, the oil filter, and the air cleaner more frequently than required for normal conditions. Clean all lubrication points before applying lubricants. Clean around the crankcase oil-fill cap and the crankcase oil-level gauge before checking the oil level or adding oil.
- Prevent dust and sand from entering the fuel system. Inspect the fuel filter after each operating period. Clean the filters and strainers more frequently than required for normal conditions.
- Check the air cleaner frequently for restrictions.

RAINY/HUMID

Perform the following PMCS for power-generating equipment used in rainy or humid areas:

- Provide protection from rain. Keep all doors and panels on the generator closed when the set is not in use. Open the doors and panels during dry weather so the equipment can dry.

- Keep electrical equipment dry to prevent corrosion, deterioration, and short circuits. Inspect all electrical wiring for cracks, breaks, or frays. Report defective wiring to organizational maintenance.

WARNING

Keep the area surrounding a generator set dry at all times. If conditions are damp, use insulating materials around the set to avoid serious shocks.

- Keep the fuel tanks as full as possible so moisture cannot accumulate in them. When adding fuel, ensure that no water enters the fuel system. Keep the reserve fuel containers tightly closed. Drain contaminated fuel tanks and refill them with clean fuel.

SALTWATER

Salt water is corrosive to metal, but it is an excellent conductor of electricity. Perform the following PMCS on equipment operating in saltwater areas:

- Ensure that the electrical equipment is never in contact with salt water. If contact occurs, wash the equipment with freshwater and allow it to dry thoroughly before operating it.
- Cover nonoperating generator sets that are outside with canvas or other weatherproof material.
- Ensure that the coolant used in the cooling system is free of salt. Use an approved rust inhibitor to prevent rust and scale from forming in the cooling system.
- Paint exposed, unpolished surfaces. Coat exposed parts of polished steel and other ferrous metals with standard-issue rustproofing material or a light coat of grease.

CAUTION

Do not use salt water in the cooling system of a generator set except in an emergency because it will damage the equipment.

HIGH-ALTITUDE

Generator sets are rated based on sea-level altitude. The rating of the set may decrease as the altitude increases. Information about operating equipment at high altitudes is usually printed on the data plate. The kilowatt rating may be reduced at high altitudes depending on the type of engine used to drive the generator. Refer to the appropriate TM for information about each model of generator set.

COMBAT AREAS

Operating generator sets in combat areas requires special precautions. Operators in combat areas must use any means available to avoid detection by the enemy. It is difficult to operate electrical generators without making the location known to the enemy. The equipment is noisy and produces large amounts of heat, which may endanger personnel and equipment nearby. The discomfort caused by the noise and heat may result in decreased performance of mission goals by personnel. The ability to hear enemy activity may be reduced. New signature-suppressed generator sets that reduce noise levels are being studied. These sets will be available to field units in the future.

NOISE

Major sources of noise associated with generator sets are the engine's exhaust system, air-intake cooling fan, and vibrating metal. Operators in combat areas can use several methods to reduce the noise from operating generators. The methods used depend on the size of the generator set.

0.5 to 10 Kilowatts

The most effective method of suppressing the noise from small-sized generator sets is to install them in a revetment. Connect an auxiliary exhaust line from the engine to the revetment chimney to remove the exhaust (*Figure 10-6*). An empty 55-gallon oil or fuel drum can be substituted for a sandbag chimney. To do this, punch a number of small holes in the bottom of the drum. The area with holes must be the same size or larger than the area of the engine exhaust. Lay the drum on its side and insert the auxiliary exhaust line inside the large hole in the drum (*Figure 10-7*). Use any flexible or rigid metal pipe that has a diameter larger than the exhaust outlet on the engine muffler. To reduce mechanical noises and the noise from the engine fan, place the generator behind a barrier such as a hill, dense woods, a large vehicle, or a plywood wall.

WARNING

1. **Do not overload a generator set. Heavily loaded generators produce excessive noise, dangerous sparks, and hot exhaust gases that can injure personnel.**

2. **Do not restrict air flow around the engine. An air-cooled engine operating in a confined area, such as a foxhole, will severely overheat and possibly destroy itself in hot weather.**

15 to 500 Kilowatts

The noise from medium- and large-sized diesel generator sets with liquid-cooled engines is very loud at the radiator end of the set. The main sources of noise are the radiator's cooling fan and the exhaust (*Figure 10-8*). Operators in long-term field units can build underground muffler systems for

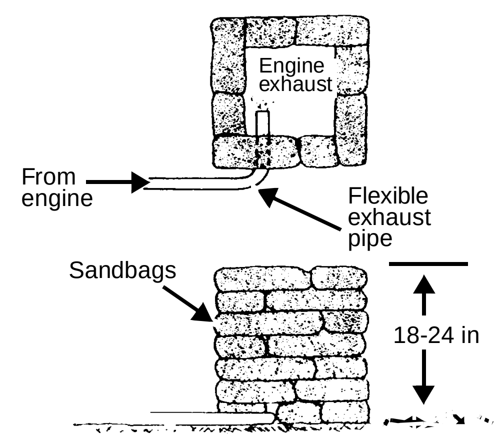


Figure 10-6. Sandbag exhaust chimney

these sets. Even with an underground exhaust system, the noise level will be high because of the unsuppressed fan noise. To reduce the fan noise, place a barrier such as a van, plywood sheets, or convex containers in the noise path. Another option is to place the equipment so that a natural barrier lies between the radiator and the direction where the noise reduction is desired. Do not restrict air flow out of the radiator.

VISIBILITY

It may be necessary to camouflage the equipment and revetments to avoid detection by the enemy.

INFRARED DETECTION

Generators have a thermal signature that can be detected by infrared sensors. At this time, there is no way to eliminate this problem.

ICE FOG

Ice fog caused by engine exhaust is visible in very cold climates (-25°F and below). To eliminate ice fog, place a tube on the exhaust pipes and cover the tube with a tarpaulin to diffuse the exhaust in the snow.

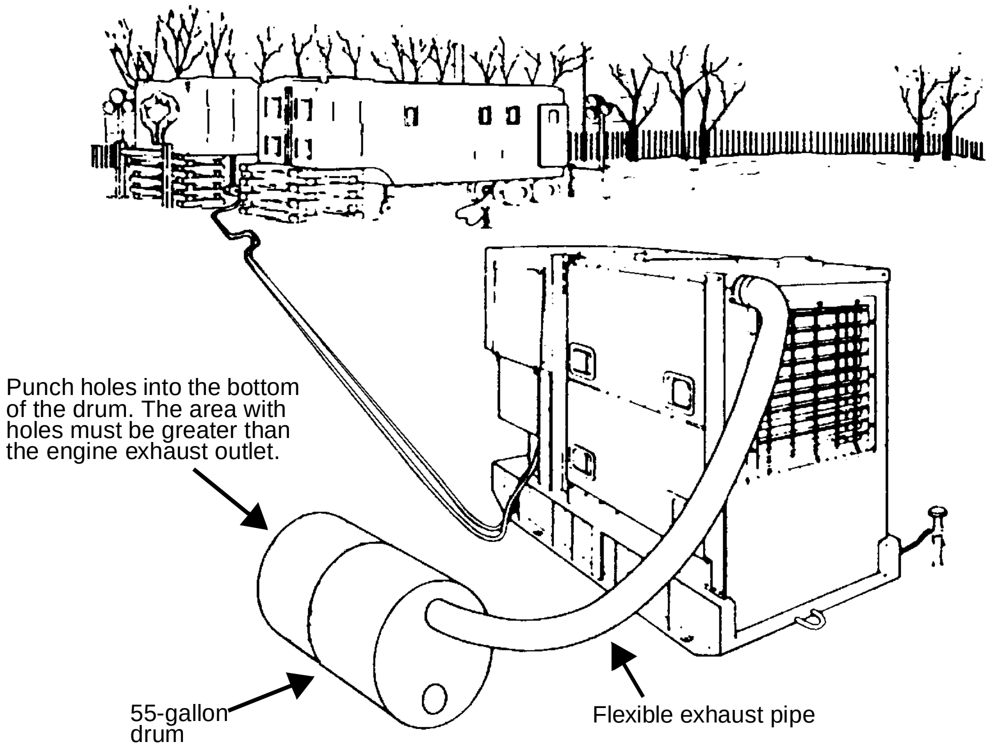


Figure 10-7. Suppression of exhaust noise

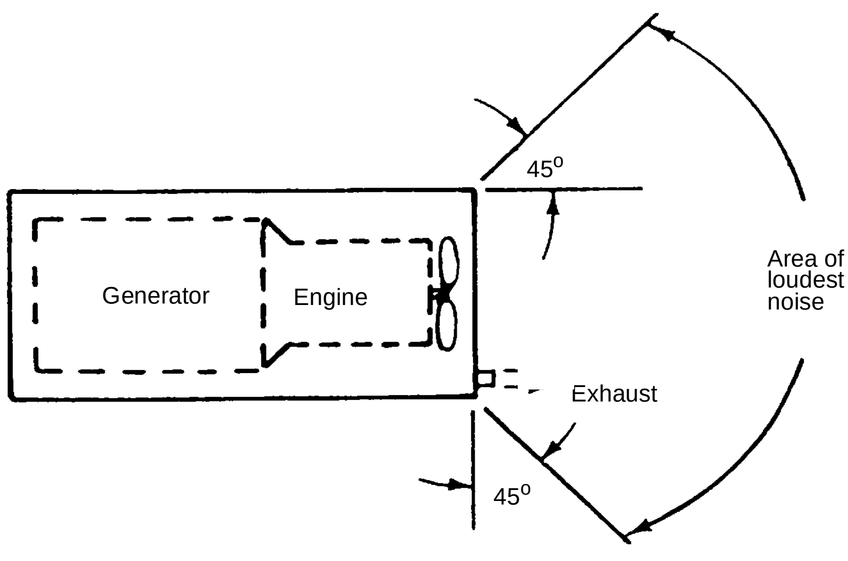


Figure 10-8. Area of loudest noise

Part Four. Other Electrical Procedures

CHAPTER 11

Building Attachments and Services

All electrical energy supplied to power-consuming devices and appliances within a building must pass through the electrical service-entrance equipment where it is metered, protected, and distributed through branch circuits. The size is determined by the amount of power-consuming devices connected. Power from military generators or the local power company is delivered into the building (overhead or underground) through lead-in conductors.

SERVICE WIRES

The service wire from the pole to the building usually consists of two, three, or four conductors on separate insulators at the pole and the building or two- or three-conductor, concentric-type service cables. When installing attachments and services, use insulated conductors. If installing an overhead service drop is impractical, run services underground from a transformer installation.

LENGTH

Keep service drops less than 100 feet long for No 8, 6, 4, or 2 wire. For No 0 or larger wire, do not exceed 75-foot spans unless proper anchoring and support is provided. Long or large services should be guyed at the line pole.

SIZE

Although No 6 wire is recommended for overhead service cable, you should determine the size by the maximum demand load of electrical equipment used in each building. Use *Table 11-1, page 11-2*, to determine the size of service conductors needed. Since these calculations do not take motor-starting currents into consideration, make a separate check for objectionable flicker. The number of wires in the service depends on the limits given in the figures and other factors, such as equipment rating. For two-wire service, the limit is two circuits in general-service buildings and four circuits or a 3-kilowatt connected load in barracks. Three-wire services are required for greater loads. Use three- or four-wire service to supply more than one service switch.

SERVICE ATTACHMENT AT BUILDINGS

Attach the service drop to the building where outlet wires can be tapped in easily without trailing along the building. Install the attachment at least 10 feet above the ground or 18 feet above a roadway. When the building is not high enough, install a riser or a pole to obtain proper clearance. *Figure 11-1, page 11-2*, shows a correct open-wire service installation. *Figures 11-2 through 11-13, pages 11-3 through 11-6*, show various methods of attaching service insulators for several types of building construction. *Figures 11-14 through 11-16, pages 11-6 through 11-8,* show methods of attaching services to structures.

Table 11-1. Conductor types and sizes

Copper (AWG or MCM)	Aluminum or Copper-Clad AL (AWG or MCM)	Ampere Rating
4	2	100
3	1	110
2	1/0	125
1	2/0	150
1/0	3/0	175
2/0	4/0	200
3/0	250	225
4/0	300	250
250	350	300
350	500	350
400	600	400

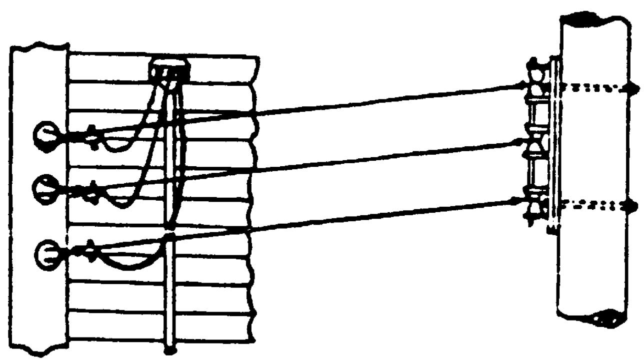


Figure 11-1. Open-wire service installation

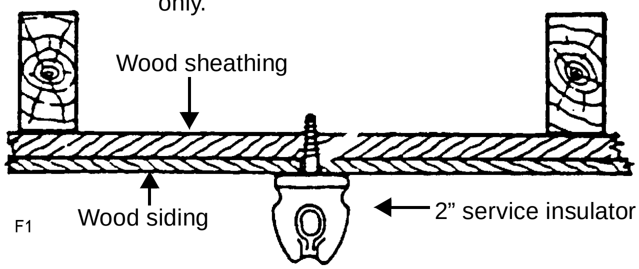


Figure 11-2. Wood siding

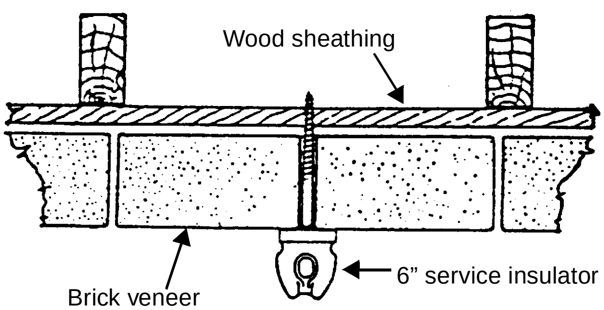


Figure 11-3. Brick-veneer wood sheathing

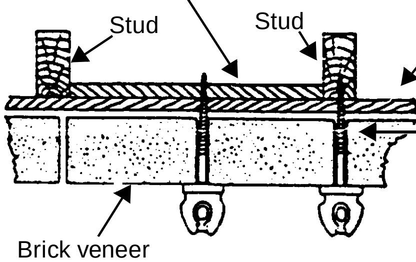


Figure 11-4. Brick-veneer composition sheathing

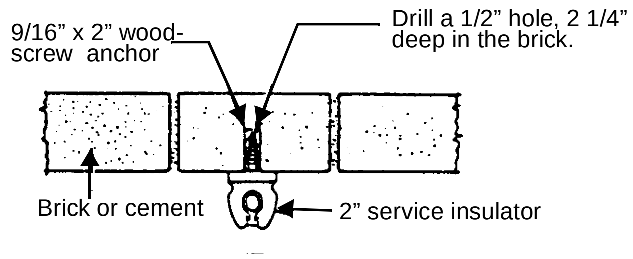


Figure 11-5. Solid masonry, brick or cement

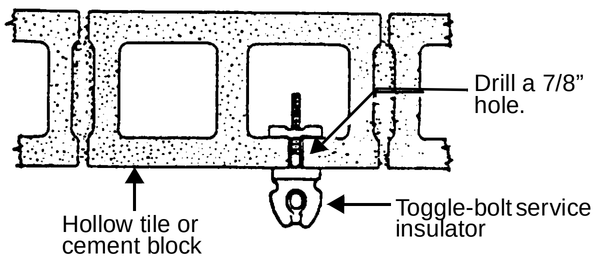


Figure 11-6. Hollow tile or cement block

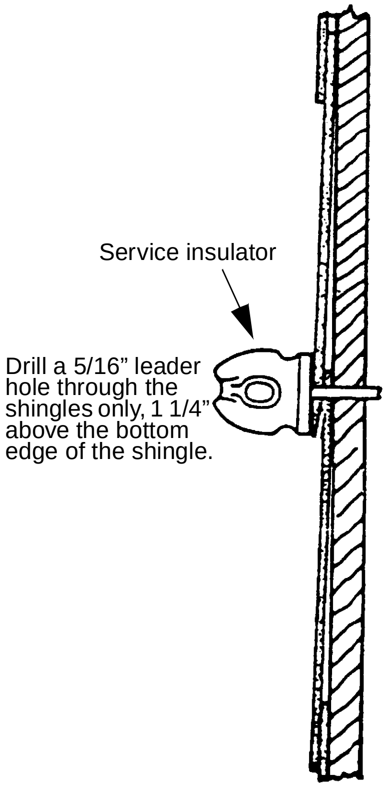


Figure 11-7. Composition or asbestos shingles

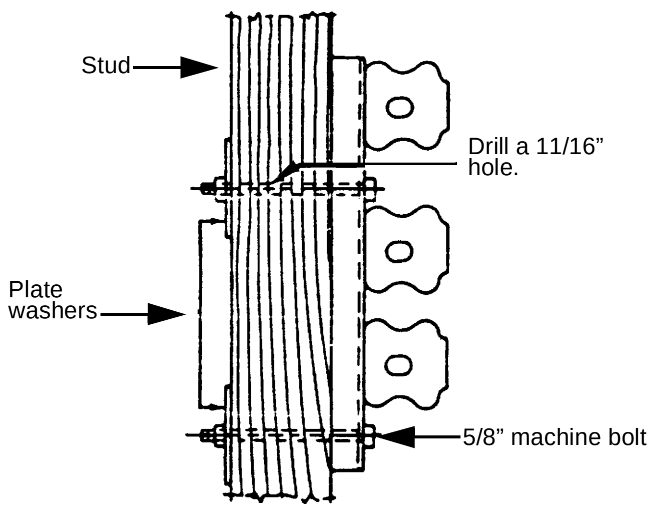


Figure 11-8. Wood, service-conductor tension over 900 pounds

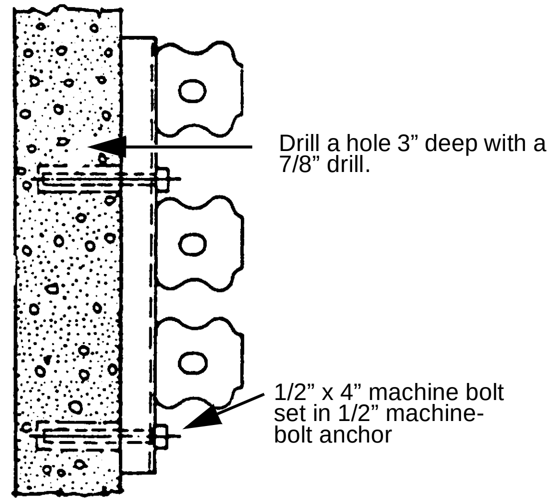


Figure 11-9. Solid masonry

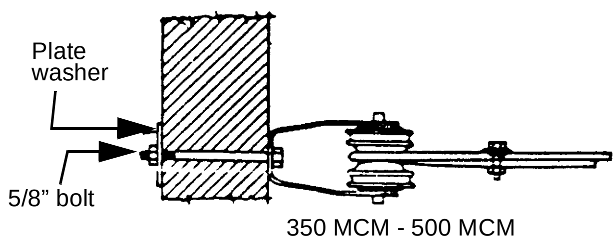


Figure 11-10. Attachment with dead-end spool

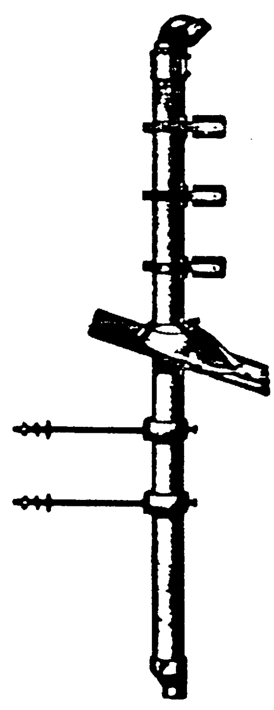
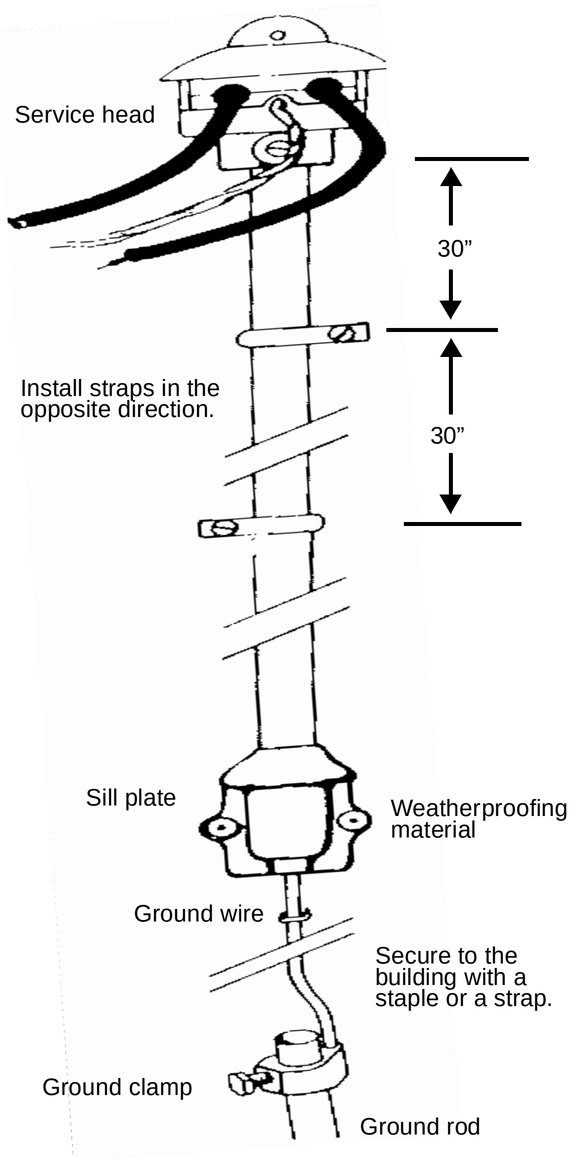


Figure 11-11. Service mast



Note: The service cable must be properly supported.

Figure 11-12. Exposed service-entrance cable

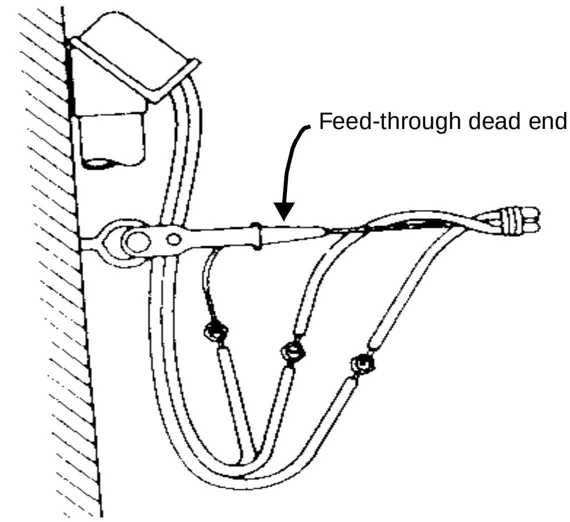


Figure 11-13. Method of attaching multiple-conductor services

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 11-14. Entrance head below the roof line

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 11-15. Typical underground service

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 11-16. Typical overhead service

CHAPTER 12

Pole Climbing and Rescue

Section I. Climbing

Pole climbing is necessary in constructing and maintaining overhead exterior electrical systems. The work is not difficult or hazardous if you are careful in selecting, fitting, and maintaining the climbing equipment. You must use sound judgment, use self-discipline, and follow the printed and verbal safety practices that are required in this career field.

The art of pole climbing is like any other art—it takes hard work. When you have mastered the art of climbing, you are about 10 percent efficient in your job. To become 100 percent efficient, you must learn to position yourself on the pole so that you can work at ease and with efficiency.

INSPECTION

POLE

Inspect the pole for unsafe conditions both before and during the climb. Unsafe conditions include such things as rake (leaning of the pole), shell rot, cracks, breaks, knots, woodpecker holes, and foreign attachments to the pole. Inspect the pole for rot in the center, called *heart rot*, by sounding the pole with a hammer (if it sounds solid when hit with a hammer, it is safe). When the pole has been in the ground for a long time, inspect it for *butt rot* by digging down about 6 inches at the base of the pole and drilling a hole partway into the pole base. The shavings from the hole will indicate if the pole is rotted. Plug the hole after completing this test. Remove rocks and other objects that are within 10 feet of the pole to prevent injury if you fall.

CLIMBING EQUIPMENT

Pole-climbing equipment is needed to accomplish exterior overhead electrical distribution work. Basically, there are five main parts to a lineman's equipment—a set of climbers, a body belt, a safety strap, a hard hat, and leather gloves. Inspect your climbing equipment before climbing a pole. The proper procedures for inspecting climbing equipment are covered in Chapter 13 and in TM 9-243.

CLIMBING PROCEDURES

BELTING IN

Climbing is an essential part of your job. In order to have your hands free to perform work up the pole, you must be able to *belt in* at the work position. Practice will help you become skilled in positioning yourself on a pole.

The safety strap is the first consideration. It must be carried on the body belt in the correct way. A right-handed person should carry the safety strap in the left D-ring. Snap the double (looped) end so the keeper will face outward nearest the body. The single end and the keeper will face inward farthest from the body. This will keep the strap from twisting. A left-handed person carries the safety strap the same way but on the right D-ring.

Make initial adjustments to the safety strap before climbing a pole. While belted in at the base of the pole, with your feet at equal heights, place your elbow against your stomach and raise your fist toward the pole. There should be 1 to 2 inches between your fist and the pole. With your elbow still against your stomach, extend your fingers. If your fingers do not touch the pole, your strap is too long and needs to be adjusted.

Position yourself so that both gaffs are firmly set into the pole. If you are right-handed, your left leg will be low and locked. Your right leg will be about 6 inches above your left leg in a comfortable position. Keep your knees and hips away from the pole and unsnap the single end of the safety strap with your left hand while holding onto the pole with your right hand. Pass the single end around the pole to your right hand. Grasp the pole with your left hand and snap the keeper into the right D-ring with your right hand. Both keeper snaps will face outward when you are correctly strapped around the pole. The strap should lie flat against the pole. You can then place your body weight on the safety strap. *Figure 12-1* shows the proper belt-in method.

NOTE: A left-handed person should reverse the belting-in and unbelting procedures.

CAUTION

Always ensure that the snaps are secured and properly engaged.

Figure 12-1. Belt-in method

UNBELTING

Reverse these procedures for unbelting. If you are right-handed, your left leg should be low on the pole and locked. Your right leg should be approximately 6 inches above the left leg and in a comfortable position. Grasp the pole with your left hand and pull up on your left leg, being careful to keep the correct angle on the gaff. With your right hand, carefully unsnap the hook from the right D-ring. Pass the safety strap to your left hand. Grasp the pole with your right hand and use your left hand to snap the safety strap into the left D-ring.

ASCENDING

When ascending a pole, always climb the high side if possible. Keep your arms and body relaxed; and keep your hips, shoulders, and knees a comfortable distance from the pole. Climb with short steps (step length should be natural for each individual, approximately 8 to 10 inches), using your hands and arms for balance only. Extend your arms and place your hands on the pole at approximately shoulder level. If you place them at a higher level (above your head), you will have a tendency to pull yourself up with your arms. Your hands should not be overlapped on the back side of the pole because this will bring your body closer to the pole, which could be unsafe. Aim your gaffs at the heart (center) of the pole, with your toes pointed upward. The distance between your heels will change according to the diameter of the pole. See *Figure 12-2* for the proper climbing position.

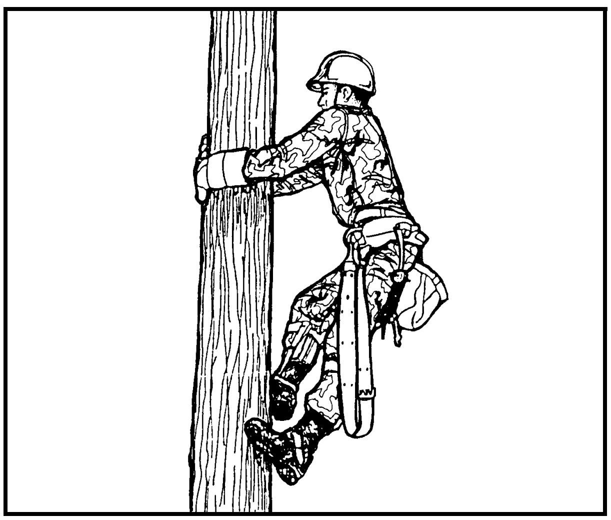


Figure 12-2. Proper climbing position

In order for the gaff to penetrate into the pole's heart and to ensure a safe position, your feet must be turned out and kept apart so that the gaff, not the side of your foot, will hit the pole. Imagine perpendicular lines through the center of the pole (*Figure 12-3*). The gaffs should be positioned where the perpendicular lines intersect the surface of the pole. Proper gaff positions are at points A and B, B and C, C and D, or D and A. They should not be positioned on opposite sides of the pole such as points D and B or A and C. The horizontal position of gaffs usually ranges from 4 to 6 inches apart.

WARNING
If the gaffs are positioned on opposite sides of the pole, they point away from the center and can cause you to cut out (fall).

You must develop a coordination between your hands and feet. As your left foot raises, your left arm must raise; and as your right foot raises, your right arm must raise. This is just the opposite of walking.

Your steps should be short and comfortable. The weight of your body will be transferred to the lower foot with each step. Each time

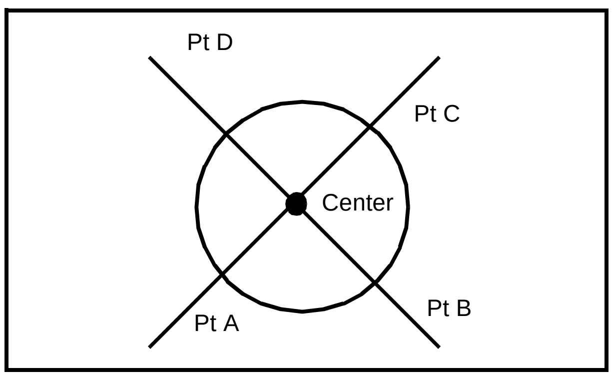
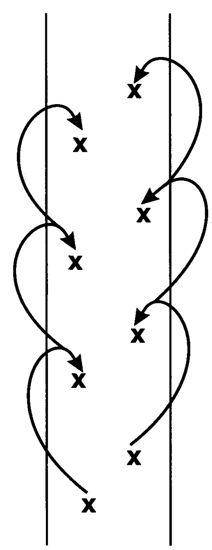


Figure 12-3. Gaff positions

you step with a foot, you will transfer your body weight to that foot and lock the knee. Step length is flexible and can be adjusted to avoid hazards on the pole such as knots, nuts, and holes. Always look where you are going and inspect the pole as you are climbing.

The gaffs must come above the point to be penetrated and then be brought back down into that point at about a 30-degree angle. Always set the gaff firmly into the pole. To maintain the 30-degree angle, keep approximately 8 inches between your knee and the pole. You can accomplish this process by using the inverted-J method (*Figure 12-4*).



NOTE: The “x” represents gaff positions.

Figure 12-4. Inverted-J method

When using the inverted-J method, keep your gaffs aimed at the heart of the pole and your knees away from the pole. Never *sneak* (ease up a pole by lightly setting the gaffs into the pole) or *slap* (kick horizontally) your gaffs into the pole. Always set your gaffs in firmly. Let your legs do the work. Your weight should be shifted smoothly and easily from one foot to the other. **NOTE: Do not be tempted to pull yourself up with your hands. The shorter the step, the less the temptation; the longer the step, the greater the temptation.** *Figure 12-5* shows the proper body position for ascending a pole.

Figure 12-5. Proper position for ascending a pole

DESCENDING

Descending a pole is just the opposite of ascending. Keep the proper climbing position and ensure that your shoulders, hips, and knees remain a comfortable distance from the pole.

When descending a pole, watch where you are going so that you do not step into a bad spot. Look down your body, between your feet, not from side to side. Your coordination will be the same; your right hand and right foot will move together, and your left hand and left foot will move together. The gaffs should naturally break out of the pole when you roll your knee to the outside during your descent, with an outward and lowering movement of your knee. *Figure 12-6* shows the proper body position for descending a pole.

Break out the upper gaff by rolling your knee to the outside. Keep the gaff aimed at the heart of the pole at all times. Relax, straighten your leg, and lock your knee. When your straightened and relaxed leg is lined up with the heart of the pole and your body weight has been shifted above the gaff, drop the gaff into the pole. Your leg is merely lowered into position with your body weight behind it. Your steps should be approximately twice as long when descending a pole as they are when ascending a pole, but they should not be excessively long. Do not try to coast or slide like a lumberjack when descending a pole. Try to make your last step to the ground about 6 inches or less to prevent gaffing yourself.

HITCHHIKING

After you are belted in at the work position, you must move so that work can be done. You can move up and down without unbelting by *hitchhiking*. But, like anything, you must practice to gain confidence.

Climb to the proper height of work. If you are working around a crossarm, climb only until you are at eye level with the lag screw on the crossarm brace, belt in, and then hitchhike to a comfortable working position.

- To hitchhike up, slide the safety strap up the pole by moving your hips slightly toward the pole and moving the strap with your hands. With the strap angled up, take one or two small steps up. These steps should be smaller than normal climbing steps. Remember to lock your leg back when stepping up. Repeat this procedure until you reach the proper height.

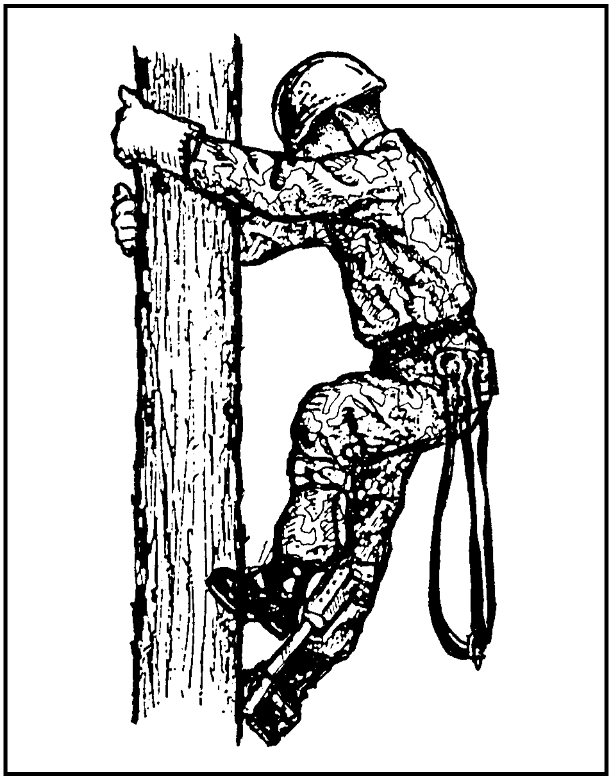


Figure 12-6. Proper position for descending a pole

- To hitchhike down, reverse the procedure. Slide the strap down slightly by moving your hips in. Use your hands to slide the strap. The belt will naturally fall down when you remove pressure. Take one or two small steps down. These steps should be smaller than normal steps. Use your weight to drive the gaff into the pole. Repeat this procedure until you reach the proper height. If you are close to the ground, unbelt before stepping from the pole.

CIRCLING

You cannot perform all work on a pole from one position. You must move about on the pole to be in a safe, comfortable position.

Procedures

To circle to the left, position your left foot about 6 inches lower than your right foot and lock your left knee. Position your right gaff close to your left foot, about 6 inches higher than your left foot. Shorten the safety strap on the left side by rotating your hips slightly clockwise. This action will create a slight pull to the left to help you swing to the left.

As you step up on your right foot and lock your right knee, the left gaff will come out of the pole and your body will swing to the left. Keep your left knee locked and your left gaff aimed at the heart of the pole at all times. At this time, both knees should be locked. Swing your left foot 3 to 4 inches to the left, unlock your right knee, and drop onto your left gaff. The steps around the pole should not be more than 3 to 4 inches apart (horizontally) because it could cause your right gaff to come out of the pole.

Continue the process of positioning your right foot, shortening your safety strap, stepping up onto your right foot, swinging to the left, and dropping onto your locked left leg until you have reached your desired position. If you do this procedure correctly, you will stay at the same height on the pole.

Reverse this procedure to circle to the right. Keeping your right leg low and locked, bring your left foot close to the right and about 6 inches higher. Shorten your safety strap, step up on your left foot, and swing to the right, keeping the gaff aimed at the pole and dropping down onto your locked right leg.

Work Positions

Even though you are in the location of the work, you may have to lean out to change insulators on the end of the crossarm. Ensure that you are in the correct position when you do so.

To get in a work position to the right, keep your right leg low and locked. Lengthen your safety strap slightly to the right, then twist slightly in your body belt to face your work. All your weight will be on your right foot. You are not using your left leg for this, so position it any way you feel comfortable. **NOTE: Reverse this procedure to get to a work position on the left.**

> **CAUTION**
> Working in the incorrect position could cause back injuries.

HOISTING TOOLS AND MATERIALS

Use a lineman's knot (*Figure 12-7*) to tie items to a lineman's rope, and hoist the items to the work position.

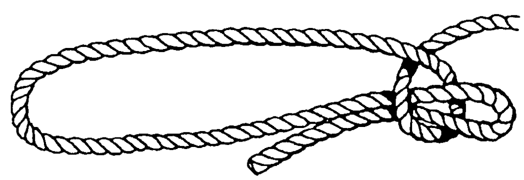


Figure 12-7. Lineman’s knot

SAFETY

A great portion of your time in the field will be spent working on poles. Both groundmen and linemen should pay particular attention to safety precautions during pole work. It is impossible to list all the hazards you may be exposed to, so you must be constantly alert and on the lookout for potential hazards. Each job or task has its own unique circumstances. Evaluate each situation before the work begins to determine if any hazards exist. Chapter 13 covers some common safety practices for pole work.

Section II. Rescue

Electrical shock is one of the hazards of this field that may occur on the ground, on a pole, around several people, or all alone. When it happens, your speed, rescue method, and knowledge of first aid may save a life. In fact, an individual's life could depend on your ability to perform this procedure quickly and safely. Therefore, pole-top rescue is a skill you must develop and maintain proficiency in. This section discusses the one-man concept of pole-top rescue.

PURPOSE

The purpose of pole-top rescue is to quickly and safely remove a victim from a power pole. There are many reasons why you may need to rescue a person from a pole and lower him to the ground. Some of the reasons are electrical shock, heart attack, heat stroke, physical injury, and equipment failure. No matter what the reason, when a victim is unable to remove himself from a pole, you must perform a pole-top rescue.

EQUIPMENT

The equipment necessary for pole-top rescue is important and should be available on all line trucks. The equipment should include but not be limited to—

- Personal climbing equipment such as hooks, body belts, and safety straps.
- A rescue rope that is 1/2 inch in diameter and twice the height of the highest crossarm on the base plus 10 feet.
- A knife.
- Rubber protective equipment (used if the victim or the pole is energized).

PROCEDURES

There are four basic steps in accomplishing the one-man concept of pole-top rescue—evaluate the situation, provide personal protection, climb to the rescue position, and lower the victim to the ground.

EVALUATE THE SITUATION

Call to the man on the pole and ask if he is okay or if he needs help. If there is no response or if the victim seems stunned or dazed, go to his aid. Time is extremely important. Evaluate the surroundings. Determine if the pole or crossarm is split, cracked, or on fire; if the victim is in contact with a live conductor; and if you need rubber goods or hot sticks. Look at the whole scene, not just the victim.

PROVIDE PERSONAL PROTECTION

Your safety is very important to the rescue mission because there will be no rescue without you. Your personal climbing tools and rubber goods must be in good condition. Hot-line tools must be ready in case they are needed. The physical condition of the pole must be surveyed for damaged conductors and equipment, fire, and splits. Remember, do not take chances where your safety is concerned.

CLIMB TO THE RESCUE POSITION

Carefully climb to the rescue position. If necessary, clear the injured of any hazards and then reposition yourself in order to determine the victim's condition. Slightly above the victim and to one side is normally the best position for checking and working with the victim (*Figure 12-8, page 12-8*). The condition of the victim may vary, but this section will discuss the conditions most commonly encountered.

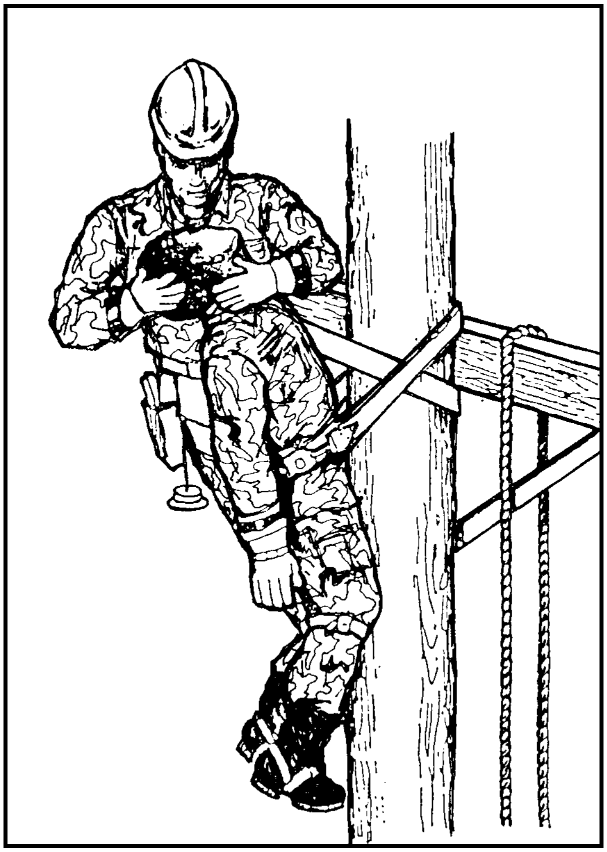


Figure 12-8. Rescue position

Assess the Victim's Condition

- *Conscious.* If the victim is conscious, he will be able to tell you of his need. Administer first aid, tie the victim off, lower him to the ground, administer further first aid, and call for help.
- *Unconscious, breathing.* Try to revive the victim. If you cannot revive him, tie him off, lower him to the ground, administer first aid, and call for help.
- *Unconscious, not breathing.* Tie the victim off, lower him to the ground, administer first aid (mouth-to-mouth or cardiopulmonary resuscitation [CPR]), and call for help.

Tie the Rescue Rope to the Victim

Position the rescue line over the crossarm or other part of the structure as shown in *Figure 12-9*. Placement is normally dictated by the position of the victim, your position in relation to the victim, and whether you are right- or left-handed.

Place the rescue line 2 to 3 feet from the pole for the best operation. Wrap the short end of

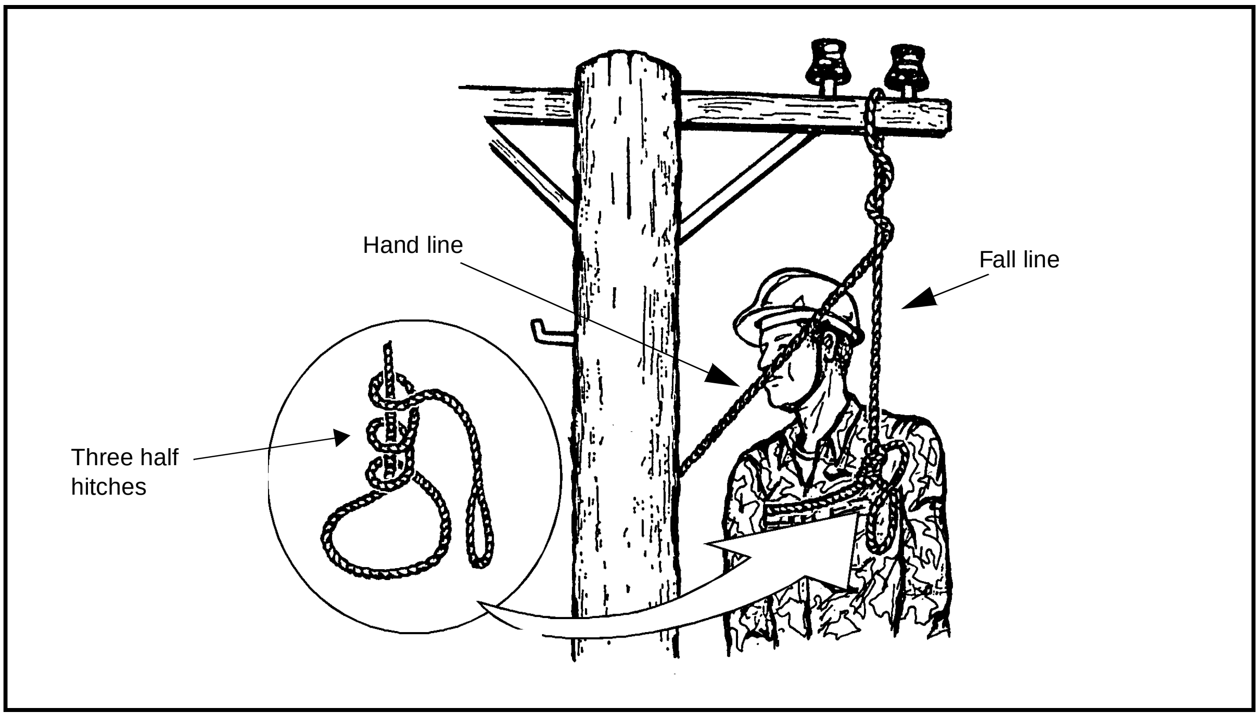


Figure 12-9. Rescue-line position

the line around the fall line twice, then pass it around the victim's chest, and tie it with three half hitches. The knot should be in front of the victim, near one armpit and high on the chest.

LOWER THE VICTIM TO THE GROUND

Remove the slack in the hand line by pulling on it. Then take a firm grip on the fall line with one hand, and use the other hand to cut the victim's safety strap on the side opposite the desired swing.

Lower the victim and control his descent by tightening and loosening the two twists in the rope with one hand, and use the other hand to guide the victim through any lower obstructions.

WARNING

Do not accidentally cut your own safety strap when cutting the victim's safety strap.

Part Five. Safety and Maintenance Procedures

CHAPTER 13

Safety

This chapter emphasizes safety rules and principles in electrical wiring and repair work that will minimize or eliminate the hazards and dangers in electrical wiring. The practices described in this manual conform to the rules of applicable safety codes and regulations that are covered in detail in TM 5-682 and follow guidelines of the National Electrical Code (NEC). The NEC governs all electrical construction. Deviations from these practices resulting from emergency expedients must be corrected at the earliest possible time after such an emergency ceases to exist. Military personnel must never take safety for granted but should keep it in mind and practice it at all times. Strict observance and enforcement of the following procedures will minimize both the number of accidents and the costs of installing, operating, and maintaining the systems.

Section I. Basic Safety Rules

GENERAL WORKING PRACTICES

KEEPING THE JOB AREA CLEAN

Make every attempt to keep the work area in the field or the electrical repair shop free of materials and debris. Grease, oil, water, and similar material on the floor create slipping hazards that can cause serious injuries. In addition, loose fittings, wire and conduit ends, and other debris stored or thrown at random on the floor in or around the job site create tripping hazards that can cause personal injuries. Developing good housekeeping in and around the work area establishes good work habits that are carried over into wiring installation.

WARNING FELLOW WORKERS

Warn fellow workers who get into dangerous positions. These warnings protect not only the person warned but also the rest of the crew. Some members of a crew are less experienced than others and may not realize the danger of their working positions.

ACTING RECKLESSLY

Avoid horseplay, wrestling, scuffling, practical jokes, and unnecessary conversation during duty hours. Electrical work is not dangerous when you take proper care, but it may become dangerous if your attention is distracted.

WEARING CLOTHING AND JEWELRY

Apparel is an important safety consideration for persons working on or near electrical equipment. Everyone must follow the practices below:

- Never wear shirts, trousers, overalls, or any items of clothing that have zippers or other metal fasteners unless the fastener is covered.
- Always roll shirt sleeves down.
- Never wear loose, flapping clothing or flammable articles such as celluloid cap visors.
- Never wear shoes with thin soles, heel plates, or hobnails. Wear high-cut shoes with sewed soles when possible.
- Always wear suitable gloves and clothing and approved goggles or head shields when operating welding equipment.
- Wear leather gloves (linemen and groundmen).
- Remove all jewelry before starting work. Never wear rings, metal wrist bands, or watch chains.
- Inspect all personal gear (climbing gear, hard hats, and rubber gloves) before use.

REPORTING UNUSUAL CONDITIONS

Promptly report to the installation engineer any unusual conditions in stations, substations, or underground and overhead systems that may affect the continuity of service or endanger life or property. Take necessary protective steps immediately, even if stopping other work is necessary.

PREVENTING FIRES

Observe the following safety rules:

- Do not obstruct approaches to fire-fighting apparatus by blocking driveways, doors, or aisles.
- Deposit all flammable waste materials in waste cans with self-closing covers. Remove the materials at the end of the day.
- Keep flammable liquids in approved safety cans with self-closing covers. Do not store more than 1 gallon in each safety can inside a building.
- Never use flammable liquids to start a fire in a salamander or a rubbish pile.
- Do not use gasoline as a cleaning agent; use a low-hazard solvent, preferably nonflammable.
- Never use a gasoline furnace or a blowtorch where flammable vapors are present.
- Train all personnel in the proper selection and use of a fire extinguisher that is appropriate for different classes of fires.
  - *Class A*. Class A fires include ordinary combustible material such as paper, wood, and textiles. Use a water-type extinguisher.

CAUTION

When using a carbon-tetrachloride or carbon-dioxide fire extinguisher (especially in unventilated spaces such as small rooms, closets, or confined spaces), try not to breathe the vapors or gases liberated or produced.

  - *Class B*. Class B fires include flammable liquids such as oil or gasoline. Use a foam, carbon-tetrachloride or carbon-dioxide extinguisher; dry compound; or sand.
  - *Class C*. Class C fires are in electrical equipment. Use a carbon-tetrachloride or carbon-dioxide extinguisher.
- Notify the fire department immediately whenever a fire extinguisher has been used so that it can be recharged or replaced.

USING FIRST AID AND RESUSCITATION

Observe the following rules in the installation electrical shop (*see FM 21-11 for additional information*):

- Ensure that the electrical shop and each of its trucks have adequately stocked first-aid kits.
- Treat minor cuts and injuries on the job; ensure that serious cuts and injuries receive appropriate medical attention.
- Report all accidents to the foreman.
- Train personnel thoroughly in prone-pressure and pole-top methods of applying artificial respiration. The electrical foreman in each shop should schedule practice in artificial respiration once a month for every member of the electrical section.

OPERATIONAL SAFETY PRACTICES

WIRE STRIPPING

One of the most common electrical operations is wire stripping. This can be done with a tool designed for this purpose or an electrician's knife. When using a knife, ensure that the force of cutting is directed away from your body and other personnel.

SOLDERING

Observe the following precautions when soldering:

- Keep furnaces away from manhole openings so that hot metal or compound cannot spill into the manhole if the furnace is overturned.
- Never put a cold or wet ladle or other objects in molter solder or in hot compound because spattering results.
- Attach the pot with a hook and a steady line to prevent excessive swinging when raising or lowering molter solder or hot compound on a hand line. Ensure that persons on the ground or in a manhole stand clear.
- Always work from above or the side when soldering to prevent burns from splashing solder.
- Wear goggles when soldering large joints and tinning lugs or T connectors.

CIRCUIT TESTING

Never attempt to modify or repair an existing circuit until you have tested the circuit following the procedures in Chapter 14. Do not test a circuit with your fingers or with any tools other than a test lamp or a voltmeter.

SWITCHING AND TAGGING

Notifying Serving Utility

The installation engineer must notify the system operator of the serving utility before any switching operations are performed that may affect the serving utility's system. This is necessary so the serving utility can provide for a substantial power increase or decrease or can carry out prearranged emergency measures in case circuit breakers are tripped out.

Switching Operation

The electrical foreman must perform the switching operation with great care. He must see that each worker knows exactly which equipment is energized before starting work.

Tagging Procedure

When any line, feeder circuit, or apparatus is taken out of service for inspection, repair, or maintenance work, a tag or marker must be placed on all main or control switches.

Ensure that the equipment remains de-energized until it is released by the individual who initially removed it from service. The tag or marker must contain the following information:

- The words "DANGER. Do not remove this tag or energize the circuit."
- The name of the individual removing the item from service.
- The date and hour the tag was placed.

A sample tag is shown in *Figure 13-1*. Tags can be purchased from sign sources or fabricated from a manila folder or similar material.

Once all the work is complete, the individual who initially installed the tag must remove the tag and restore service.

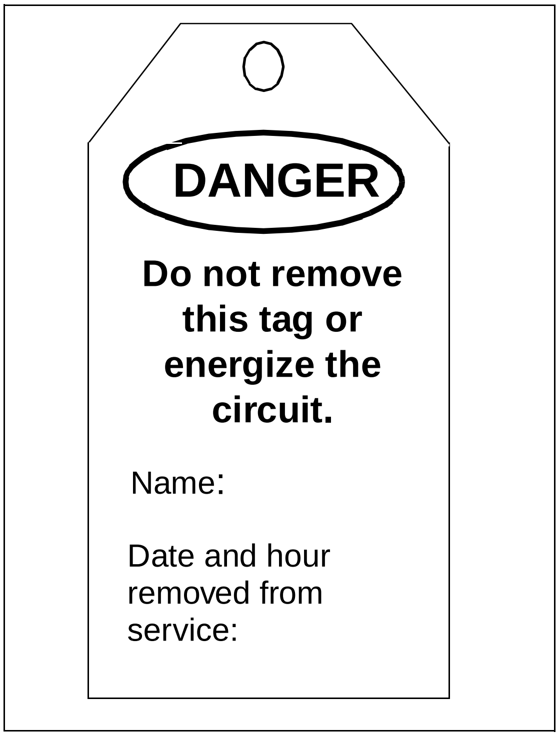


Figure 13-1. Sample tag

TOOL AND EQUIPMENT USAGE

Maintain tools and equipment in good operating condition and replace them when broken. For both safety and good workmanship practices, never use improperly operating equipment in wiring practice. Inspect tool handles periodically for correct positioning with reference to their working surface. Ensure that handles are tight and insulate them against shock hazard when possible. Keep drills, chisels, saws, and similar cutting tools and equipment sharp. Cover workbench surfaces and surrounding floor areas with rubber insulation.

HAND TOOLS

The general safety principles for electrical tools also apply to personal safety in electrical installation. Insulated handles are an added safety precaution only and should not be relied on for full shock immunity. The following safety precautions apply for tools and equipment used by electrical workers:

- Select the right tool for the job. Avoid using make-shift tools.
- Keep all keen-edge tools sharp because they are safer sharp than dull. Store them properly when not in use.
- Ensure that skinning knives do not have sharp points and that the metal shank of the knife does not extend through the handle.
- Ensure that work is substantially anchored when using a draw knife.
- Ensure that pipe-wrench jaws are sharp so they cannot slip.
- Use the right-size wrench for the job. Face the jaws of an adjustable wrench in the direction of pull.
- Avoid using a hammer on highly tempered tools such as drills and files because chips may fly into your face and hands.

- Tape the handles of pliers, especially the ends, to lessen the likelihood of dropping them.
- Never use tools that have cracked or broken handles, no handles, or cracked or broken heads. Replace damaged tools with new ones.
- Never use a wrench on a running motor.
- Never use any tool in such a way that your hands or body can be injured if the tool slips.
- Use flashlights in basements, vaults, manholes, or other dark places when light is needed. Never carry open flames into these places because of the danger of explosion or fire.

GOGGLES

Wash goggles thoroughly with soap and water before somebody else wears them. You must wear goggles if you are—

- Tinning or soldering lugs or large joints.
- Chipping, breaking, or drilling concrete, brick, stone, or other materials where chips are likely to fly.
- Doing any work, such as tree trimming, that is likely to cause flying chips or particles.
- Installing or removing fuses or jumpers from live distribution busses. Use goggles with approved colored lenses.
- Welding. Only use goggles that meet the specifications of the American Standards Association and are approved for electric arc work. Goggles used for acetylene welding cannot be used for electric arc welding.

SCAFFOLDS AND LADDERS

SCAFFOLDS

When the wiring location is inaccessible from normal work areas and the installation is large or complex, use scaffolds rather than ladders for overhead or elevated work platforms. All scaffolds should be sturdy, well-built, securely anchored, and cross-braced. The scaffold planking should be free of knots, checks, and cross-grained sections. Planks used for scaffolding should be load-tested periodically with up to three times their workload. Do not use them if failure or weakness shows up in the test.

LADDERS

All ladders used to reach the work area must be in good condition, constructed safely, and unpainted. When using a ladder, anchor it to the building with a rope or a chain or place it against a projection on the supporting surface. If you cannot secure it in either of these ways, have an assistant stand at the base of the ladder. The distance between the base of the ladder and the vertical surface against which it is supported should be approximately one-quarter the length of the ladder.

Using Ladders

- Inspect ladders at regular and frequent intervals.
- Do not paint wooden ladders. Remove excessive dirt that might conceal defects.
- Use a safety strap (*Figure 13-2, page 13-6*) when doing a job that requires using both hands.
- Do not use a ladder in a strong wind.
- Do not use a ladder for a guy, brace, skid, horizontal scaffold member, or any other purpose other than that for which it is intended.
- Never use a metal ladder when working on electrical equipment.
- Do not use makeshift ladders made by fastening cleats across a single rail.

Figure 13-2. Proper use of a safety strap while working from a ladder

- Ensure that all straight ladders and extension ladders have approved antislip devices or are otherwise safely secured.
- Work with another person when using an extension ladder near heavy traffic. Have the person stand at the bottom of the ladder and hold a red flag in daylight or a light in darkness.
- Do not reach out from the ladder in any direction; move the ladder as the work requires.

Placing Ladders

- Never place ladders on a slanting or slippery footing unless they are securely tied or held in place.
- Ensure that stepladders are fully opened before using them.
- Ensure that the distance from the foot of the ladder to the wall is one-fourth the length of the ladder.
- Ensure that extended extension ladders are in a standing position and that hooks are securely caught on rungs so that the ladder cannot telescope when jarred.
- Do not place ladder jacks above the third rung from the top of a 24- or 36-foot extension ladder or above the fourth rung from the top of a 46-foot extension ladder. This ensures that the ladders have the proper strength and stiffness.

Ascending and Descending Ladders

- Always face the ladder when ascending or descending.
- Allow only one person to ascend or descend at a time.
- Do not ascend or descend without the free use of both hands.
- Do not ascend higher than the third rung from the top on straight or extension ladders; do not ascend higher than the second rung from the top on stepladders.
- Never slide down a ladder.

Section II. Exterior Safety Rules

TOOL AND EQUIPMENT USAGE

The following safety rules apply when handling tools or equipment:

When in the work area—

- Do not throw tools or materials up or down to workers on different levels. Use hand lines to raise or lower them individually, in canvas tool bags, or in buckets.
- Stand clear when tools or materials are raised or lowered; avoid coming directly under the load until it is properly placed and secured.
- Prevent tools and materials that are raised or lowered from coming in contact with wires or other equipment.
- Avoid working at the base of a structure or a pole while others are working on it except in an emergency.

When handling materials—

- Pick up insulators by the top to avoid cutting your rubber gloves or hands on the petticoat. Do not screw down insulators too tightly because the top may break off and cut your gloves or hands.
- Be very careful when lifting heavy material by hand. Bend your knees and keep your back straight. Use mechanical devices to lift heavy weights, when possible, or obtain enough help to do the job easily.
- Use ropes or tackle to control the motion when moving heavy loads on inclines. Ensure that workers do not stand on the downhill side.
- Lift heavy material or equipment with an approved hoisting apparatus that is capable of carrying the load safely. Rope off areas immediately below the load. Display warning signs and guard the area properly.
- Lash or securely tie transformers and oil drums to prevent sliding or tipping while being transported.

ROPE

Take the following precautions when using rope:

- Ensure that any rope used near live conductors or equipment is free of metal strands.
- Turn in the rope for replacement when the strands become frayed.
- Keep the rope clean so that sharp particles of solder or other substances cannot cut your hands or rubber gloves.
- Keep your hands at a safe distance when taking hold of a rope passing through a block.
- Do not place tape, string, or marlin cord on a rope to repair defects.
- Never loop a rope over your hand or arm because it could be a tripping hazard while climbing.
- Never leave uncoiled wire, rope, or other material unguarded on streets, roadways, or alleys because of the potential tripping hazard.
- Never hang safety lines, ropes, or wires from a pole because they could interfere with passing traffic.

BODY BELTS AND SAFETY STRAPS

The foreman should inspect all body belts and safety straps during regular tool inspections to determine the condition of all parts. If he finds or suspects the following faulty conditions, straps or belts must be repaired or replaced at once (*see TM 9-243 for further guidance*).

- The leather is worn or crushed. Ensure that the leather loops holding the D-rings are not worn or crushed enough at the edges to weaken the leather or cause it to tear. If the straps are otherwise sound, you can use them until they are not less than 1/8 inch thick in any portion other than the doubled part of the strap. In this portion, the leather may wear slightly less than 1/8 inch because a double portion is approximately twice as strong as a single portion.

- The leather is hard and dry.
- The leather is burnt. Burnt leather is dry on the outside. Bending at the burn spot cracks the leather, and small pieces between the cracks may be removed easily with your fingernail.
- The leather has cracks, cuts, nicks, or tears (particularly across or on the edges of the strap) that tend to affect its strength.
- Rivets (particularly those in the loops holding the D-rings) are loose or broken.
- The pouch for holding pliers is broken.
- The buckle is broken or defective.
- The snaps are broken or defective.
- The steel-reinforcing strap is broken or badly worn.
- The buckle hole is torn or excessively enlarged. The tongue should work freely without side play and close securely under the spring tension.
- The grain on the straps is worn. If the smooth side of the leather is worn so that fibers are plainly visible and a red stitching becomes visible, the strap should be cut up and thrown away.

RUBBER PROTECTIVE EQUIPMENT

Follow the safety rules below for inspection, use, and care of rubber protective equipment:

Inspection

- Before starting work on or near live conductors or equipment carrying between 300 and 5,000 volts, ensure that each worker personally tests his rubber gloves. Make a thorough visual inspection for holes and thin spots. When rubber gloves or other protective equipment is believed to be defective, tag it and turn it in for replacement immediately.
- In addition to the daily visual check, give rubber gloves a semiannual electrical test. Give other rubber protective equipment an electrical test annually. Make arrangements with the servicing utility to conduct these tests.

Use

- Wear rubber gloves when working on or within reach of energized conductors or equipment operating at voltages between 300 and 5,000 volts.
- Wear leather protective gloves over rubber gloves to protect them from mechanical damage. Pin holes or thin spots caused by using gloves without protectors may be hazardous to workers.
- Use approved live-line tools without using rubber gloves for work on lines that are energized at more than 5,000 volts.
- Wear rubber gloves while cutting supposedly dead cables and while testing supposedly burned-out transformers on both primary and secondary sides.
- Do not remove rubber gloves until you are entirely out of reach of energized equipment.
- Do not work with the gauntlet of rubber gloves rolled down.
- Wear rubber gloves if you are tending reels when wire is being strung or removed near other wires energized between 300 and 5,000 volts, and if you are working near someone who is near conductors or equipment energized at voltages between 300 and 5,000 volts.
- Use a hand line to raise or lower all rubber protective equipment in a canvas tool bag or a bucket (*Figure 13-3*).

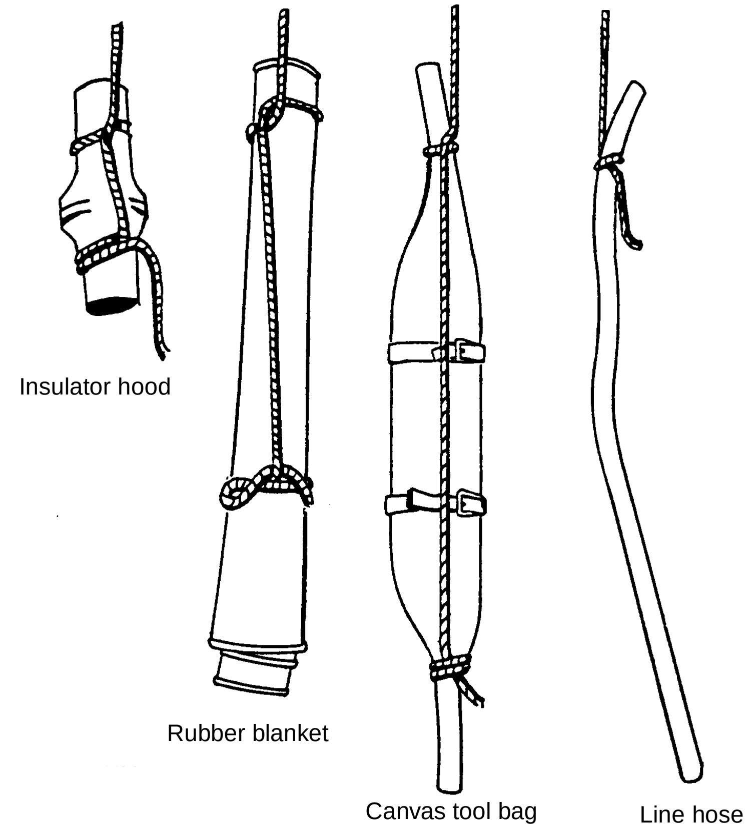


Figure 13-3. Methods of lowering equipment with a hand line

Care

Rubber gloves should be issued to each lineman, and he will be the only user of this personal item. It is his responsibility to take the following safety precautions:

- Store rubber gloves in a canvas bag when they are not in use.
- Give rubber gloves an air test each day before starting work and each time you encounter an object that may have damaged the gloves.
- Wash gloves with warm water and mild detergent.
- Be careful when applying or removing rubber protective equipment. Do not work over energized conductors or equipment or get in a position that may cause you to come in contact with them.
- Dry rubber protective equipment before putting it away if possible. If you must put it away wet, dry it as soon as possible to prevent deterioration.
- Do not carry rubber protective equipment in compartments on trucks or in tool bags with tools or other equipment.
- Always roll, never fold, rubber blankets when putting them away.
- Put rubber hoods and hoses flat in truck compartments.

GAFFS

Take the following precautions to ensure that gaffs are the proper length and sharpness:

- Never sharpen gaffs on the underside, except to make the shoulder, because it changes the angle to which they are set and renders the climber unsafe.

- Make the underside straight when removing metal to make the shoulder, because a wounded surface may cause the gaff to break out of the pole when climbing.
- Do not sharpen the gaff with a grindstone or an emery wheel.
- Put the climber (*Figure 13-4*) in a vise with the gaff uppermost.

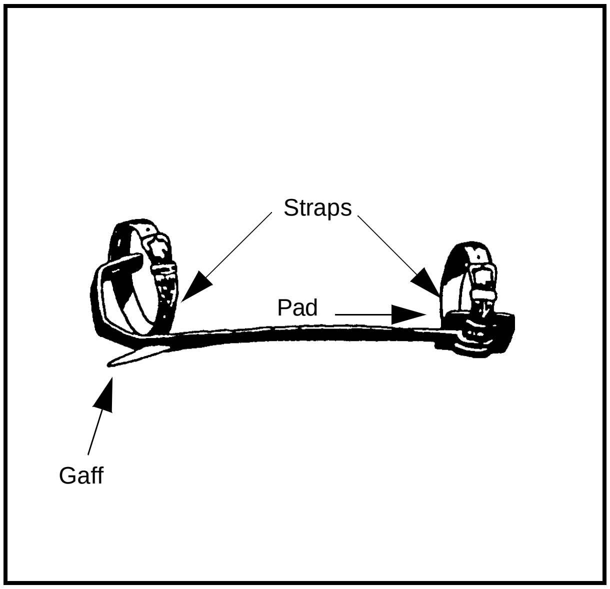


Figure 13-4. Climbers

- Sharpen the gaff on the two outer surfaces with a file. Take long strokes from the heel to the point of the gaff. Remove only enough material to make a good point.
- Never sharpen the gaff to a needlepoint. Leave a shoulder about 1/8 inch back from the point. The distance across the gaff at the shoulder should be about 5/32 inch. Sharpening the gaff in this manner prevents the point from sinking too far into the pole.

CLIMBERS

Take the following precautions when using climbers:

- Do not use climbers after gaffs are worn shorter than 1 1/4 inches on the underside.
- Remove climbers when moving from job to job or when working on the ground.
- Remove climbers before working on a ladder, standing on a rubber blanket, or riding in a vehicle.

HOT-LINE TOOLS

The following safety rules govern work with hot-line tools:

- Do not perform hot-line work when rain or snow is threatening or when heavy dew, fog, or other excessive moisture is present. Exceptions to this rule are when conducting switching operations, fusing, or clearing damaged equipment that presents a hazard to the public or to troops.
- Stay alert. If rain or snow starts to fall or an electrical storm appears while a job is in progress, complete the work as quickly as possible to allow safe, temporary operation of the line until precipitation or lightning ceases. Judgment of safe weather conditions for hot-line work is the foreman's responsibility.
- Perform hot-line work during daylight if possible. In emergency situations, you may work under artificial light if all conductors and equipment being worked on are made clearly visible.
- Do not wear rubber gloves with hot-line tools because they make detection of brush discharges impossible.
- Avoid holding outer braces or other metal attachments.
- Avoid unnecessary conversation. This distracts the attention of linemen from work, causes confusion, and adds unnecessary hazards.
- Maintain close cooperation among everyone on the job.
- Treat wooden pole structures the same as steel towers. Do not depend on the insulating value of the wood.

- Be careful with distribution primaries. When they are located on the same pole with high-tension lines, cover them with rubber protective equipment before climbing through or working above them.
- Do not change your position on the pole without first looking around and informing others.
- Never use your hands to hold a live line clear of a lineman on a pole. Secure the line with live-line tools and lock it in a clamp.
- Stay below the live wire when moving it until it is thoroughly secured in a safe working position.
- Take special precautions on poles having guy lines.
- Do not use a rope on conductors carrying more than 5,000 volts unless the rope is insulated from the conductor with an insulated tension link stick.

VEHICLES

Follow the safety rules below when operating or working with vehicles:

- Never hang coils of wire or rope outside a truck because they could easily catch on passing vehicles.
- Take care when using materials or tools that extend 4 feet or more behind a truck body. Attach a danger flag near the end of the projection during the day, and use a red lantern at night.
- Provide a red lantern or taillight with any equipment that is being pulled by a truck at night.

EXTERIOR WORKING PRACTICES

EXCAVATION

- Place necessary barriers, red flags, and warning signs to protect traffic and guard workers when making excavations in or near highways. Place red lights or flares at night to give ample warning to approaching traffic.
- Place signs between 100 and 300 feet from the outside edge of the work area. Follow shoring and bracing procedures defined in Engineer Manual (EM) 385-1-1.
- Display a *MEN AT WORK* sign or another suitable warning when opening manholes briefly in daytime for inspections, tests, troubleshooting, and so forth.
- Notify the person in charge when you find obstructions in digging. This notification will help avoid accidental contact with live cables and damage to property.

MANHOLES

Follow the rules below when working at manholes:

- Make a gas check before opening a manhole cover, if possible.
- Remove or replace manhole covers with cover hooks or other approved tools.
- Do not enter a manhole until after a gas check has been made. Use a mine safety lamp or a chemical detector to make checks several times throughout the day. Carefully check manholes near gasoline storage tanks. If gas exists, ventilate the manhole with a power blower.
- Use only gasproof lights in a manhole if you suspect explosive gases.
- Assign someone with a red flag or lantern to warn pedestrians and vehicular traffic when a manhole is opened during

daylight. At night, mark open manholes as shown in *Figure 13-5*.

- Ensure the safety of workers in manholes if they cannot be seen by fellow workers on the surface, even if interrupting other duties is necessary.

POTHEADS

- Open the neutral pothead last and close it first when opening and closing circuits with potheads.
- Do not stand on a concrete floor or on the ground while operating potheads in manholes or vaults. Instead, use an insulated stool, a crossarm, or other dry lumber. Cover all grounded framework safely. In locations containing water, take all possible precautions.
- Keep your body clear of all grounded equipment when working on or near potheads.

POLES

Working On

- Warn persons nearby when moving a pole by hand, with a pole cart, or with the truck derrick. Station someone with a red flag to warn or stop traffic as necessary.
- Report poles to the foreman that appear unsafe for climbing so that they can be properly braced or guyed. Take special care with untreated pine poles because they deteriorate rapidly.
- Do not remove wires or supporting guy lines from a pole until the condition of the butt has been checked.
- Support unsound poles with pike poles or guy lines before starting excavation or removing wires.
- Remove all the equipment around the pole being removed before starting excavation.

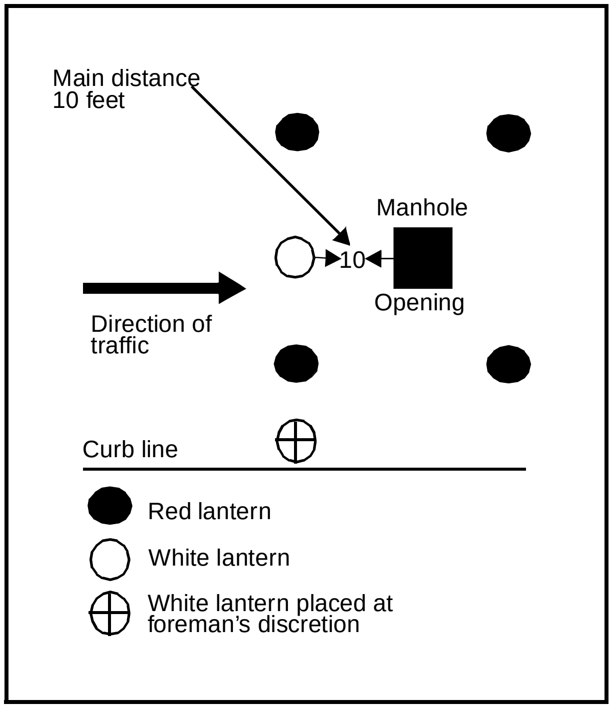


Figure 13-5. Method of protecting open manholes at night

- Climb to your working position by the safest path and take the safest position possible, keeping all parts of your body clear of grounded or live portions of equipment.
- Do not use pins, braces, or guy lines as handholds.
- Never carry any tools or material in your hands when climbing.
- Watch for hazardous and dangerous conditions such as rusted hardware and defective guy lines, braces, and arms. Repair such conditions immediately.
- When more than one person is ascending or descending, ensure that the first person reaches his working position or the ground before the second person starts to ascend or descend.

Climbing

- Take care when climbing past another worker so you do not damage his safety strap with your gaffs.

- Ensure that your safety strap does not catch on the pole steps when climbing. When wearing a body belt and a safety strap, snap both ends of the strap into same D-ring when you are not in the working position.
- Never put both snaps of your safety strap in one D-ring while in the working position on a pole. Ensure that one snap is fastened in each D-ring.
- Avoid pressure on the tongue snap when leaning against arms, pins, braces, and wires to prevent the safety snap from becoming disengaged from the D-ring.

Section III. Electrical Safety Rules

VOLTAGE

LOW

Electricians may work on energized conductors and equipment operating at 300 volts or less if all adjacent energized or grounded conductors and equipment are covered with insulating material or approved rubber protective equipment. Follow the safety precautions below when working on energized conductors and equipment operating at 300 volts or less:

- Tape or cover all bare or exposed places on one conductor before exposing another one.
- Open switches and remove fuses when working on building wiring, motors, belting, shafting, blowers, or other machinery (including shop machine tools). Attach hold cards to the switches.
- Do not touch steam or water pipes when handling portable electric tools or light cords.
- Never leave joints or loose ends of wire untaped unless otherwise protected.
- Never turn on current in a building where a fire has occurred and electric wiring or apparatus has been affected until a careful safety inspection is made by the fire department or a safety inspector. Parts damaged by heat, water, or extinguisher fluid may short-circuit and rekindle the fire.

INTERMEDIATE

De-energize ground lines and equipment operating between 300 and 5,000 volts before starting any work. The only exception to this is when working on overhead lines. When working on them, wear rubber gloves. All work on energized lines, except in an emergency, is executed only when directed by a work order.

Checking Energized Conductors

Consider conductors and equipment normally operating between 300 and 5,000 volts to be energized until positively proved otherwise. When you cannot establish positive proof by a visual check, use an approved voltage detector. Before using the detector, you must check it on a conductor that is known to be energized and note a positive indication. You must repeat this check on a known live conductor after making the test on a dead conductor. If rechecking the voltage detector on a live conductor is impossible, use two voltage detectors, one as a check against the other.

Insulation

When working within reach of conductors or equipment operating between 300 and 5,000 volts, all energized and grounded conductors or equipment must be covered with rubber line hose, insulator hoods, line protectors (pigs), or blankets or must be isolated with suitable barriers. If you change your position, cover or barricade any energized or grounded conductors and equipment coming within reach before starting new work.

Use the following safety precautions when working on equipment and conductors operating at 300 to 5,000 volts:

- De-energize by opening sectionalizing switches and effectively ground the section of line being worked on.
- Treat line wires being installed on poles as if they were energized when those poles are already carrying energized conductors. Use rope to pull line wires into position.
- Remove wire from the underside of reels.
- Ground the truck when using a pay-out reel to string wires near energized wires of this classification.
- Take care when stringing wire near other wires energized with 300 to 5,000 volts. Ensure that the worker tending the pay-out reel wears rubber gloves and does not allow any part of his body to come in contact with the wire being strung. Whenever possible, see that he stands on dry lumber or other insulating materials.
- Apply the brake to the rim of the pay-out reel on the side opposite the direction the wire is being pulled. A crossarm or sidearm may be used as a brake.
- Hold the loose ends of jumpers in the clear, or have someone at each end hold them if necessary.
- Keep the tie wire coiled during installation or removal to prevent accidental contact with an energized conductor.
- Have a worker test for voltage before removing a primary or secondary wire. The wire should be rechecked by the foreman to ensure that it is dead.
- Treat the spans of wire to be removed as energized. Attach a rope to each end and lower the spans one at a time.
- Make all possible connections to dead wires and equipment with only the final connection made to the energized conductor.
- Never open the ground connection at a ground pipe or a bus bar unless it has first been disconnected at the point of contact with the equipment it is intended to ground. This prevents an accident if the circuit is energized.
- Make the ground pipe connection first whenever a ground wire on a pole is to be connected.
- Treat coil wires in the take-up reel that was used to coil the wires as energized when removing the reel from the line arms. Attach a rope to the wires at the end farthest from the take-up reel, and wear rubber gloves when tending the reel.
- Ensure proper direction of phase rotation when restoring three-phase power service. This is the responsibility of the person in charge.
- Identify cable while in the manhole before anyone cuts a cable or makes an opening in the lead sheath or sleeve. Check its duct location with that shown on the working print. This working print must have been checked against the installation engineer's map records. In addition, check the cable identity by listening with an exploring coil for the pulsating beat of the interrupter signal. This is the responsibility of the foreman or the person in charge.
- Remove a 3-inch strip of lead around the cable and test it with two voltage detectors after the cable has been identified and grounded. Do this one at a time, at two or more points around the cable and at the center of the exposed insulation.

- Place a hacksaw on the exposed cable insulation adjacent to and touching the grounded lead sheet when cutting cable.
- Open the switch before working on an oil circuit breaker that has an operating bus feed switch.
- Treat series circuits, series lamps, and devices in series circuits as energized unless they are opened by disconnects.
- Never open a series circuit at the point where work is in progress, such as at lamps or other series-circuit devices. Always bridge the point of the circuit being working on with a jumper.

HIGH

Lines and equipment operating at 5,000 volts or more must be de-energized and grounded before any work is started. An exception is overhead lines, which you may work on with live-line tools. Execute all work on energized lines (except in case of emergency) only on an authorized work order. Follow the rules below when working on high-voltage equipment operating at 5,000 volts or more:

- Do not work on more than one conductor at a time with live-line tools.
- Keep live-line tools dry and free from dirt. Thoroughly dry and test tools subjected to damp weather before using them again.
- Protect live-line tools carried on line trucks to prevent scars and abrasions. Waterproof canvas bags, compartments with padded hooks, or bins built into the truck may be used for this purpose.
- Maintain the minimum body clearance from energized lines and equipment (see *Table 13-1, page 13-16*).
- Perform all work on de-energized circuits between two sets of grounds. Place one set on the first pole or structure toward the source of energy and the other on the pole nearest the load.
- Do not ground a supposedly dead circuit without first feeling out the circuit for a static discharge with a switch pole.
- Net off energized equipment properly at the substation before working near it, and install suitable barriers and warning signs.
- Remove substation apparatus from service when wiping, cleaning, repairing, or performing other maintenance. Place hold cards on the main and control switches before starting work. If you cannot see hold cards distinctly, use a red light to illuminate them.
- Do not perform work on any apparatus until the electrical foreman has proved it to be dead and safe.
- Do not approach or touch reactors and connected equipment unless they have been disconnected from all live lines and have been grounded.
- Do not raise, move, or lower cables that are energized at voltages up to 12 kilovolts more than 18 inches. Do not move cables that are energized at voltages over 12 kilovolts.
- Discharge electrolytic and oxide-film lightning arresters by grounding and shorting the horn gaps before touching the arresters.

CIRCUITS

DE-ENERGIZED

Do all electrical installation work on a de-energized (dead) circuit if possible. Most electricians rip the main service-entrance switch, remove the fuses, and then tag the switch. The tag should give the electrician's name, the date, and the time that he turned the switch off. If existing conditions do not permit this procedure, de-energize the circuit being repaired or modified by removing the branch circuit fuses or tripping the circuit breaker connected to the branch circuits to OFF.

Table 13-1. Minimum body clearance

Operating Voltage (kilovolts)	Minimum Distance (feet)
5 to 7.5	1
7.5 to 12	2
12 to 33	3
33 to 66	4
66 to 132	5
132 to 220	8

HOT

Working on hot circuits is not recommended except in emergency situations. In such situations, only experienced personnel who have been cautioned on the dangers involved should work on these circuits. AC voltages as low as 67 volts and DC voltages as low as 110 volts have caused death by electrocution. When working on a hot line, closely follow the procedures listed below:

- Insulate yourself to prevent your body from becoming a conductor path for the current flow.
- Work on only one side of the circuit at a time.
- Use insulating gloves at all times and stand on nonconducting materials.
- Ensure that all equipment, tools, and wearing apparel is dry, because dry materials offer more resistance to the flow of electricity than do moistened or wet items.

PROTECTION

Fuses or circuit breakers are installed as overload and short-circuit protection for circuit components and connected loads. Limit their selection with regard to ampere rating to the maximum value allowable for the smallest conductor or equipment used in the circuit. For example, if an electrical device has a 15-ampere fusible rating and it is connected to a circuit wired with No 12 conductors rated at 20 amperes, the fusing of the circuit should be 15 amperes. *Tables B-12 and B-13, page B-14,* list the current requirements for single-phase and three-phase AC motors at different voltage levels.

OVERLOAD

Frequently blown fuses or tripped circuit breakers indicate short circuits, grounding, or circuit overloads. Do not solve this problem merely by installing larger fuses than those recommended for use in the circuit because this exposes both the building and the personnel to an electrical fire. Instead, determine the cause of trouble and rewire overloaded circuits by increasing the wire size of the run or dividing the connected load into several circuits.

BYPASSED

Do not use jumpers to bypass the fuse or remove the circuit-breaker protection from the circuit except when testing for short circuits. These primary safety devices are of vital importance in a circuit installation. If these protective devices are bypassed, the electrical installation loses its circuit-current limitation and short-circuit protection. If the devices are removed, the troubles that caused the power interruption or circuit failure will not be isolated to the local circuit but will cause the rest of the fuses to blow or the circuit breakers to operate, cutting off the entire system from power.

TRANSFORMERS AND CIRCUIT BREAKERS

Take the following safety precautions when working on transformers and circuit breakers:

- Prevent moisture from entering when removing covers from oil-filled transformers. Do not allow tools, bolts, nuts, or similar objects to drop into the transformers. Tie tools or parts with suitable twine. Have workers empty their pockets of lose articles such as knives, keys, and watches. Wipe all oil from transformer covers, the floor, and the scaffold to eliminate slipping hazards.
- Exhaust gaseous vapor with an air blower before allowing work in large transformer cases because they usually contain some gaseous fumes and are not well ventilated. If you feel any effects from gas while working in a transformer case, give an alarm immediately and get out into the fresh air.
- Stay away from the base of the pole or structure while transformers are being raised or lowered.
- Ensure that anyone working on a pole or structure takes a position above or well clear of transformers while the transformers are being raised or supported with blocks.
- Ground the secondary side of a transformer before energizing it except when the transformer is part of an ungrounded delta bank.
- Make an individual secondary-voltage test on all transformers before connecting them to secondary mains. On banks of three transformers connected Y-delta, bring in the primary neutral and leave it connected until the secondary connections have been completed to get a true indication on the lamp tests.
- Disconnect secondary-phase leads before opening primary cutouts when taking a paralleled transformer out of service. Do not disconnect secondary neutral or ground connections until you have opened the primary cutouts.
- Do not stand on top of energized transformers unless absolutely necessary and then only with the permission of the foreman and after all possible precautions have been taken. These precautions include placing a rubber blanket protected with a rubbish bag over the transformer cover. Do not wear climbers.
- Treat the grounded case of a connected transformer the same as any grounded conductor. Treat the ungrounded case of a connected transformer the same as any energized conductor because the case may become energized if transformer windings break down.
- Ensure that the breaker cannot be opened or closed automatically before working on an oil circuit breaker and that it is in the open position or the operating mechanism is blocked.
- Ensure that metal-clad switching equipment is de-energized before working on it.
- Ensure that regulators are off the automatic position and set in the neutral position before doing any switching on a regulated feeder.
- Do not break the charging current of a regulator or large substation transformer by opening disconnect switches because a dangerous arc may result. Use oil or air brake switches unless special instructions to do otherwise have been issued by the proper authority.
- Do not operate outdoor disconnecting switches without using the disconnect pole provided for this purpose.
- Ensure that all contacts are actually open and that safe clearance is obtained on all three phases each time an air brake switch is opened. Do not depend on the position of the operating handle as evidence that the switch is open.

- Do not operate switches or disconnect switches without proper authority and then only if thoroughly familiar with the equipment.
- Remove potential transformer fuses with wooden tongs. Wear rubber gloves and leather overgloves.
- Do not open or remove disconnect switches when carrying load. The oil circuit breaker in series with the switches must always be opened first. Open disconnect switches slowly and reclose immediately if an arc is drawn.

WIRE MARKERS

On equipment or in wiring systems where wires are numerous and circuit identification is difficult, wire markers are a distinct aid to installation. However, use them merely as a guide, and carefully check the condition of each conductor with a test lamp or voltmeter before working on the circuit. This rule also applies to wires that are color coded to conform with the prescribed circuit or ground requirements.

Section IV. Electrical Shock

CAUSES OF ELECTRICAL SHOCK

Electrical shock can be caused by equipment or human failure, equipment and human failure, or a combination of events so unlikely and unusual that it would be almost impossible to prepare for them in advance. Luckily, accidents of this kind are rare. If they were not, working with electrical equipment would be extremely hazardous.

Human failure is prevalent, perhaps because people often have a casual attitude toward the deadly possibilities of electrical circuits and equipment. Scientists have not yet found a way to make electrical equipment that will not shock its users when it is improperly used. Human failure that can lead to electrical shock includes—

- Failing to observe the necessary safety precautions when using or working on equipment that would be perfectly safe if handled properly. For example, a careless electrician might fail to test equipment to ensure that it is de-energized before working on it, or he might not use proper care to avoid contact with equipment or conductors that were known to be energized.
- Making unauthorized modification to equipment or using unauthorized equipment.
- Failing to make adequate repairs on equipment that has already caused nonfatal shocks.
- Failing to test the insulation resistance and the completion of the ground connection after the equipment has been repaired.

GROUNDING

Safety codes require that every 120-volt circuit have a system of grounding. This is a preventive measure, much like oxygen masks on a commercial airliner. During normal operation, the grounding system does nothing; in the event of a malfunction, however, the grounding is there for your protection.

Grounding assumes that all metal parts of a circuit that you might come into contact with are maintained at zero voltage because they are connected directly to the earth.

Example: *A circuit contains a metal pull-chain switch. The hot wire accidentally becomes dislodged from the fixture terminal and comes into contact with the metal canopy of the light fixture. The fixture and the pull chain are electrically charged or hot. You touch the chain or the fixture, a short circuit occurs, and you provide the path to the ground for the electric current. In other words, you receive a shock.*

This same situation could occur in any number of places where electricity and conductive materials are together, such as power tools and appliances with metal housings; metal switch, junction, and outlet boxes; and metal faceplates.

The shock in this example could have been prevented if the circuit had a grounding system. A grounding wire connecting the neutral bus bar to the metal housing of the light fixture would provide an auxiliary electrical path to ground in the event of a short circuit. This grounding wire would carry the fault current back to the distribution center and assure that the fuse or circuit breaker protecting the circuit would open, shutting off all current flow.

CHAPTER 14

Maintenance

The rules and routines outlined for a maintenance program for any electrical wiring system are determined primarily by the selection, location, and installation of the original equipment installed. Maintenance is merely a system of routines designed to keep the equipment in satisfactory operating condition through periodic inspection, cleaning, testing, tightening, adjusting, and lubricating. These basic maintenance operations should be set down in the above-listed order, and the various duties should be delegated to specific electrical personnel to prevent operating breakdowns. This chapter reviews and outlines the various procedures and recommended practices necessary to perform maintenance and troubleshooting.

Section I. Preventive Maintenance

INSULATION

The insulation materials designed to shield or protect the conductors from accidental contact with other conducting substances are built into the conductor during manufacture or may be installed in the field as part of the system's installation. Since it is important to maintain these protective coatings or shields on the wire conductors, ensure that preventive maintenance includes periodic tests and checks to expose potential trouble locations where the wire insulation has become frayed or where protective devices have been damaged. Tape, repair, or replace such wire areas and locations as required.

Conductor shielding installed in the field (such as antishort bushings and damage protection) should always be maintained and should be replaced when dislodged or damaged. To ensure a trouble-free system, routinely inspect and maintain conductors and conductor-enclosure supports. Replace damaged electrical parts, components, and conductors immediately.

LOOSE FITTINGS

To avoid the possibility of short circuits, the maintenance organization responsible for power distribution in an electrical system should periodically spot-check the electrical fittings. These fittings include such items as conduit couplings, connectors, and box-entry devices. Check fittings for looseness or separation and tighten or reclamp them as necessary.

CAPACITORS

Since the static capacitor or condenser remains charged after being disconnected from the energy source, you must not inspect it and work on it until it is completely discharged.

CONDUCTOR CONNECTION

The conductor connections made to electrical devices or other conductors should also be included in the periodic maintenance checks to determine the condition of solder splices, wire taps, and terminal connections. Loose, partly contacting, or partly broken connections at the screw terminals or splices of an electrical device can cause short circuits, arcing and burning, and radio interference. This may result in the rapid oxidation of the connecting materials or a dangerous short circuit if the free wire contacts other metallic components that are grounded. Moreover, the increased resistance resulting from a loose or poor connection increases the voltage drop in the circuit, causing inefficient operation of the devices on the system. If this increased resistance in the wire or terminal connections is high enough, the heat resulting from the resistance in an electrical connection may cause a fire by igniting surrounding materials.

WARNING
Wait 5 minutes after the circuit is opened before short-circuiting the capacitor terminals. This waiting period allows time for the discharge device to drain off the major portion of the residual charge. You may then short-circuit the capacitor between terminals, but stay clear of the discharge arc.

DEVICES

Periodically inspect all operating devices in the wiring system for defects. As outlined in Chapter 3, the inspection checks include normal operation and operation under the rated load. Any devices that fail these tests, are broken, or are loosely supported in their mountings should be replaced or repaired to prevent operation breakdown or potential hazard to personnel. If breakage repeatedly occurs in specific locations, replace electrical devices with items that are able to withstand the use or relocate outlets and switches.

Section II. Circuit Testing

WHAT TO TEST FOR

Although you may have de-energized a circuit by pulling the main switch, removing a circuit fuse, or tripping a local switch, you must recheck the circuit with an indicating instrument such as a test lamp or a voltmeter before starting work. The voltage rating of the test lamp should be twice the estimated voltage of the circuit because the electrician cannot be positive of the voltage when spot-checking. A series combination of test lamps, each rated at the estimated voltage, will also serve this purpose. Check the voltage rating by placing the test prods of the instrument on the hot and neutral circuit wires at the fuse, the circuit-breaker panel, the device (receptacle, lamp, switch), or the outlet box where the work is to be done.

SHORT CIRCUITS OR GROUNDS

The most important thing to check for is a *short circuit*, which results when two bare conductors of different potential come in contact with each other. For example, if a hot wire touches something that is grounded, such as a neutral wire, a grounding wire, or a metal box, it causes a short circuit. This could happen because insulation is damaged, a staple has penetrated the cable, or the wiring is incorrect. If a conductor inadvertently contacts a metallic part of a wiring system, such as a motor frame or conduit, the system is sometimes said to be *grounded* instead of having a short circuit. Grounds or short circuits can be *solid*, *partial*, or *floating*.

Solid

A full voltage can be measured across the terminals of a blown fuse when the load is disconnected from the circuit. Because the circuit resistance is very low and the current is very high, the fuse blows or the circuit breaker trips immediately.

Partial

The resistance in the short-circuit path is partially lowered but still remains high enough to prevent enough current flow to blow the fuse or trip the circuit breaker. Grounds of this type are generally more difficult to locate than solid grounds. You can detect a partial ground or short in a light circuit operated from a two- or three-phase source by the dim operation of some lights while others are operating normally.

Floating

The resistance of the defect in the system varies from time to time. Grounds of this type may be present in an electrical system for some time before their existence becomes known. A floating ground is indicated when fuses are blown on the phase side of a circuit a number of times, and a circuit test shows no defects in the system. In grounds of this type, fuse trouble may not occur for several days; then the ground reappears and the fuses are blown again.

OPEN CIRCUITS

You can test for an open circuit if you have time. However, an open circuit is usually the result of an incorrect, loose, or missing connection at a box; and it can be spotted and corrected quickly after the device is installed and the service is turned on.

WHEN TO TEST

Test the circuit at the *rough* stage, while the wiring is still exposed and problems are easy to spot and correct. Switches, receptacles, and light fixtures are not installed at this stage; but hot, neutral, and grounding wire splices should be made so that each circuit is continuous to the last box. Retest the circuit after installing walls, ceilings, and floors (before adding final touches) because a nail will occasionally penetrate the wiring and cause a short.

WHAT TO TEST WITH

You can purchase a continuity tester *(Figure 14-1, page 14-4)*, or you can easily make your own. The idea of these testers is quite simple. A battery provides the power source, and a light (if a continuity tester) or a doorbell (if a homemade tester) provides a signal when the circuit is complete.

PURCHASED CONTINUITY TESTER

Continuity testers are available in several forms. One form contains a battery and a light; another uses a battery and a buzzer or a bell. Use either form to tell whether a circuit is open or broken or whether a short circuit exists.

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 14-1. Continuity tester

HOMEMADE CONTINUITY TESTER

Use a doorbell and a 6-volt, dry-cell battery to make your own continuity tester. Connect one battery terminal to one doorbell terminal with a short piece of wire. Next, connect a 2-foot wire to the other terminal on the doorbell. Momentarily touch the free wire end to the free battery terminal to test for correct connections; the doorbell should ring.

> **WARNING**
> **Turn off the breaker or pull the fuse before using a continuity tester.**

EXAMPLE OF TESTER USE

You have just completed a circuit from the distribution center to a new light fixture, and you need to test the circuit before turning on the breaker. Do not put a light bulb in the fixture. Put a continuity tester between the breaker end of the hot wire and the ground. Attach the alligator clip of the tester to the neutral bus bar and touch the end of the hot wire with the tester probe. Have someone turn the light switch on and off. If the tester does not light (or ring), you have not shorted the hot wire. Now, put the light bulb in the fixture and have your helper repeat the switching. If the continuity tester lights (or rings) with the switch on and does not with the switch off, the circuit is working correctly. After testing, put the new hot wire into the circuit-breaker terminal and energize the circuit. A continuity tester can also be used to determine whether or not a cartridge fuse is good.

HOW TO TEST

First, check your wiring visually. Start at the distribution center and walk through each circuit looking for problems. Think about what each wire is supposed to do and verify that the circuit is correctly wired.

TESTING FOR SHORT CIRCUITS

To ensure that your test will run the entire length of a circuit, temporarily join the hot wires at each switch location. This simulates the ON position and thereby extends the circuit test to include the wiring from the switch to whatever it will control.

At the service-entrance panel, hook one lead of the tester (the alligator clip of a continuity tester or the free wire of a homemade tester) to the neutral bus bar. Touch the hot wire of each circuit to the tester (the tester probe or the free battery terminal) one at a time. The circuit should be open (no bell or light); if the light comes on or the bell rings, there is a short in that circuit.

When testing circuits at a subpanel, run the above test twice. First, hook the clip to the neutral bus bar to check the hot-wire/neutral-wire circuits. Then, hook the clip to the grounding-wire terminal to check the fault-current circuits.

TESTING FOR OPEN CIRCUITS

Although testing for open circuits can wait until the power is turned on, you may want to check the continuity of the ground-fault circuit (the bonding of the conduit sections) if the wiring involves conduit that will be covered. One method of doing this at each box is to touch the neutral wire and the box to the two ends of the tester. The light should come on or the bell should ring; if it does not, check for a loose connection along the neutral or conduit path.

FINDING A SHORT

First, ensure that the free-device wires at each box are not inadvertently touching each other or the metal box. If the wiring is exposed, you should be able to see the problem by carefully checking the circuit. If you cannot find the problem or if the wiring has already been covered, undo the wire splices at the next-to-the-last box on the circuit and retest the circuit at the distribution center. Continue this procedure by moving closer to the source each time until the circuit tests open. You have now isolated the short between the box where the circuit checked open and the previous box or at one of those boxes.

DETERMINING THE CAUSE OF A SHORT

Most short circuits occur in flexible cords, plugs, or appliances. Look for black smudge marks on faceplates or frayed or charred cords connected to a dead circuit. Simply replace the damaged cord or plug before installing a new fuse or resetting the breaker.

TROUBLESHOOTING

Follow the troubleshooting procedures outlined in *Table 14-1, pages 14-5 through 14-9,* when a malfunction occurs or a fuse repeatedly blows. *Figure 14-2, page 14-10,* shows the procedures for determining the cause and location of a malfunction in a circuit.

Table 14-1. Troubleshooting

Symptom	Probable Cause	Possible Solution
The engine is hard to start or fails to start.	• The fuel tank is empty. • The fuel filters are clogged. • The fuel-pump screen is clogged. • The fuel contains foreign material. • The air cleaner is clogged. • The overspeed switch is tripped. • The battery's circuit fuze is blown. • The batteries are discharged.	• Fill the tank. • Replace the filters. • Clean the screen. • Drain the tank and refill it with clean fuel. • Clean or replace the filter element. • Reset the switch. • Replace the fuze. • Charge or replace the batteries.

Table 14-1. Troubleshooting (continued)

Symptom	Probable Cause	Possible Solution
The engine stops suddenly.	• The fuel tank is empty. • The fuel filters are clogged. • The fuel-pump screen is clogged. • The auxiliary fuel hose is clogged. • The safety device is tripped. • The engine's oil level is low. • The coolant level is low. • The engine is overheating. • The cooling system is clogged. • The fan-drive V-belt is inoperative. • The shutter control is inoperative.	• Fill the tank. • Replace the filters. • Clean the screen. • Clean the hose. • Inspect the engine's oil and coolant levels, reset the overspeed switch, and operate the unit at the proper speed. • Add oil to the proper level. • Add coolant to the proper level. • Provide proper ventilation. • Flush the system. • Tighten to the proper tension. • Operate the shutter manually, and report the condition to organizational maintenance.
The engine oil pressure is low.	• The oil pressure is low. • The engine's oil level is low. • The oil filter is clogged. • The engine's oil is diluted.	• Adjust the oil pressure. • Add oil to the proper level. • Replace the filter. • Change the oil.
The engine exhaust smokes excessively.	• The engine's temperature is low due to insufficient warm-up time. • The engine's temperature is low due to a defective shutter. • The engine's oil level is too high. • The air cleaner is clogged. • The fuel grade is incorrect.	• Allow sufficient time for the engine to warm up before applying load to the unit. • Operate the shutter manually and report the condition to organizational maintenance. • Drain the oil to the proper level. • Clean or replace the filter element. • Drain the tank and fill it with the correct grade of fuel.
The engine lacks power.	• The air cleaner is clogged. • The fuel filters are clogged. • The fuel system contains water. • The fuel-pump screen is clogged. • The fuel grade is incorrect.	• Clean or replace the filter element. • Replace the filters. • Drain the tank and refill it with clean fuel. • Clean the screen. • Drain the tank and refill it with the proper grade of fuel.

Table 14-1. Troubleshooting (continued)

Symptom	Probable Cause	Possible Solution
The engine knocks or makes excessive noise.	• The engine's oil level is low.	• Add oil to the proper level.
CAUTION Stop the engine immediately if the engine knocks or is noisy when the engine's oil is at the proper level. Continued operation may cause serious damage. Report the condition to organizational maintenance.		
The starter fails to crank the engine.	• The battery's circuit fuze is blown. • The battery's circuit breaker has tripped. • The battery's cable connections are loose or corroded. • The batteries are discharged.	• Replace the fuze. • Reset the circuit breaker. • Tighten and clean the connections. • Charge or replace the batteries.
The main generator fails to build up rated voltage.	• The frequency or voltage is too low. • The wiring is defective.	• Adjust the frequency and voltage. • Inspect the wiring and report defective wiring to organizational maintenance.
The main generator's voltage is too high.	• The voltage has been adjusted improperly. • The frequency has been adjusted improperly.	• Adjust the voltage properly. • Adjust the frequency properly.
The main generator overheats.	• The generator's ventilation doors are closed. • The generator's ventilation screens are obstructed. • The generator is overloaded.	• Open the doors. • Remove the obstructions. • Reduce the load.
The main circuit breaker continues to trip.	• The generator's output voltage is too low. • The generator's wiring is defective. • The generator is overloaded.	• Increase the output voltage. • Inspect the wiring and report defective wiring to organizational maintenance. • Reduce the load or report the condition to organizational maintenance.
The frequency drops after increasing the generator load.	• The speed droop is adjusted improperly.	• Adjust the droop.
The frequency fluctuates.	• The air cleaner is clogged. • The fuel filters are clogged. • The fuel system has air in it. • The governor is adjusted improperly.	• Clean or replace the filter element. • Replace the filters. • Prime the fuel system. • Report to organizational maintenance.
The main generator is noisy.	• An object is in the main generator screen.	• Remove the object.

Table 14-1. Troubleshooting (continued)

Symptom	Probable Cause	Possible Solution
CAUTION Stop operating the equipment immediately if you hear unusual noises. Unusual noises from the main generator usually indicate a part failure. Continued operation may cause additional damage. Report unusual noises to organizational maintenance.		
Instruments fail to function properly.	• The generator controls are adjusted improperly. • The needle is stuck on the dial gauge.	• Refer to the operator's manual. • Tap the gauge lightly with your finger.
The winterization heater fails to ignite or to keep burning.	• The battery's circuit fuze is blown. • The heater's fuel filters are clogged. • The heater's fuel-pump screen is clogged. • The main fuel tank is empty.	• Replace the fuze. • Replace the dirty filters. • Clean the screen. • Fill the tank.
The 120-volt AC receptacle will not supply current.	• The 120-volt AC receptacle fuze is blown or the circuit breaker is off.	• Replace the fuze or reset the circuit breaker.
The 24-volt DC receptacle will not supply current.	• The 24-volt DC receptacle fuze has blown.	• Replace the fuze.
The lamp will not light.	• The tube is burned out (blackened ends). • The tube has been installed improperly. • The fuze is blown or the circuit breaker is tripped. • The starter is burned out. • The tube is dirty (rapid-start only). • The tube holder is broken. • The fixture is too cold. • The tube pins have oxide film buildup.	• Replace the tube. • Take the tube out and reinstall it. • Replace or reset the tube. • Replace the starter. • Remove the tube and wash, rinse, dry, and replace it. • Replace the tube holder. • Raise the temperature to at least 50°F. • Rotate the tube in the tube holders once or twice.
The lamp flickers.*	• The lamp has poor contact with the tube holders. • The tube has been installed improperly. • The tube is nearly worn out (blackened ends). • The tube pins have oxide buildup. • The fixture is too cold.	• Realign, straighten, and if necessary, resand the tube holders. • Take the tube out and reinstall it. • Replace the tube. • Rotate the tube in the tube holders once or twice. • Raise the temperature to at least 50°F.

Table 14-1. Troubleshooting (continued)

Symptom	Probable Cause	Possible Solution
The ends of the tube are discolored.**	• The tube is almost worn out.	• Replace the tube.
• If it is a preheat type with new tubes—	• The starter is defective.	• Replace the starter.
• If it is discolored on one end only—	• The tube is temperamental.	• Remove the tube and turn it end for end.
The ends of the tube glow, but the center does not.	• The starter is defective. • The ballast is defective.	• Replace the starter. • Replace the ballast.
The lamp fixture hums.	• The ballast has been installed incorrectly. • The ballast is the wrong type. • The ballast is defective.	• Check the wiring on the ballast diagram and correct it. • Check the wattage and the type. Replace the ballast. • Replace the ballast.
*New tubes may flicker for a short time after installation. **Darkened bands about 2 inches from the ends are normal.		

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure 14-2. Cause of a short circuit

Section III. Generator Maintenance

Regular and systematic maintenance helps ensure that a generator operates as required at all times. Preventive maintenance is important because it allows the operator to discover and correct defects before they cause serious damage or equipment failure. This section describes the maintenance procedures required for all electrical generator sets. Refer to the operator's manual for the PMCS that are required for a specific generator.

PREVENTIVE MAINTENANCE CHECKS AND SERVICES

Perform regular PMCS as shown in *Table 14-2, pages 14-12 and 14-13*. Equipment operators must identify and write down all faults and shortcomings of the equipment. Stop operating the equipment immediately if the deficiency could endanger personnel or damage the equipment. Operators can repair most of the faults they identify. If they cannot repair them or if replacement parts are required, they must record the problem or the defective part number(s) on DA Form 2404 and submit the form to organizational maintenance (see DA Pamphlet 738-750).

TESTING

Test an electrical generator set before operation, periodically during operation, and after parts are repaired or replaced. These tests ensure that the generator is working properly, will not malfunction under different load conditions, and can maintain the load. Maintaining the load when the set is in operation reduces carbon buildup in the internal-combustion engine.

Operators can test a generator set with the equipment it was designed to power or with a load bank. The load-bank method is preferred because it lets the operator set up and control the power specifications. The load bank should be used to test generators that frequently operate with little or no load.

The load bank is a self-contained test unit that is mounted in a cabinet and generates no power. It operates on an external power source through the system being tested. Cables are required to connect the load bank to the generator. Some load banks are designed to operate automatically. Others are operated manually to maintain a minimum load on the generator.

WARNING

Store and use the load bank only in an upright position, never upside down or on end. Ground the frame to avoid possible shocks. If excessive vibration or unusual noises occur during operation, turn the load bank off. Shut down the power source before touching, connecting, or disconnecting any electrical leads or parts. Disconnect the load bank at once if the motor or other components heat up excessively. NEVER use water to put out an electrical fire; ALWAYS use carbon dioxide.

The load test is made by adding increments of resistive or reactive electrical loads to the generator. Operators can change increment combinations to simulate any electrical load within the bank's rating. For example, the load bank can test the output of generator sets rated for single-phase, two-wire, 120/240 volts; three-phase, three-wire, 240 volts; and three-phase, four-wire, 120/208 or 240/416 volts. The tests can be applied at frequencies ranging from 50 to 1,000 cycles per second.

Table 14-2. Preventive maintenance checks and services

LUBRICATION SYSTEM	
Crankcase	• Inspect for leaks around the crankcase. • Ensure that the oil in the crankcase is at the proper level.
Crankcase Breather	• Replace defective breathers.
Oil Filter	• Tighten the hardware and replace worn parts. • Inspect the oil filter for loose or missing mounting hardware. • Inspect the oil lines for leaks, breaks, or wear. • Service the filter as directed in the lubrication order.
COOLING SYSTEM	
Radiator, Grille, and Shutter	• Inspect the radiator, grille, and shutter for leaks, loose mounting, or obstructions in air passages. • Inspect all lines and connections for leaks. • Check the hoses for signs of deterioration and loose connections. • Record the freezing point on the maintenance records if antifreeze is used. • Drain, flush, and refill the cooling system if the coolant is contaminated. • Replace defective hoses, lines, and gaskets. • Ensure that the manual shutter control operates properly.
Water Pump, Fan, and Fan Guard	• Inspect the water pump for cracks, leaks, loose or missing mounting hardware, or other damage. • Inspect the fan and fan guard for loose mounting.
Fan-Drive V-belt and Pulleys	• Inspect the fan-drive V-belt for wear. • Replace frayed or worn belts. • Check for proper alignment and tension between the pulleys, as prescribed in the technical manual.
Thermostat Housing	• Inspect the thermostat housing for cracks.
FUEL SYSTEM	
Fuel Pump	• Inspect the fuel pump for leaks, damage, and loose or missing mounting hardware.
Fuel Filters	• Inspect the primary and secondary fuel filters for loose or missing mounting hardware, cracks, leaks, or other damage. • Service the filters as required in the technical manual.
Fuel Supply	• Ensure that enough clean fuel of each required type is available for the planned period of operation.
Fuel Tank, Cap, and Gasket	• Inspect the fuel tank for leaks. • Drain sediment from the fuel tank. • Inspect the cap and strainer for dirt, wear, and defects. • Inspect the chain and gasket for wear. • Open or close the cap vent as required.
Fuel Lines and Fittings	• Inspect the fuel lines and fittings for cracks, leaks, and loose or damaged connections.

Table 14-2. Preventive maintenance checks and services (continued)

ELECTRICAL SYSTEM	
Batteries	• Inspect the batteries for cracks, leaks, dirt, and corroded or damaged cables and terminals. • Check the electrolyte level.
Electric Generator and Starter	• Inspect the commutator and brushes for wear, tension, dirt, corrosion, and oil deposits. • Ensure that the brushes move freely in their holders. • Ensure that all electrical connections are tight and free of corrosion.
Lights, Wiring, and Switches	• Inspect the panel lights for loose connections, loose mountings, and corrosion. • Inspect all electrical leads in the engine and the main generator for looseness, breaks, and damaged or worn insulation. • Inspect all switches for signs of excessive wear, failure, or other damage.
Engine Generator Regulator	• Inspect the engine generator regulator for external damage.
Gauges	• Inspect the fuel gauge, thermometer (water-temperature gauge), and oil-pressure gauge for loose or missing mounting hardware, cracked or broken glass, or other damage.
Meters	• Inspect the battery-charge ammeter and hour meter for loose or missing mounting hardware, cracked or broken glass, loose connections, or other damage.
Fault-Indicator Panel	• Inspect the indicator lights for damage. • Test the lights for proper operation.
Rheostats	• Inspect the regulator-control rheostat and the crosscurrent compensation for loose connections or other damage. • Turn the knobs to the left and right to ensure that they operate freely.
Speed-Control Governor	• Inspect the speed-control governor for excessive wear, loose mounting, or other damage.
Main Generator	• Inspect the main generator for damage. • Blow dust and dirt from the generator housing with a low-pressure, dry air compressor.
Control-Panel Meters	• Inspect the frequency meter, AC meter, AC voltmeter, and kilowatt meter for loose mountings, loose connections, cracked or broken glass, or other damage.

COMMON EQUIPMENT MALFUNCTIONS

While PMCS usually keeps an electrical generator set operating as required, malfunctions do occur. Operators can correct most equipment failures or unsatisfactory performance. *Table 14-1, pages 14-5 through 14-9,* identifies common malfunction symptoms, probable causes, and possible solutions. If the suggested solution does not correct the malfunction, report to the next higher level of maintenance.

NOTE: Any malfunctions that are beyond the scope of the operator or the crew must be reported to organizational maintenance.

Section IV. Miscellaneous Equipment Maintenance

HOUSEKEEPING

ROTATING EQUIPMENT

Electrical rotating equipment is manufactured to operate at a particular temperature, rated in degrees above ambient temperature. This term limits the maximum operating temperature of the equipment, which is derived by adding the rating to the atmospheric temperature of the operating location. For example, if a motor is rated at 30°F above ambient and the temperature of the surrounding area is 80°F, the maximum operating temperature of the motor would be 110°F. To help maintain the operating temperature below the danger point, you must keep the equipment clean and dry. Excessive amounts of dust or moisture on equipment surfaces act as an insulator and prevent the heat from dissipating into the atmosphere through the equipment housing. Poor housekeeping conditions in a wiring area or wiring installation increase the possibility of short circuits.

LIGHTING

The efficiency of a lighting installation is reduced when poor housekeeping conditions prevail. When dirt collects on reflectors, lamps, walls, or ceilings, the initial or designed foot-candlepower of the installation drops. Though original installations are usually planned with an expected drop of 10 to 15 percent in candlepower, lack of proper cleaning may drop the lighting output as much as 50 percent. For proper maintenance under normal conditions, fixtures and lamps should be cleaned at least every 3 months. Clean them more frequently when working in conditions that are dirtier than normal.

STORAGE

Store electrical materials and tools in or on shelves, racks, or cabinets. Proper storage helps minimize the number of grounds or short circuits in an electrical circuit because the possibility of accidental damage to conductor insulation is reduced. Good storage facilities can reduce the time required for wiring installation because damaged conduit, fittings, cable, and supports can create time-consuming problems on the job.

TOOLS AND EQUIPMENT

Maintain tools and equipment in good operating condition and replace them when broken. Never use improperly operating equipment. Inspect tool handles periodically for tightness and correct positioning with reference to their working surface. Insulate handles against shock hazard when possible. Keep drills, chisels, saws, and similar cutting tools and equipment sharp. Cover workbench surfaces and surrounding floor areas with rubber insulation.

FLUORESCENT LAMP REPAIRS

Tubes, starters, ballasts, and tube holders (also called *sockets*) are the components usually involved in the repair of fluorescent lamps. All components are easy to replace, and most repairs are a matter of substitution. *Table 14-2, pages 14-12 and 14-13*, shows common symptoms, causes, and solutions of problems in fluorescent lamps.

TUBES

To remove a double-pin fluorescent tube, twist it a quarter turn in either direction and gently pull it out. Install a new tube by pushing it into the tube holders and twisting it a quarter turn to lock it in place. Remove a single-pin tube by pushing it against the spring-loaded tube holder until the other end can be removed. To replace a tube, put the tube pin in the spring-loaded tube holder and push until the other end can be inserted.

STARTERS

Remove the fluorescent tube to gain access to the starter. Remove the starter by twisting it a quarter turn counterclockwise and then pulling it out of its socket. Place a new starter in the socket and twist it a quarter turn clockwise.

TUBE HOLDERS

Tube holders vary considerably, so it is wise to take the one you are replacing with you when buying a new one. To remove a damaged tube holder, first disconnect the wires. If the wires are connected by terminal screws, loosen them to free the wires. If the tube holder has push-in wire connectors, release each wire by inserting a small screwdriver or a nail into the slot next to the connection. Take out the mounting screw and remove the tube holder. (On some models, you may have to take the end bracket off the fixture so you can slide off the tube holder.) Install the new tube holder by reversing the procedure.

BALLASTS

Shut off all current in the lamp, and disassemble the fixture until you get to the ballast. In table models, the ballast is located in the base of the lamp; in ceiling or wall-mounted models, the ballast is in the metal enclosure that is attached to the ceiling or wall.

The replacement ballast is already wired, and about 5 inches of each wire will be sticking out of the ballast. Remove the old ballast by cutting all the wires coming out from it about 5 inches from the ballast and removing the mounting screws. Mount the new ballast, and then connect the wires. Strip about 1/2 inch of insulation from the end of each wire, and use a medium-size wire nut for every two wires. When working with a ballast, match the color-coded wires correctly by connecting red to red, blue to blue, and so forth. Check your work against the wiring diagram printed on the ballast.

POLE-LINE HARDWARE

Salvage pole-line hardware that becomes surplus due to line removals, alterations, and maintenance work. Discard hardware that has been materially reduced in strength by corrosion or rust. The condition of bolts passing through crossarms or brackets is difficult to determine because the point of greatest corrosion is usually hidden from view. As a rule, replace a bolt when the head is rusted over.

LUBRICATION

All rotating equipment rotates in housings on a ball, a roller, or sleeve bearings. To ensure maximum operating performance, routine PMCS should include lubrication according to the lubrication orders for the equipment. The type of lubricant, the lubricating period, and the points of lubrication are often attached to the equipment as a data plate. It is equally important not to overlubricate by using too much oil or grease or by shortening the lubrication intervals, because overlubrication can also cause equipment to malfunction. When oil or grease comes in contact with insulated conductors, it hastens their deterioration. Overlubrication causes overheating and leakage, and oily or greasy equipment surfaces collect dust and abrasive materials in the air. If the surfaces are not cleaned promptly, this dirt can cause wear on the bearing ends as well as eventual breakdown of the equipment.

APPENDIX A

Common Electrical Parts and Equipment

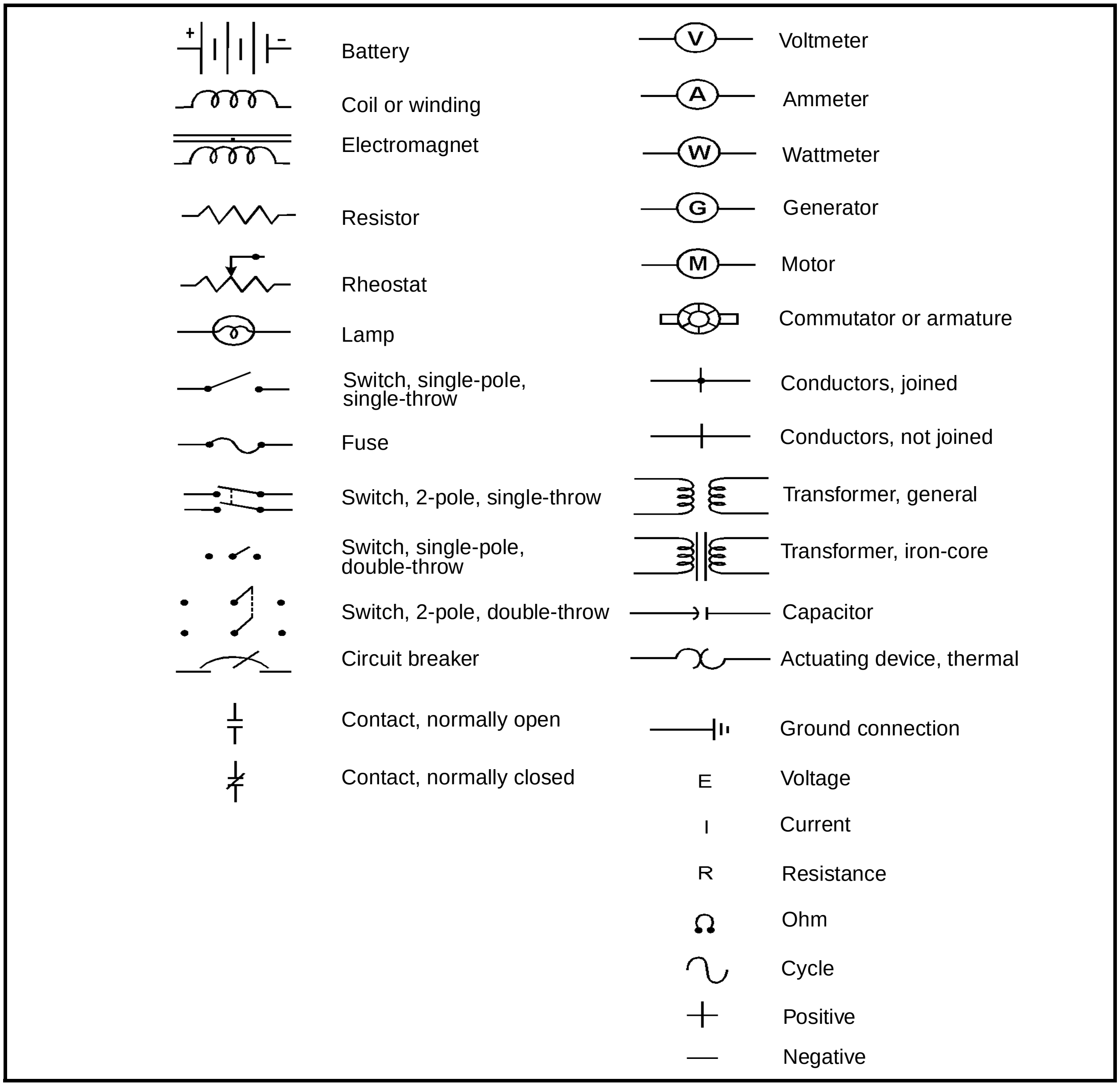


Figure A-1. Basic circuiting symbols

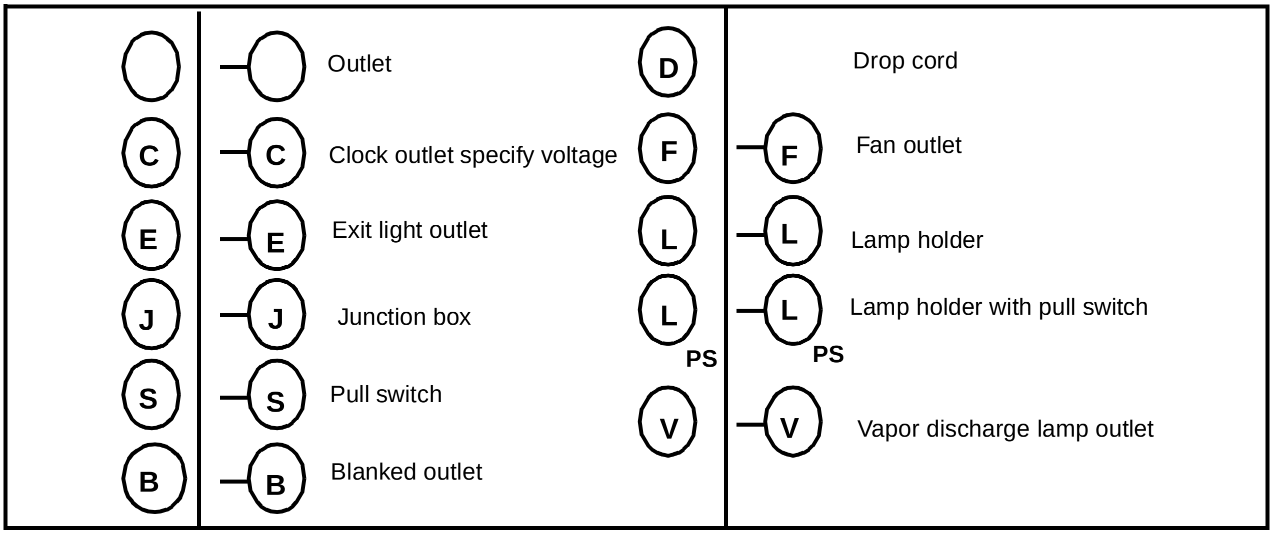


Figure A-2. General outlet symbols

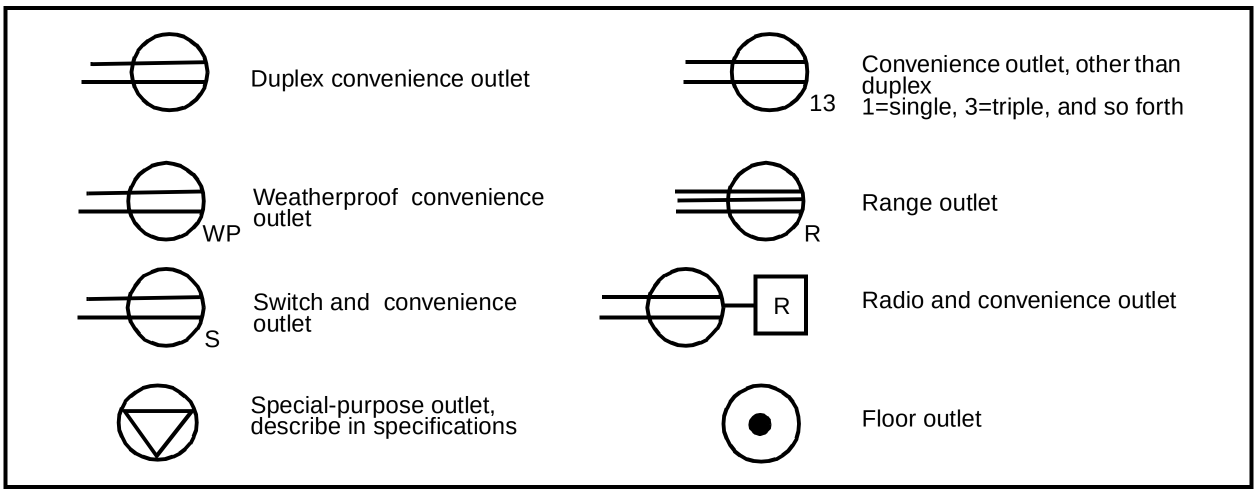


Figure A-3. Convenience outlet symbols

S	Single-pole switch	S_4	Four-way switch
S_3	Three-way switch	S_E	Electrolier switch
S_D	Automatic-door switch	S_P	Pilot lamp and switch
S_K	Key-operated switch	S_{WCB}	Weatherproof circuit breaker
S_{CB}	Circuit breaker	S_{RC}	Remote-control switch
S_{MC}	Momentary contact switch	S_F	Fused switch
S_{WP}	Weatherproof switch	S_{WF}	Weatherproof fused switch
S_2	Double-pole switch		

Figure A-4. Switch outlet symbols

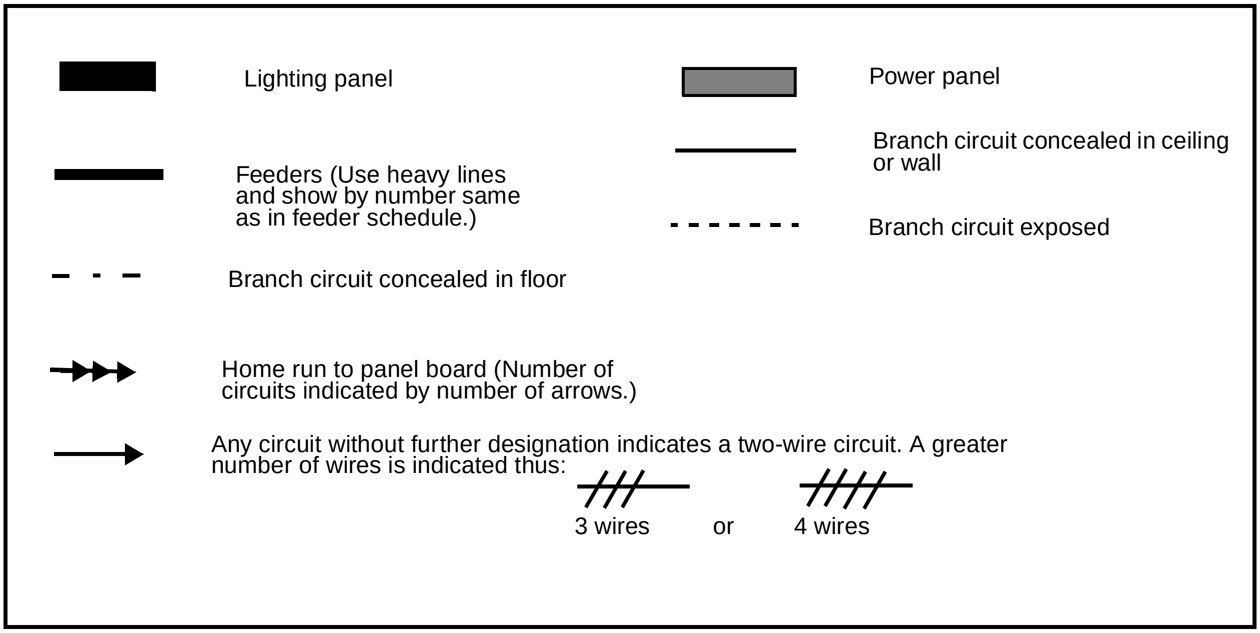


Figure A-5. Panels and circuits

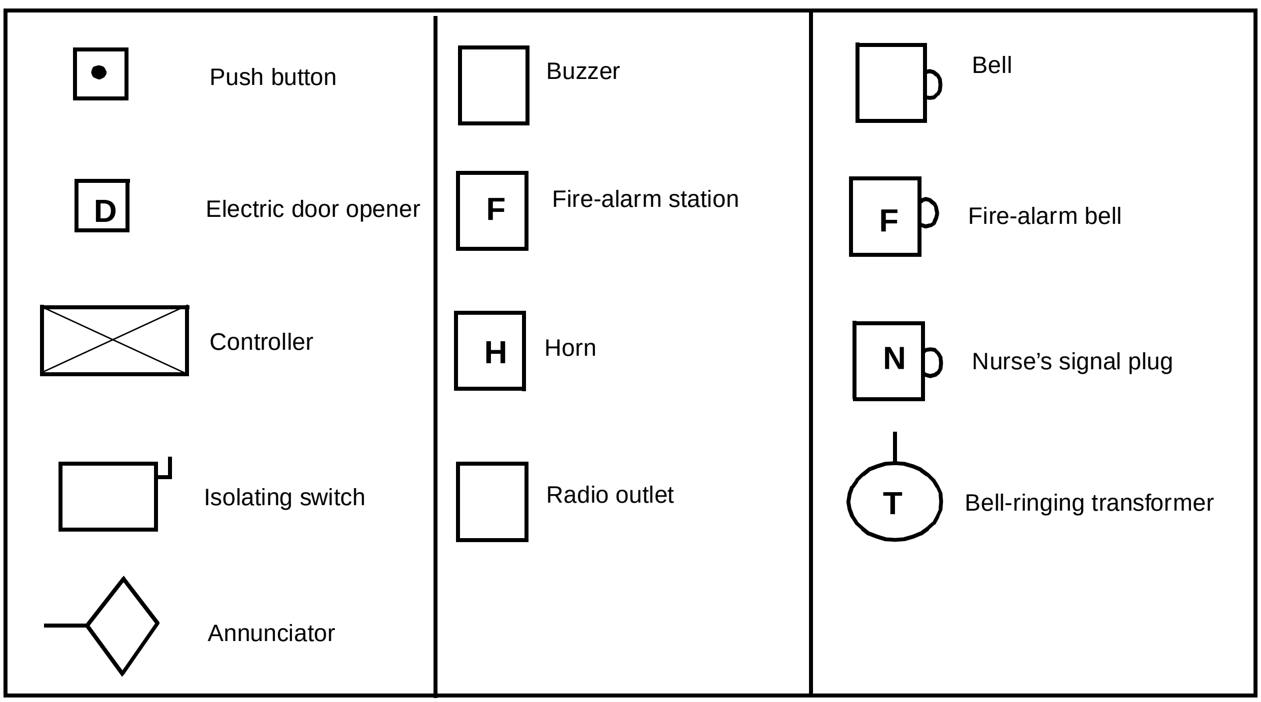


Figure A-6. Miscellaneous symbols

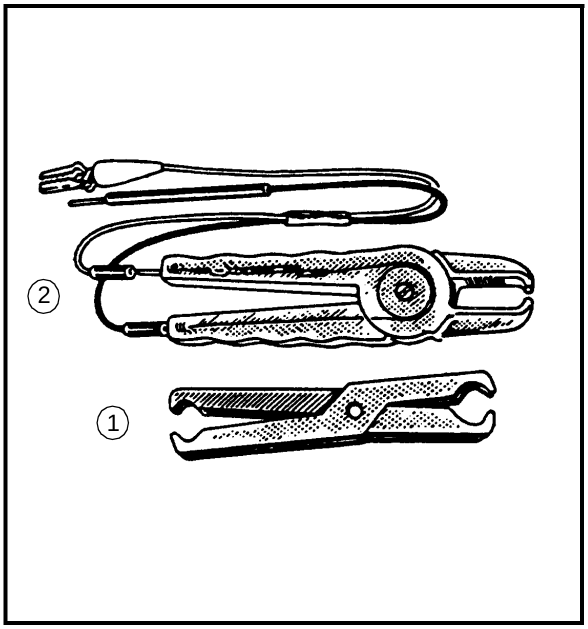


Figure A-7. Fuse pullers

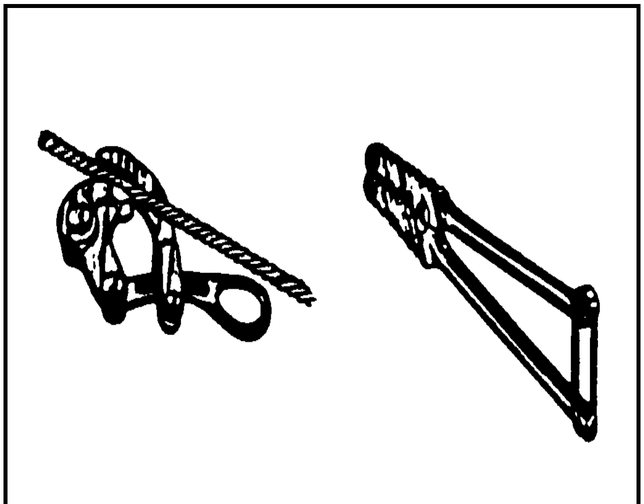


Figure A-8. Wire grip and splicing clamp

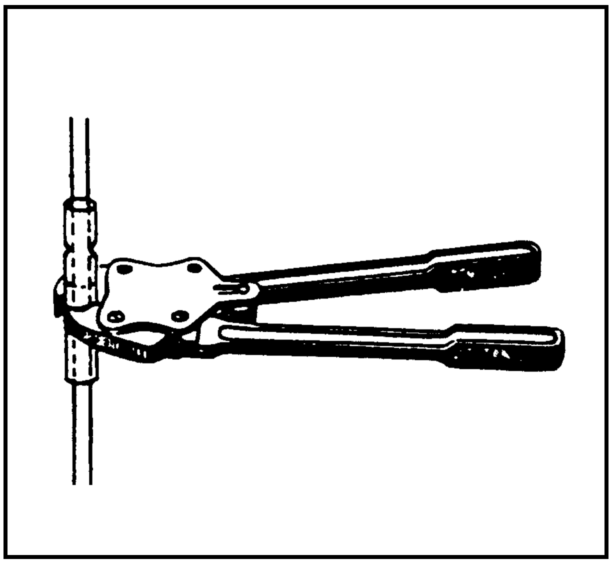


Figure A-9. Thin-wall conduit impinger

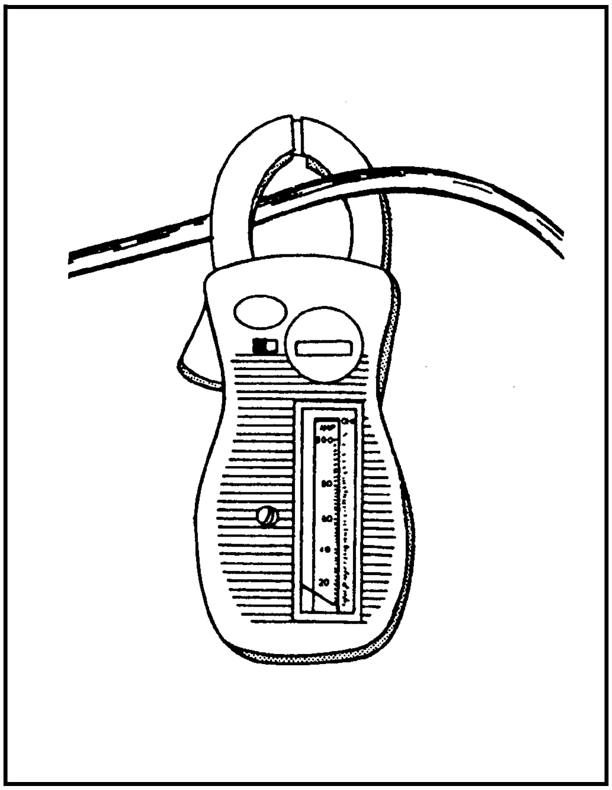


Figure A-10. Multimeter

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure A-11. Steel electrical boxes and covers

Due to copyright restrictions, this graphic is unavailable electronically. You must refer to the hard copy of this product to view this graphic.

Figure A-12. Special-situation boxes

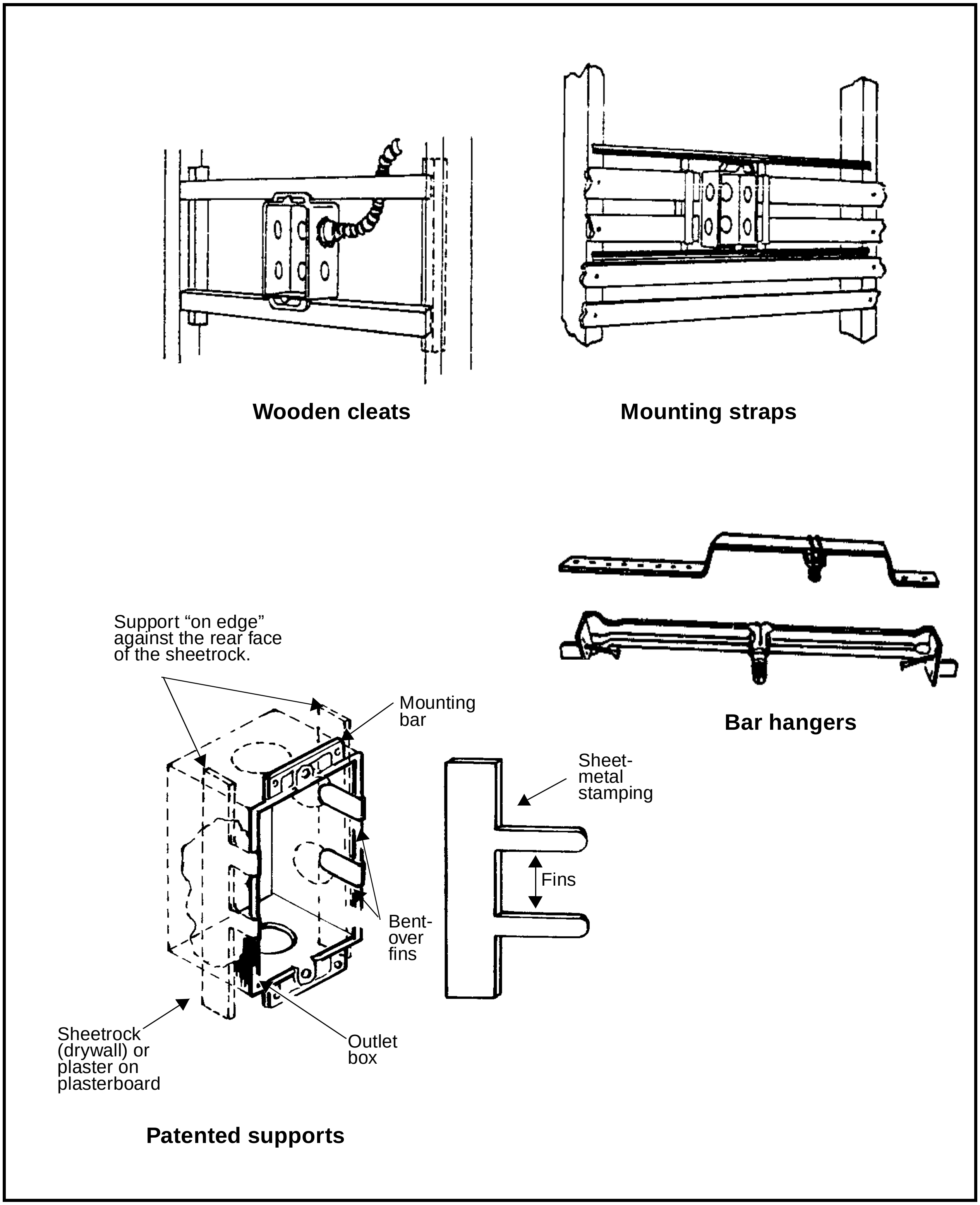


Figure A-13. Typical box mountings

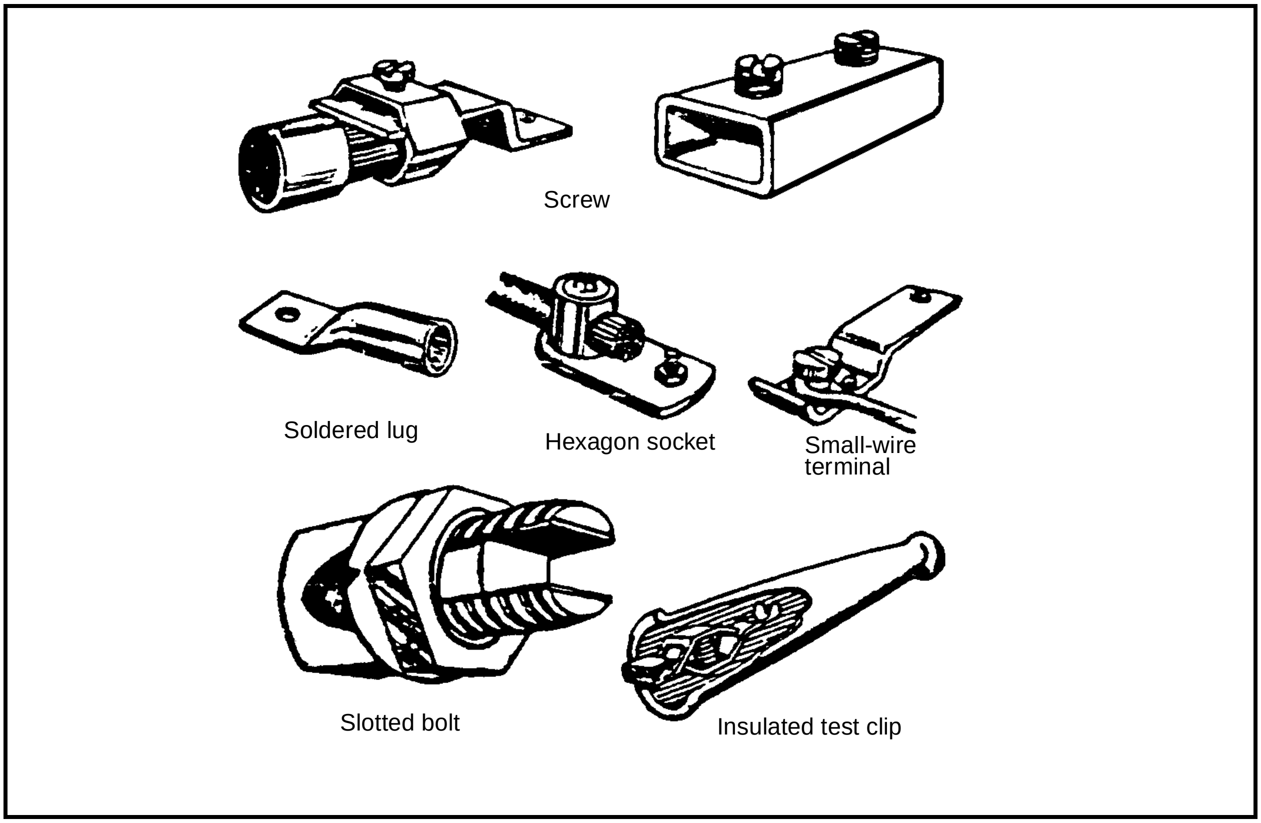


Figure A-14. Cable and wire connectors

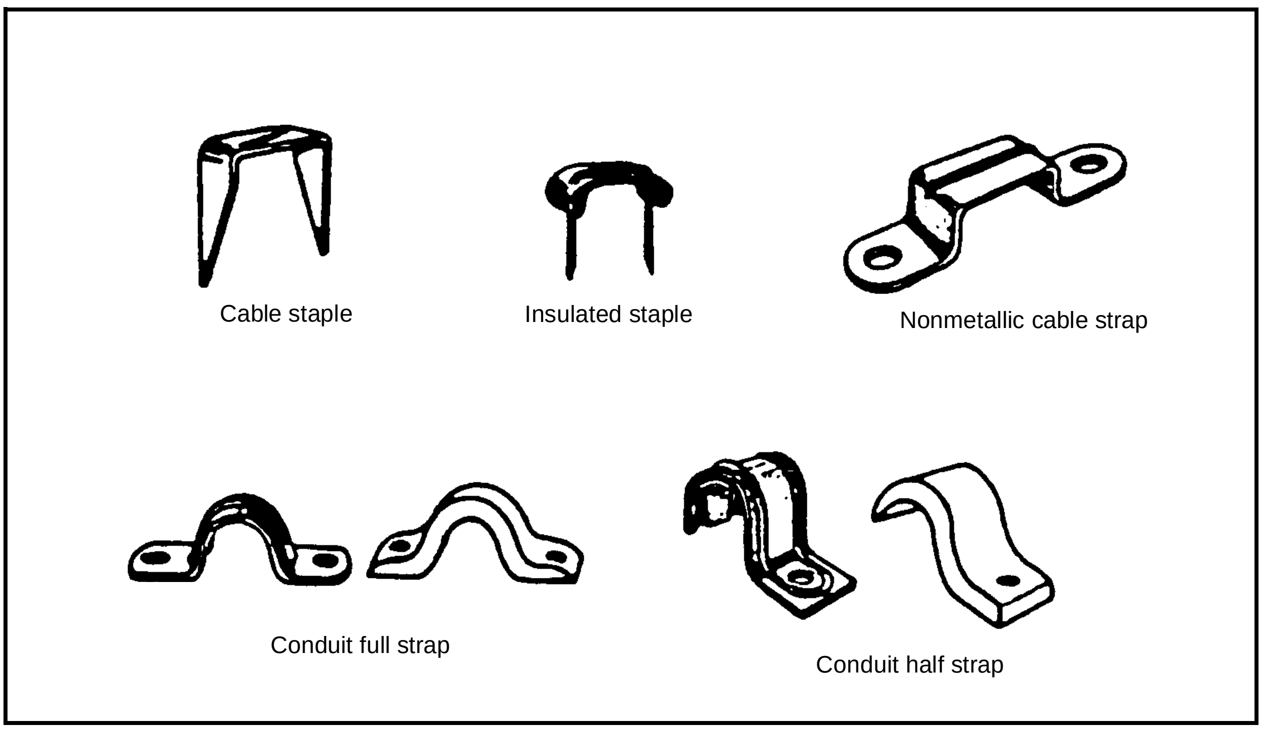


Figure A-15. Straps and staples

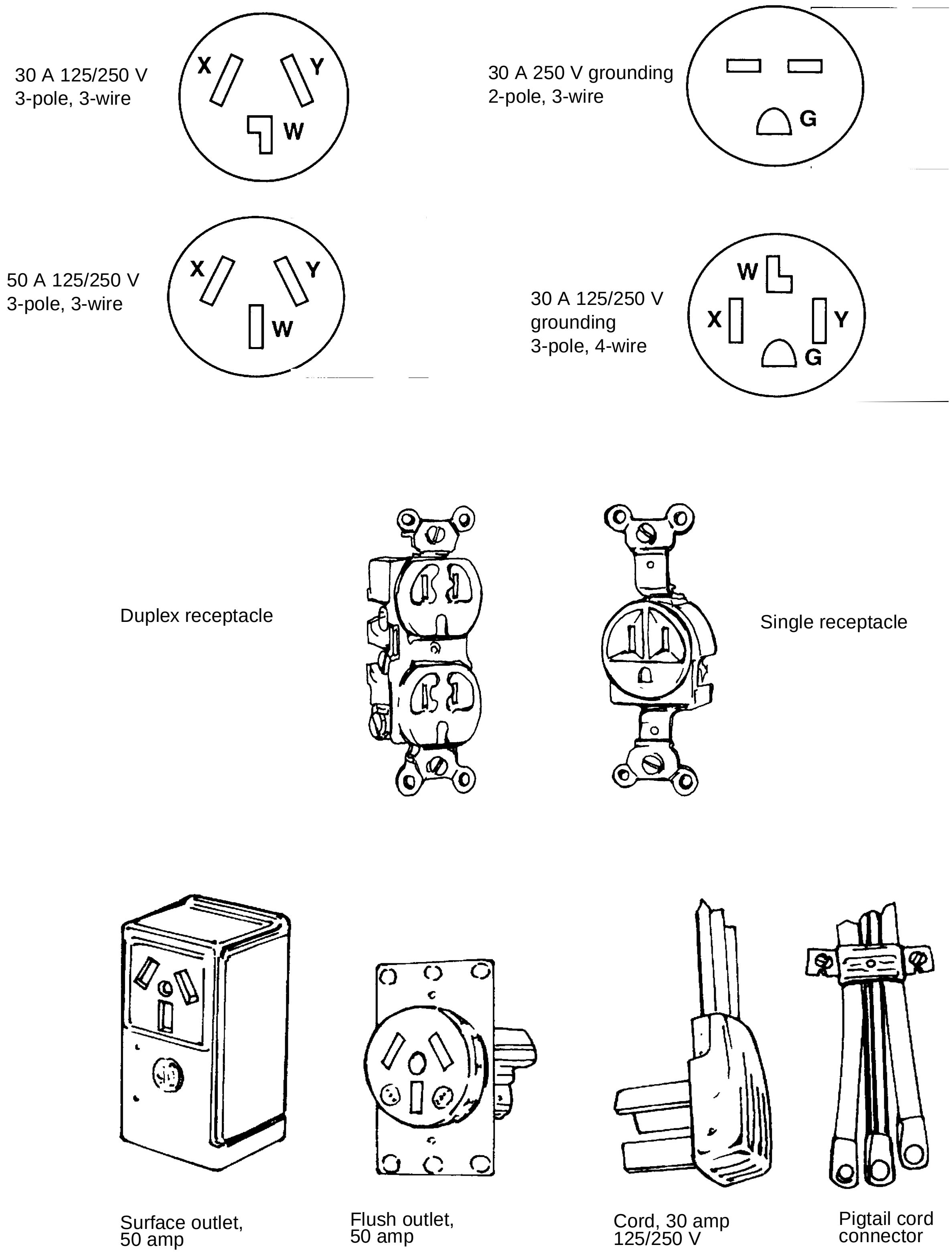


Figure A-16. Receptacles

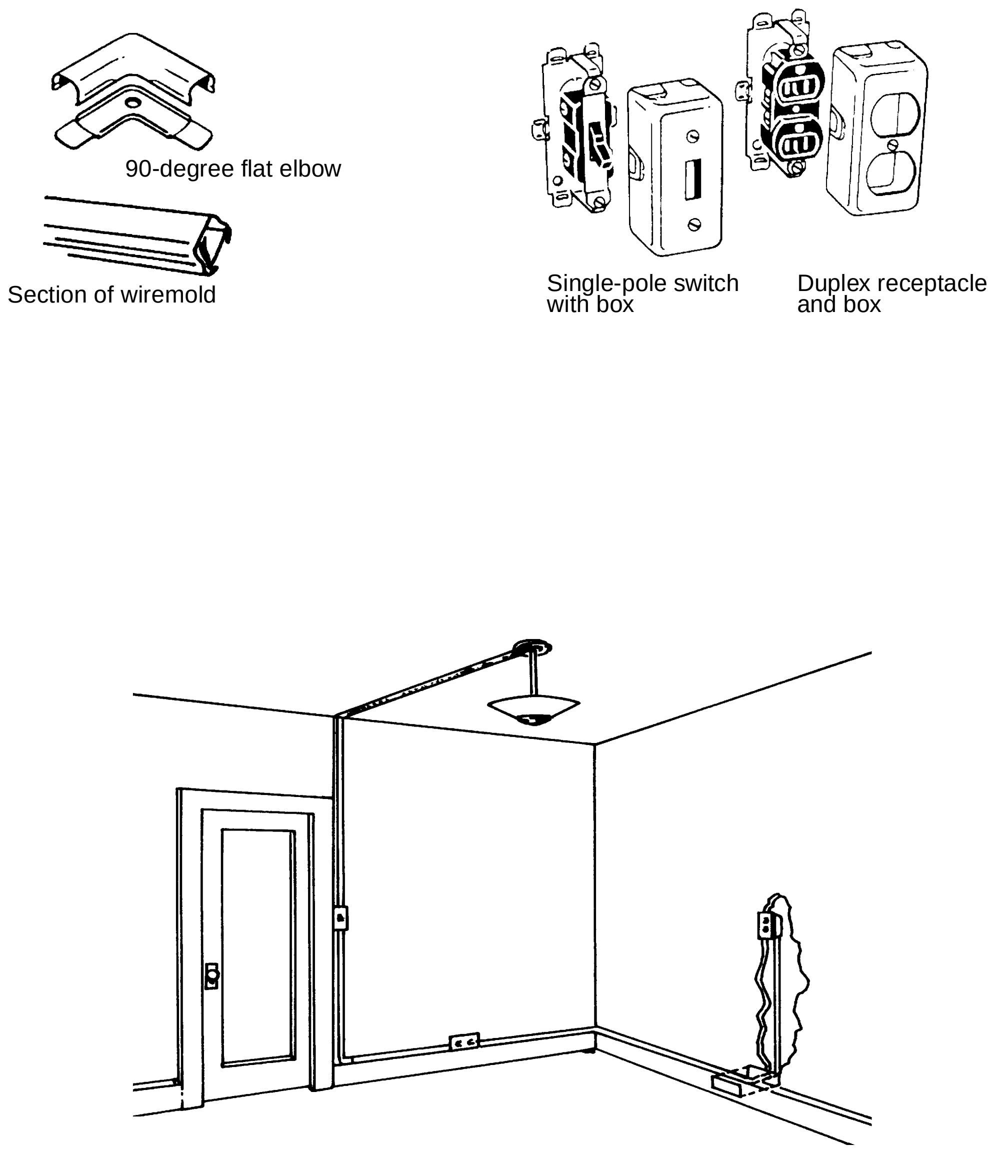


Figure A-17. Surface metal raceways

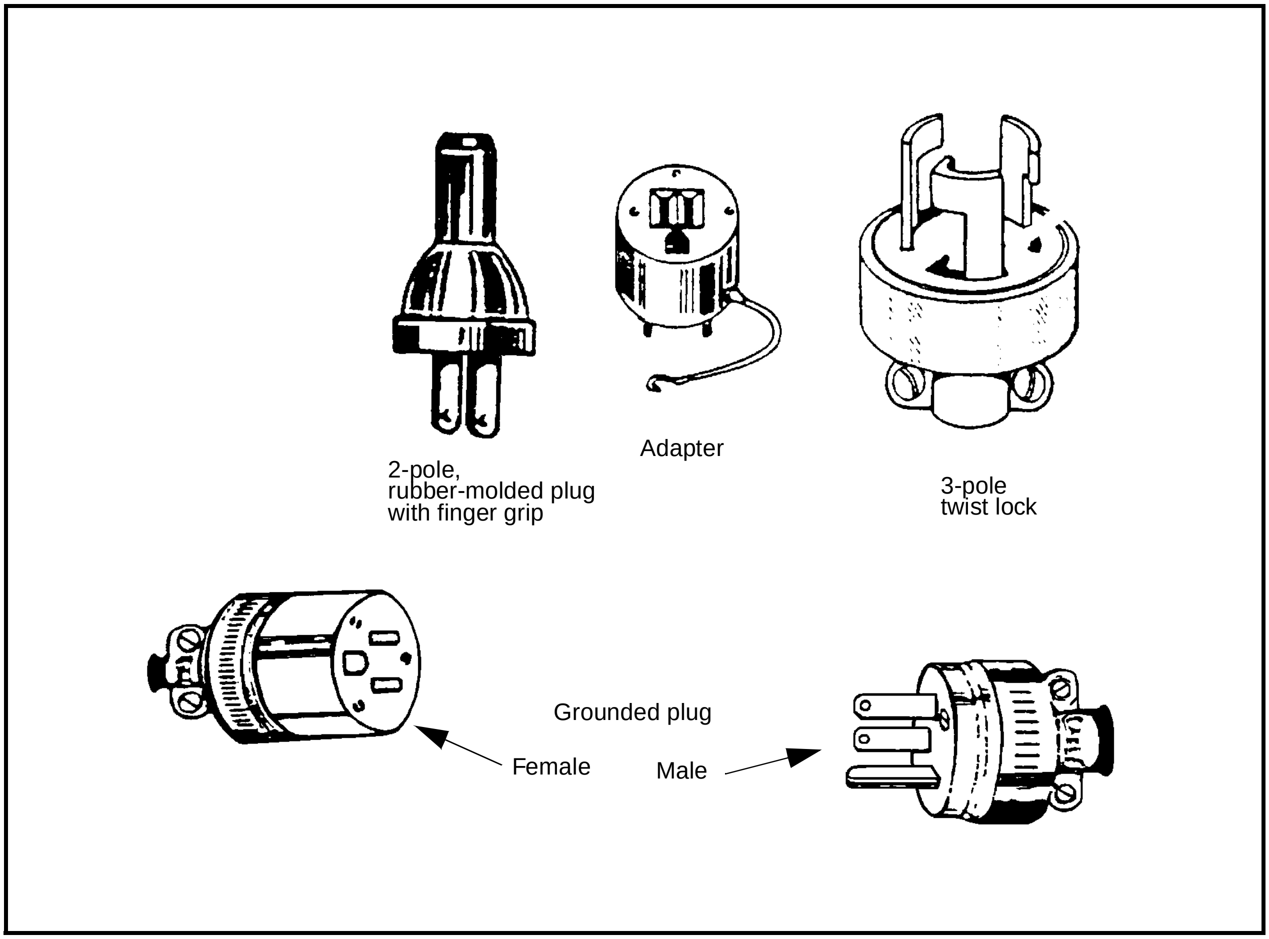


Figure A-18. Attachment plugs

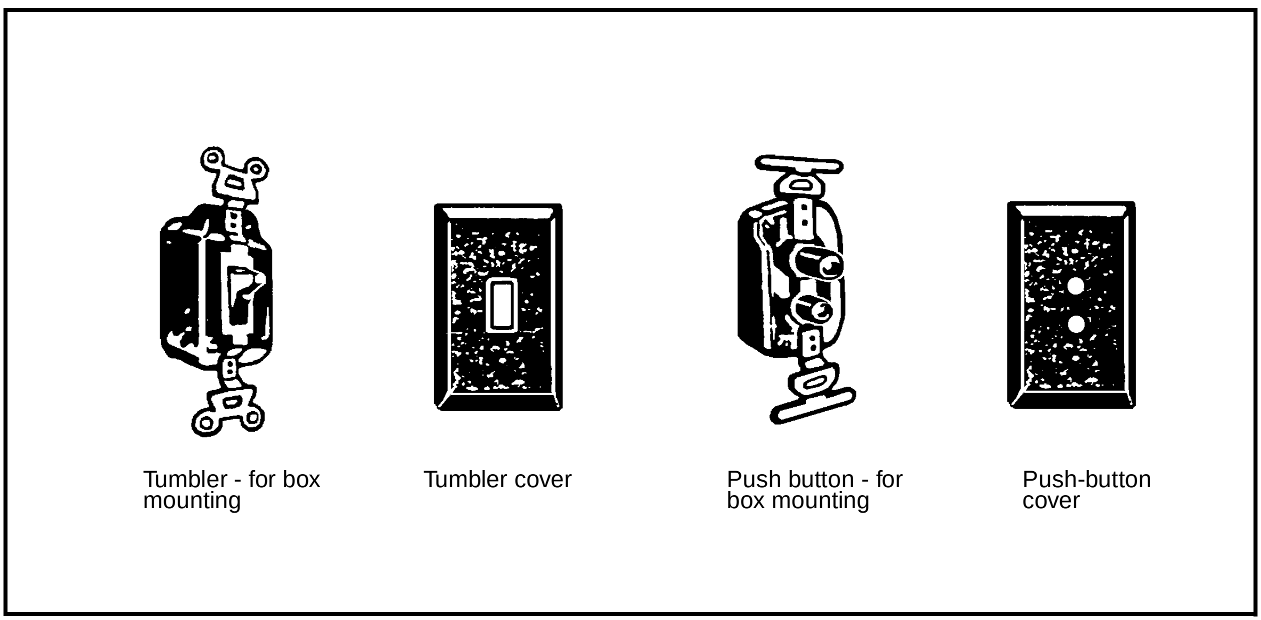


Figure A-19. Switches and covers

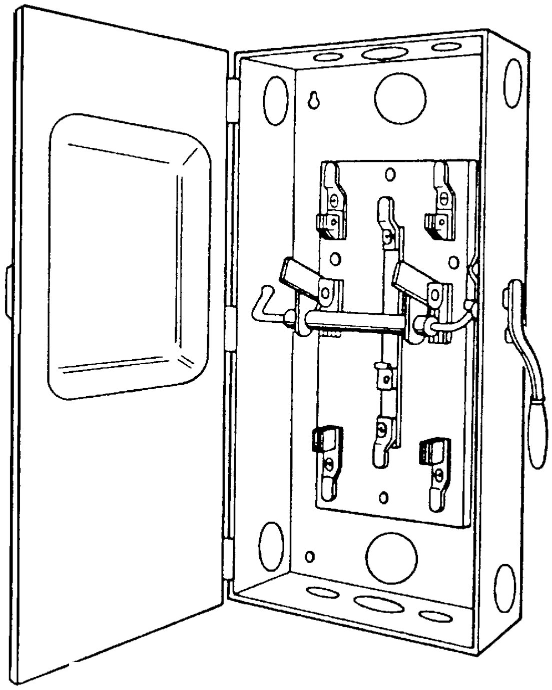
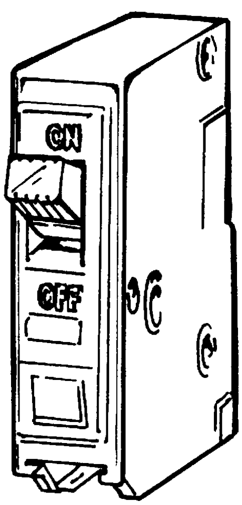
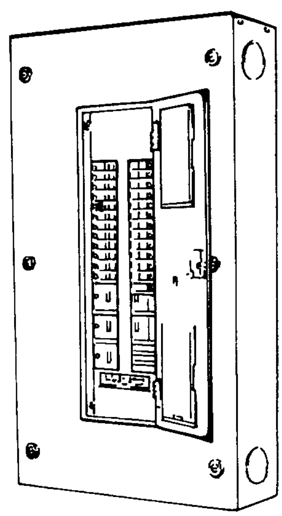


Figure A-20. Service switch box



Single-pole circuit breaker



Panel board containing several circuit breakers

Figure A-21. Circuit breakers

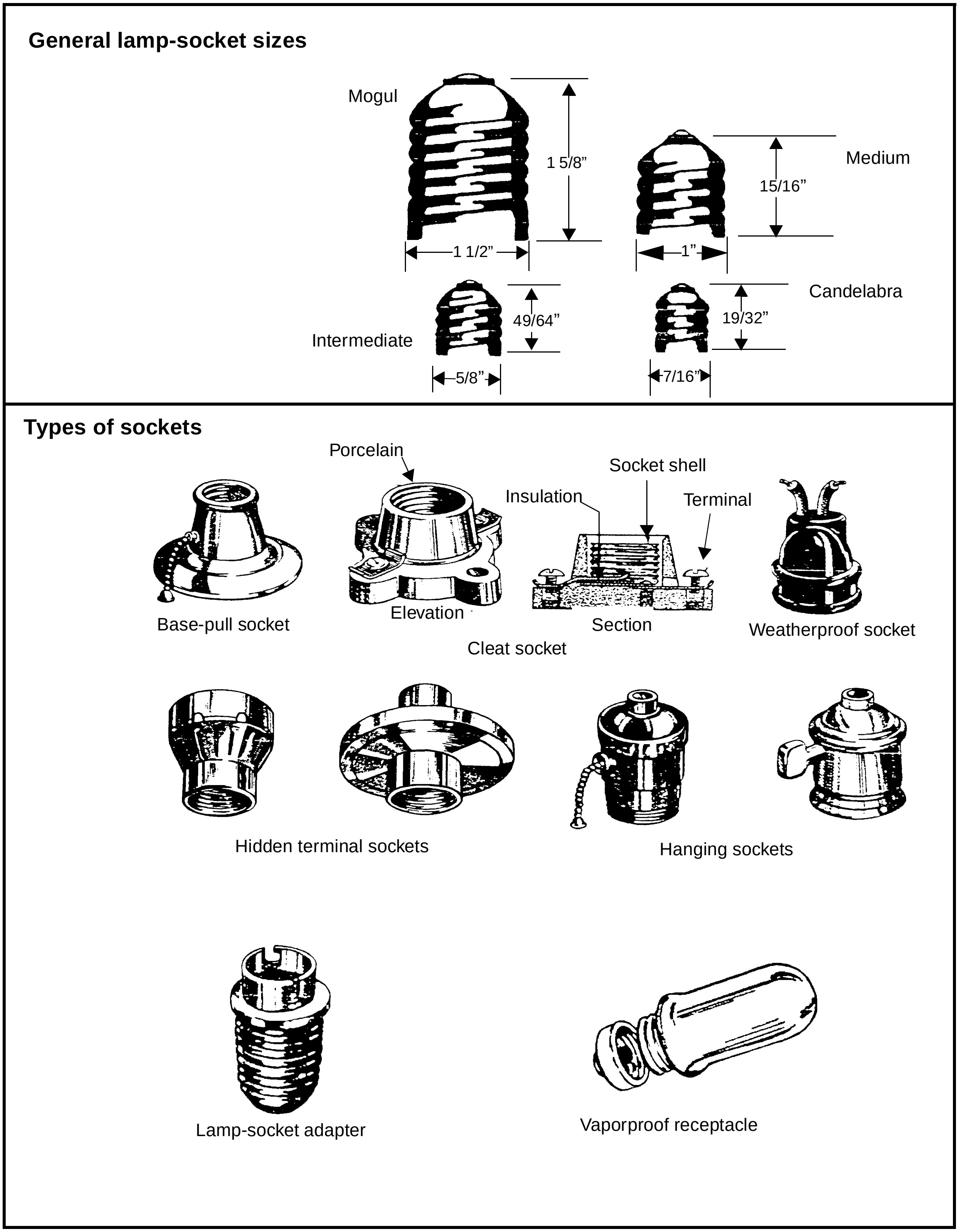


Figure A-22. Lamp holders and sockets

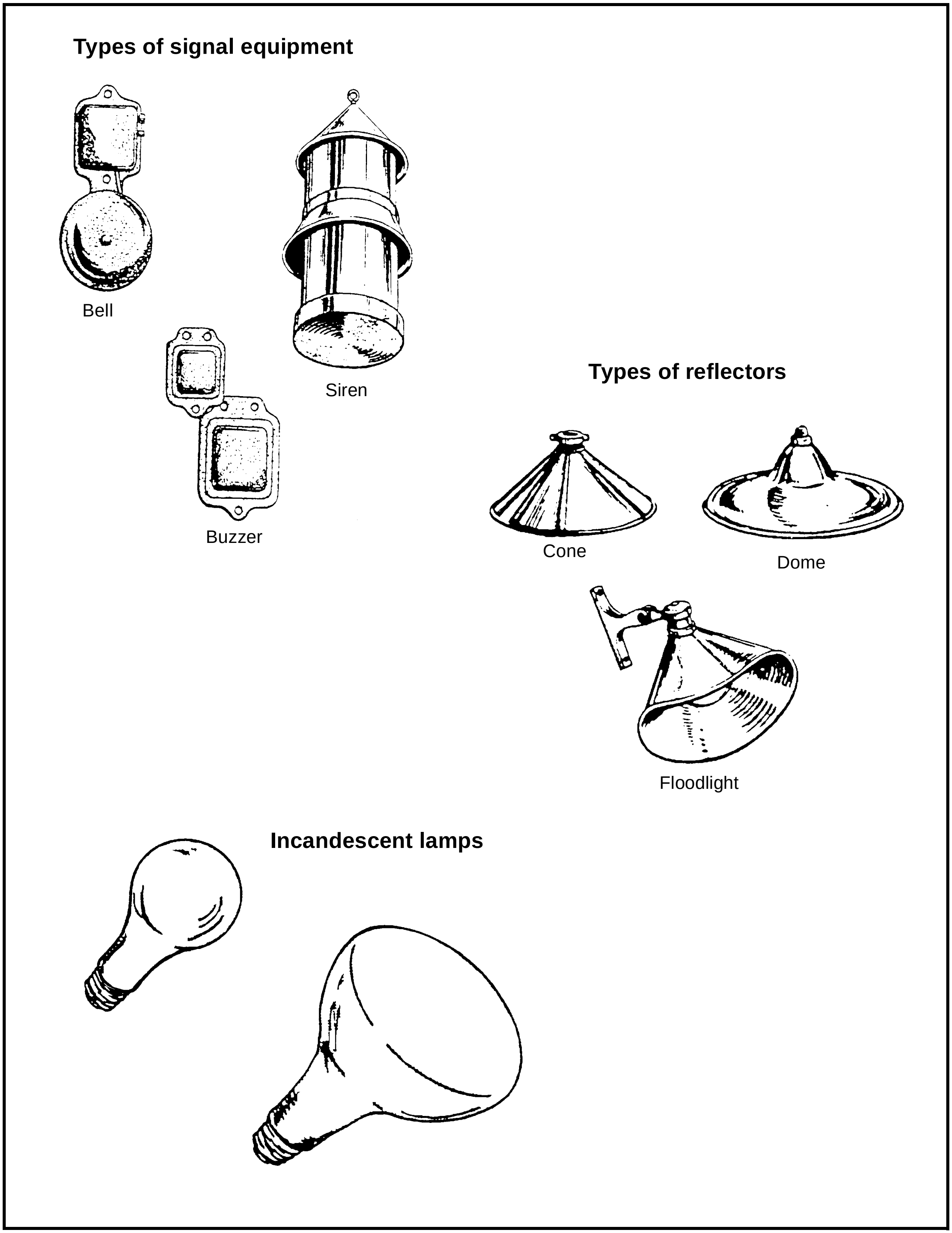


Figure A-23. Lamps, signal equipment, and reflectors

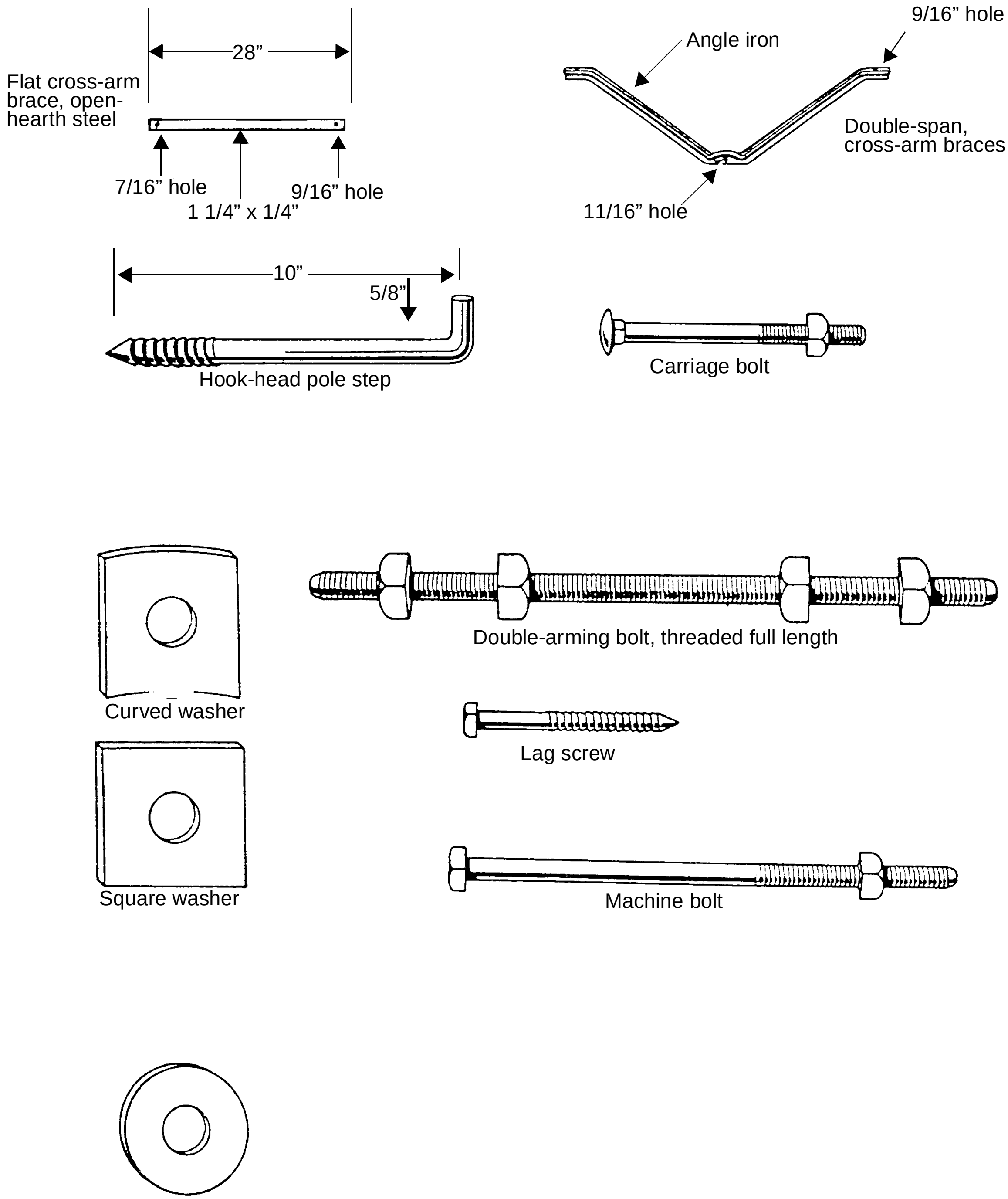


Figure A-24. Braces, bolts, and washers

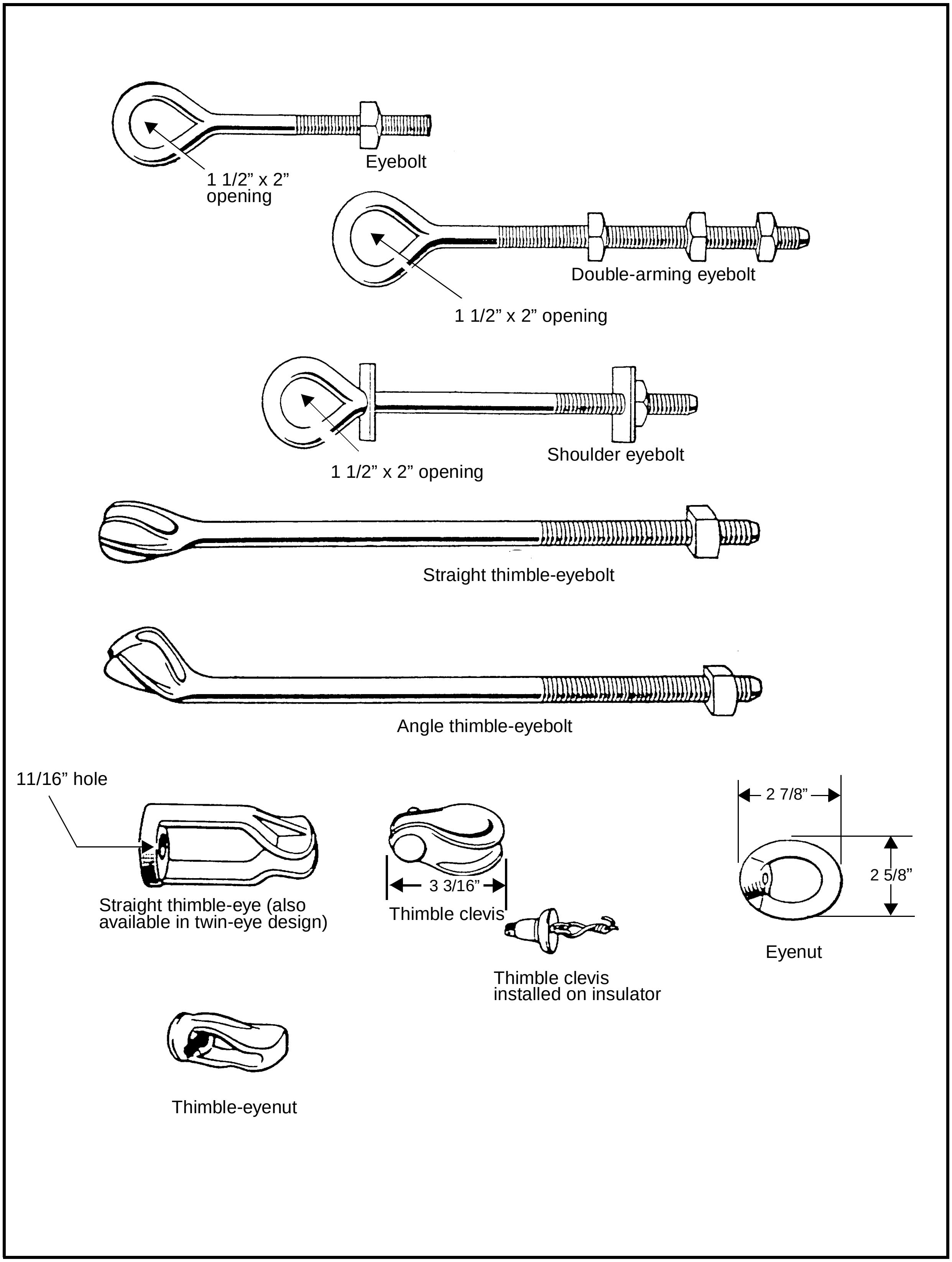


Figure A-25. Eyebolts, nuts, and clevises

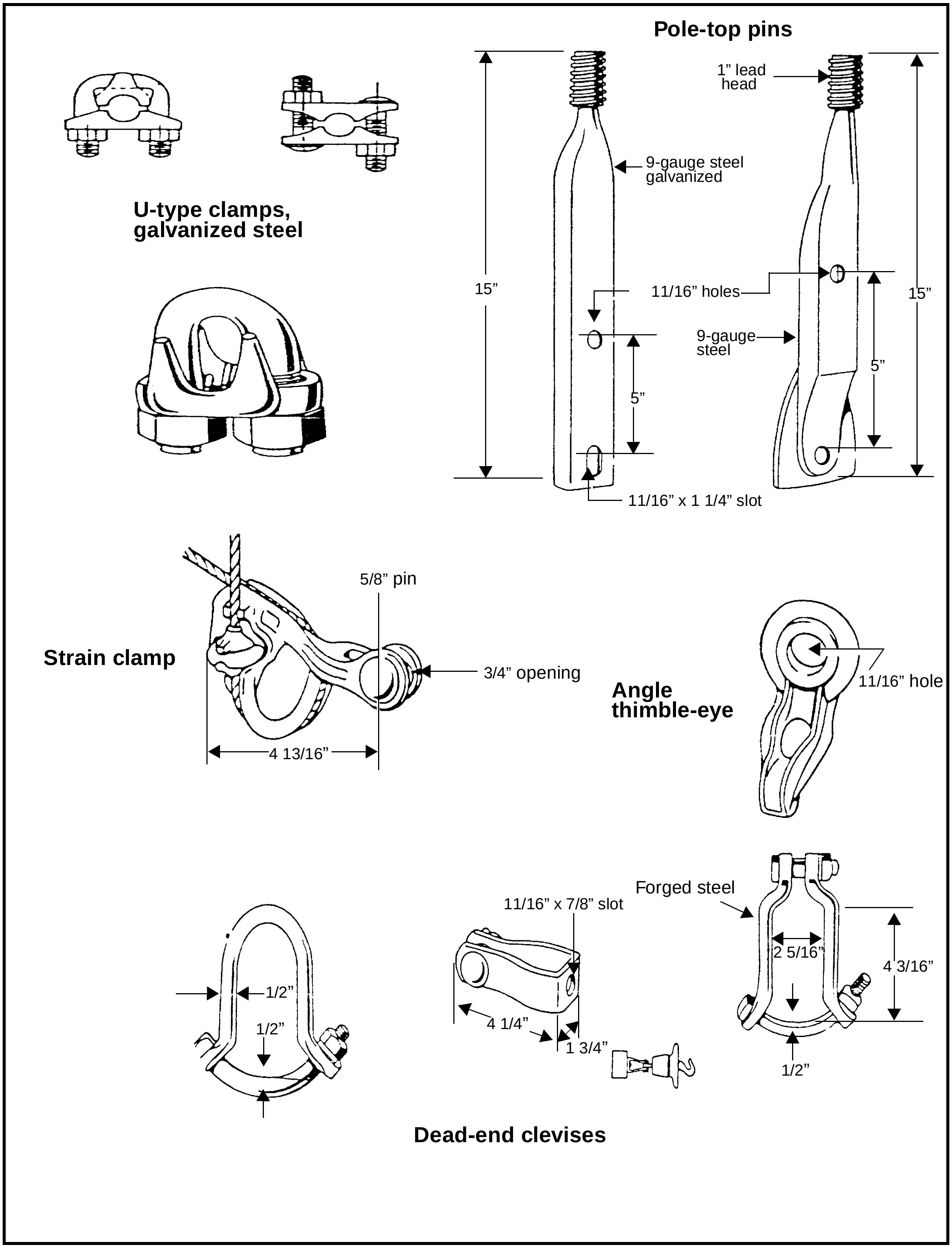


Figure A-26. Clamps, pins, thimble-eyes, and clevises

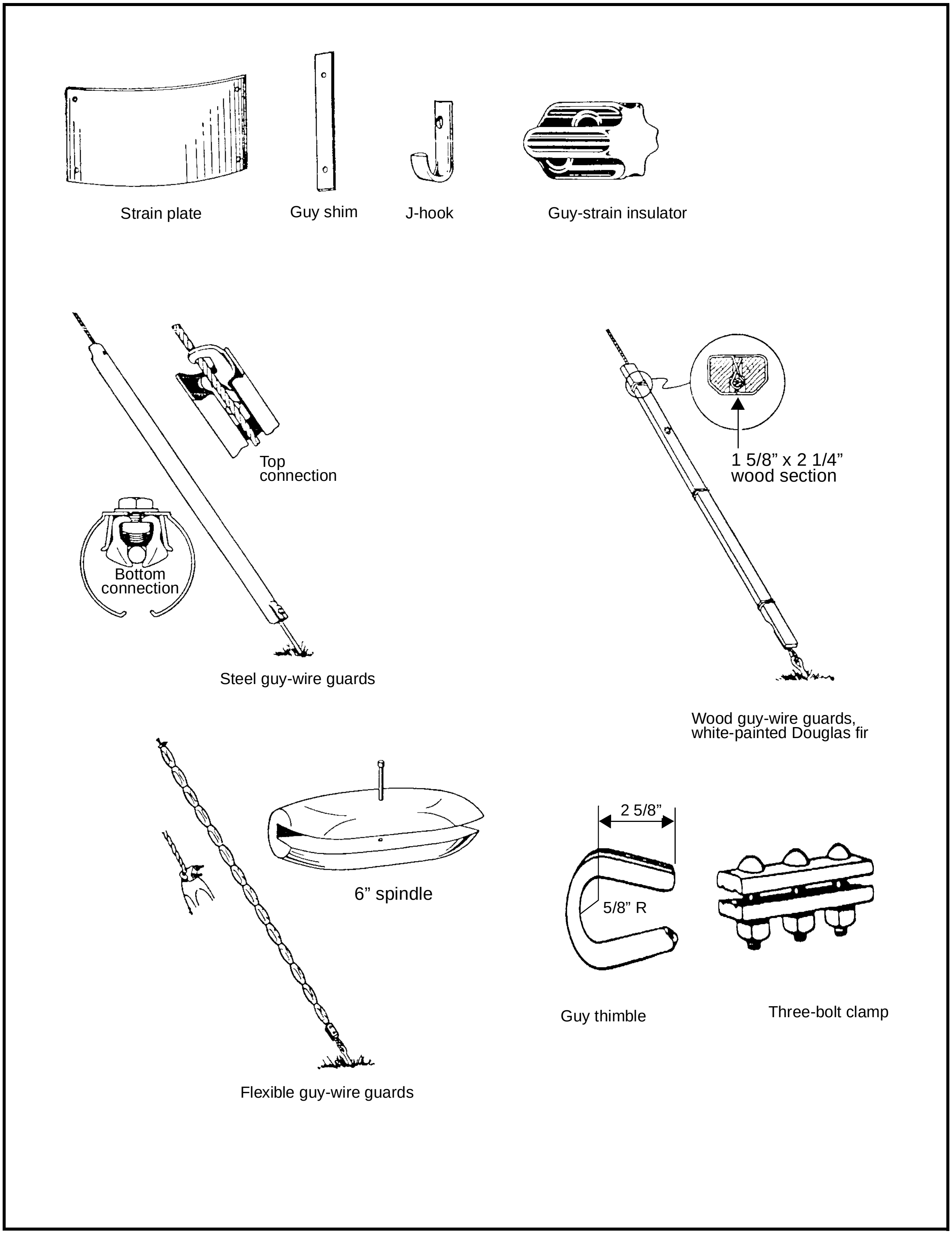


Figure A-27. Guy-wire equipment

APPENDIX B

Electric Data

Table B-1. Characteristics of electrical systems

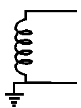
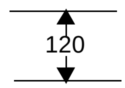
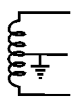
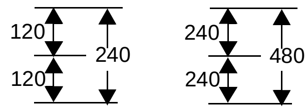
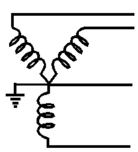
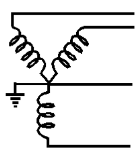
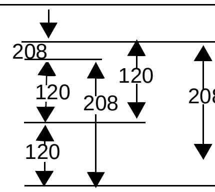
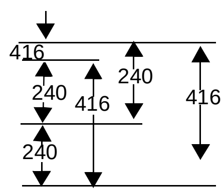
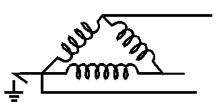
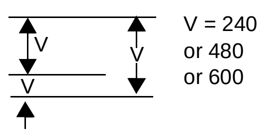
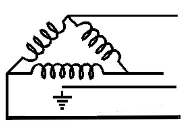
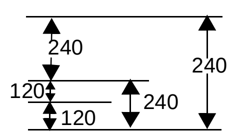
Type	Wiring Diagram	Voltage	Use
A Single-phase, two-wire 10 2 W			Lighting and small, single-phase motors, small loads
B Single-phase, three-wire 10 3 W			Local power to small buildings
C Three-phase, four-wire 30 4 W	 	 or 	Most common system for military secondary distribution
D Three-phase, three-wire 30 3 W			Large motor loads, small lighting loads
E Three-phase, four-wire 30 4 W			Motor and lighting loads

Table B-2. Conductor insulation

Trade Name	Type Letter	Temperature Rating	Application Provisions
Rubber-covered fixture wire (solid or 7-strand)	*RF-1	60°C 140°F	Fixture wiring, limited to 300 V
	*RF-2	60°C 140°F	Fixture wiring
Rubber-covered fixture wire (flexible stranding)	*FF-1	60°C 140°F	Fixture wiring limited to 300 V
	*FF-2	60°C 140°F	Fixture wiring
Heat-resistant, rubber-covered fixture wire (solid or 7-strand)	*RFH-1	75°C 167°F	Fixture wiring, limited to 300 V
	*RFH-2	75°C 167°F	Fixture wiring
Heat-resistant, rubber-covered fixture wire (flexible stranding)	*FFH-1	75°C 167°F	Fixture wiring, limited to 300 V
	*FFH-2	75°C 167°F	Fixture wiring
Thermoplastic-covered fixture wire (solid or stranded)	*TF	60°C 140°F	Fixture wiring
Thermoplastic-covered fixture wire (flexible stranding)	*TFF	60°C 140°F	Fixture wiring
Cotton-covered, heat-resistant fixture wire	*CF	90°C 194°F	Fixture wiring, limited to 300 V
Asbestos-covered, heat-resistant fixture wire	*AF	150°C 302°F	Fixture wiring, limited to 300 V and dry indoor locations
Silicone, rubber-insulated fixture wire (solid or 7-strand)	*SF-1	200°C 392°F	Fixture wiring, limited to 300 V
	*SF-2	200°C 392°F	Fixture wiring
Silicone, rubber-insulated fixture wire (flexible stranding)	*SFF-1	150°C 302°F	Fixture wiring, limited to 300 V
	*SFF-2	150°C 302°F	Fixture wiring
Code rubber	R	60°C 140°F	Dry locations
Heat-resistant rubber	RH	75°C 167°F	Dry locations
	RHH	90°C 194°F	Dry locations

Table B-2. Conductor insulation (continued)

Trade Name	Type Letter	Temperature Rating	Application Provisions
Moisture-resistant rubber	RW	60°C 140°F	Dry and wet locations; for over 2,000 V, insulation shall be ozone-resistant.
Moisture- and heat-resistant rubber	RH-RW	60°C 140°F	Dry and wet locations; for over 2,000 V, insulation shall be ozone-resistant.
		75°C 167°F	Dry locations
Thermoplastic and fibrous outer braid	TBS	90°C 194°F	Switchboard wiring only
Synthetic heat-resistant	SIS	90°C 194°F	Switchboard wiring only
Mineral insulation (metal sheathed)	MI	85°C 185°F	Dry and wet locations with Type O termination fittings, maximum operating temperature for special applications 250°C
Silicone-asbestos	SA	90°C 194°F	Dry locations, maximum operating temperature for special applications 125°C
Fluorinated ethylene propylene	FEP	90°C 194°F	Dry locations
	FEPB	200°C 392°F	Dry locations—special applications
		75°C 167°F	For over 2,000 V, insulation shall be ozone-resistant.
Moisture- and heat-resistant rubber	RHW	75°C 167°F	Dry and wet locations; for over 2,000 V, insulation shall be ozone-resistant
Latex rubber	RU	60°C 140°F	Dry locations
Heat-resistant latex rubber	RUH	75°C 167°F	Dry locations
Moisture-resistant latex rubber	RUW	60°C 140°F	Dry and wet locations
Thermoplastic	T	60°C 140°F	Dry locations
Moisture-resistant thermoplastic	TW	60°C 140°F	Dry and wet locations
Heat-resistant thermoplastic	THHN	90°C 194°F	Dry locations
Moisture- and heat-resistant thermoplastic	THW	75°C 167°F	Dry and wet locations
	THWN	75°C 167°F	Dry and wet locations

Table B-2. Conductor insulation (continued)

Trade Name	Type Letter	Temperature Rating	Application Provisions
Thermoplastic and asbestos varnished cambric	TA	90°C 194°F	Switchboard wiring only
	V	85°C 185°F	Dry locations only, smaller than No 6 by special permission
Asbestos and varnished cambric	AVA	110°C 230°F	Dry locations
	AVL	110°C 230°F	Dry and wet locations
	AVB	90°C 194°F	Dry locations
Asbestos	A	200°C 392°F	Dry locations only; in raceways, only for loads to or within apparatus; limited to 300 V
	AA	200°C 392°F	Dry locations only; open wiring; in raceways, only for loads to or within apparatus; limited to 300 V
	AI	125°C 257°F	Dry locations only; in raceways, only for loads to or within apparatus; limited to 300 V
	AIA	125°C 257°F	Dry locations only; open wiring; in raceways, only for loads to or within apparatus
Paper		85°C 185°F	For underground service conductors or by special permission

*Fixture wires are not intended for installation as branch circuit conductors nor for the connection of portable or stationary appliances.

Table B-3. Allowable current-carrying capacity of copper conductors—not more than three conductors in raceway or cable

Size		Temperature Rating of Conductor[1]					
AWG or MCM		60°C (140°F)	75°C (167°F)	85-90°C (185°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)
14		15	15	25[2]	30	30	30
12		20	20	30[2]	35	40	40
10		30	30	40[2]	45	50	55
8		40	45	50	60	65	70
6		55	65	70	80	85	95
4		70	85	90	105	115	120
3		80	100	105	120	130	145
2		95	115	120	135	145	165
1		110	130	140	160	170	190
1/0		125	150	155	190	200	225
2/0		145	175	185	215	230	250
3/0		165	200	210	245	265	285
4/0		195	230	235	275	310	340
250		215	255	270	315	335	—
300		240	285	300	345	380	—
350		260	310	325	390	420	—
400		280	335	360	420	450	—
500		320	380	405	470	500	—
600		355	420	455	525	545	—
700		385	460	490	560	600	—
750		400	475	500	580	620	—
800		410	490	515	600	640	—
900		435	520	555	—	—	—
1,000		455	545	585	680	730	—
1,250		495	590	645	—	—	—
1,500		520	625	700	785	—	—
1,750		545	650	735	—	—	—
2,000		560	665	775	840	—	—
°C	**°F**	**Correction Factors, Room Temperatures Over 30°C (86°F)**					
40	104	0.82	0.88	0.90	0.94	0.95	—
45	113	0.71	0.82	0.85	0.90	0.92	—
50	122	0.58	0.75	0.80	0.87	0.89	—
55	131	0.41	0.67	0.74	0.83	0.86	—
60	140	—	0.58	0.67	0.79	0.83	0.91
70	158	—	0.35	0.52	0.71	0.76	0.87
75	167	—	—	0.43	0.66	0.72	0.86
80	176	—	—	0.30	0.61	0.69	0.84
90	194	—	—	—	0.50	0.61	0.80
100	212	—	—	—	—	0.51	0.77
120	248	—	—	—	—	—	0.69
140	284	—	—	—	—	—	0.50

[1]Current capacities relate to conductors in Table B-2. See Table B-2 for the temperature rating of the conductor.

[2]Current capacities for types FEP, FEPB, PHH, and THHN conductors for sizes AWG 14, 12, and 10 shall be the same as designated for 75°C conductors in this table.

Table B-4. Allowable current-carrying capacity of copper conductors in free air

Size		Temperature Rating of Conductor[1]						
AWG or MCM		60°C (140°F)	75°C (167°F)	85-90°C (185°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	Bare and Covered Conductor
14		20	20	30[2]	40	40	45	30
12		25	25	40[2]	50	50	55	40
10		40	40	55[2]	65	70	75	55
8		55	65	70	85	90	100	70
6		80	95	100	120	125	135	100
4		105	125	135	160	170	180	130
3		120	145	155	180	195	210	150
2		140	170	180	210	225	240	175
1		165	195	210	245	265	280	205
1/0		195	230	245	285	305	325	235
2/0		225	265	285	330	355	370	275
3/0		260	310	330	385	410	430	320
4/0		300	360	385	445	475	510	370
250		340	405	425	495	530	—	410
300		375	445	480	555	590	—	460
350		420	505	530	610	655	—	510
400		455	545	575	665	710	—	555
500		515	620	660	765	815	—	630
600		575	690	740	855	910	—	710
700		630	755	815	940	1,005	—	780
750		655	785	845	980	1,045	—	810
800		680	815	880	1,020	1,085	—	845
900		730	870	940	—	—	—	905
1,000		780	935	1,000	1,165	1,240	—	965
1,250		890	1,065	1,130	—	—	—	—
1,500		980	1,175	1,260	1,450	—	—	1,215
1,750		1,070	1,280	1,370	—	—	—	—
2,000		1,155	1,385	1,470	1,715	—	—	1,405
°C	°F	Correction Factors, Room Temperatures Over 30°C (86°F)						
40	104	0.82	0.88	0.90	0.94	0.95	—	—
45	113	0.71	0.82	0.85	0.90	0.92	—	—
50	122	0.58	0.75	0.80	0.87	0.89	—	—
55	131	0.41	0.67	0.74	0.83	0.86	—	—
60	140	—	0.58	0.67	0.79	0.83	0.91	—
70	158	—	0.35	0.52	0.71	0.76	0.87	—
75	167	—	—	0.43	0.66	0.72	0.86	—
80	176	—	—	0.30	0.61	0.69	0.84	—
90	194	—	—	—	0.50	0.61	0.80	—
100	212	—	—	—	—	0.51	0.77	—
120	248	—	—	—	—	—	0.69	—
140	284	—	—	—	—	—	0.50	—

[1]Current capacities relate to conductors in Table B-2, pages B-2 through B-4. See Table B-2 for the temperature rating of the conductor.

[2]Current capacities for types FEP, FEPB, PHH, and THHN conductors for sizes AWG 14, 12, and 10 shall be the same as designated for 75°C conductors in this table.

Table B-5. Allowable current-carrying capacity of aluminum conductors—not more than three conductors in raceway or cable

Size		Temperature Rating of Conductor[1]					
AWG or MCM		60°C (140°F)	75°C (167°F)	85-90°C (185°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)
12		15	15	25[2]	30	30	30
10		25	25	30[2]	35	40	45
8		30	40	40[2]	45	50	55
6		40	50	55	60	65	75
4		55	65	70	80	90	95
3		65	75	80	95	100	115
2[3]		75	90	95	105	115	130
1[3]		85	100	110	125	135	150
1/0[3]		100	120	125	150	160	180
2/0[3]		115	135	145	170	180	200
3/0[3]		130	155	165	195	210	225
4/0[3]		155	180	185	215	245	270
250		170	205	215	250	270	190
300		190	230	240	275	305	—
350		210	250	260	310	335	—
400		225	270	290	335	360	—
500		260	310	330	380	405	—
600		285	340	370	425	440	—
700		310	375	395	455	485	—
750		320	385	405	470	500	—
800		330	395	415	485	520	—
900		355	425	455	—	—	—
1,000		375	445	480	560	600	—
1,250		405	485	530	—	—	—
1,500		435	520	580	650	—	—
1,750		455	545	615	—	—	—
2,000		470	560	650	705	—	—
°C	**°F**	**Correction Factors, Room Temperatures Over 30°C (86°F)**					
40	104	0.82	0.88	0.90	0.94	0.95	—
45	113	0.71	0.82	0.85	0.90	0.92	—
50	122	0.58	0.75	0.80	0.87	0.89	—
55	131	0.41	0.67	0.74	0.83	0.86	—
60	140	—	0.58	0.67	0.79	0.83	0.91
70	158	—	0.35	0.52	0.71	0.76	0.87
75	167	—	—	0.43	0.66	0.72	0.86
80	176	—	—	0.30	0.61	0.69	0.84
90	194	—	—	—	0.50	0.61	0.80
100	212	—	—	—	—	0.51	0.77
120	248	—	—	—	—	—	0.69
140	284	—	—	—	—	—	0.50

[1]Current capacities relate to conductors in Table B-2, pages B-2 through B-4. See Table B-2 for the temperature rating of the conductor.

[2]Current capacities for types FEP, FEPB, PHH, and THHN conductors for sizes AWG 14, 12, and 10 shall be the same as designated for 75°C conductors in this table.

[3]For three-wire, single-phase service and subservice circuits, the allowable current capacity of RH, RH-RW, RHH, RHW, and THW aluminum conductors shall be for sizes No 2-100 amp, No 1-110 amp, No 1/0-125 amp, No 2/0-50 amp, No 3/0-170 amp, and No 4/0-200 amp.

Table B-6. Allowable current-carrying capacity of aluminum conductors in free air

Size		Temperature Rating of Conductor[1]						
AWG or MCM		60°C (140°F)	75°C (167°F)	85-90°C (185°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	Bare and Covered Conductor
12		20	20	30[2]	40	40	45	30
10		30	30	45[2]	50	55	60	45
8		45	55	55[2]	65	70	80	55
6		60	75	80	95	100	105	80
4		80	100	105	125	135	140	100
3		95	115	120	140	150	165	115
2		110	135	140	165	175	185	135
1		130	155	165	190	205	220	160
1/0		150	180	190	220	240	255	185
2/0		175	210	220	255	275	290	215
3/0		200	240	255	300	320	335	250
4/0		230	280	300	345	370	400	290
250		265	315	330	385	415	—	320
300		290	350	375	435	460	—	360
350		330	395	415	475	510	—	400
400		355	425	450	520	555	—	435
500		405	485	515	595	635	—	490
600		455	545	585	675	720	—	560
700		500	595	645	745	795	—	615
750		515	620	670	775	825	—	640
800		535	645	695	805	855	—	670
900		580	700	750	—	—	—	725
1,000		625	750	800	930	990	—	770
1,250		710	855	905	—	—	—	—
1,500		795	950	1,020	1,175	—	—	985
1,750		875	1,050	1,125	—	—	—	—
2,000		960	1,150	1,220	1,425	—	—	1,165
°C	°F	Correction Factors, Room Temperatures Over 30°C (86°F)						
40	104	0.82	0.88	0.90	0.94	0.95	—	—
45	113	0.71	0.82	0.85	0.90	0.92	—	—
50	122	0.58	0.75	0.80	0.87	0.89	—	—
55	131	0.41	0.67	0.74	0.83	0.86	—	—
60	140	—	0.58	0.67	0.79	0.83	0.91	—
70	158	—	0.35	0.52	0.71	0.76	0.87	—
75	167	—	—	0.43	0.66	0.72	0.86	—
80	176	—	—	0.30	0.61	0.69	0.84	—
90	194	—	—	—	0.50	0.61	0.80	—
100	212	—	—	—	—	0.51	0.77	—
120	248	—	—	—	—	—	0.69	—
140	284	—	—	—	—	—	0.50	—

[1]Current capacities relate to conductors in Table B-2, pages B-2 through B-4. See Table B-2 for the temperature rating of the conductor.

[2]Current capacities for types FEP, FEPB, PHH, and THHN conductors for sizes AWG 14, 12, and 10 shall be the same as designated for 75°C conductors in this table.

Table B-7. Reduction of current-carrying capacity for more than three conductors in raceway or cable

Number of Conductors	Percent Reduction of Table B-3, page B-5, and Table B-5, page B-7
4 to 6	80
7 to 24	70
25 to 42	60
43 and above	50

Table B-8. Flexible cords

Trade Name	Type Letter	AWG	No of Conductors	Insulation	Braid on Each Conductor	Outer Covering	Use		
Parallel tinsel cord	TP	27	2	Rubber	None	Rubber	Attached to an appliance	Damp places	Not hard usage
	TPT	27	2	Thermoplastic	None	Thermoplastic	Attached to an appliance	Damp places	Not hard usage
Jacketed tinsel cord	TS	27	2 or 3	Rubber	None	Rubber	Attached to an appliance	Damp places	Not hard usage
	TST	27	2 or 3	Thermoplastic	None	Thermoplastic	Attached to an appliance	Damp places	Not hard usage
Asbestos-covered, heat-resistant cord	AFC	18-10	2 or 3	Impregnated asbestos	Cotton or rayon	None	Pendant	Dry places	Not hard usage
	AFPO	18-10	2	Impregnated asbestos	Cotton or rayon	Cotton, rayon, or saturated asbestos	Pendant	Dry places	Not hard usage
	AFPD	18-10	2 or 3	Impregnated asbestos	None	Cotton, rayon, or saturated asbestos	Pendant	Dry places	Not hard usage
Cotton-covered, heat-resistant cord	CFC	18-10	2 or 3	Impregnated cotton	Cotton or rayon	None	Pendant	Dry places	Not hard usage
	CFPO	18-10	2	Impregnated cotton	Cotton or rayon	Cotton or rayon	Pendant	Dry places	Not hard usage
	CFPD	18-10	2 or 3	Impregnated cotton	None	Cotton or rayon	Pendant	Dry places	Not hard usage
Parallel cord	PO-1	18	2	Rubber	Cotton	Cotton or rayon	Pendant or portable	Dry places	Not hard usage
	PO-2	18-16	2	Rubber	Cotton	Cotton or rayon	Pendant or portable	Dry places	Not hard usage
	PO	18-10	2	Rubber	Cotton	Cotton or rayon	Pendant or portable	Dry places	Not hard usage
All-rubber parallel cord	SP-1	18	2	Rubber	None	Rubber	Pendant or portable	Damp places	Not hard usage
	SP-2	18-16	2	Rubber	None	Rubber	Pendant or portable	Damp places	Not hard usage
	SP-3	18-10	2	Rubber	None	Rubber	Refrigerators or room air conditioners	Damp places	Not hard usage

Table B-8. Flexible cords (continued)

Trade Name	Type Letter	AWG	No of Conductors	Insulation	Braid on Each Conductor	Outer Covering	Use		
All-plastic parallel cord	SPT-1	18	2	Thermoplastic	None	Thermoplastic	Pendant or portable	Damp places	Not hard usage
	SPT-2	18-16	2	Thermoplastic	None	Thermoplastic	Pendant or portable	Damp places	Not hard usage
	SPT-3	18-10	2	Thermoplastic	None	Thermoplastic	Refrigerators or room air conditioners	Damp places	Not hard usage
Lamp cord	C	18-10	2 or more	Rubber	Cotton	None	Pendant or portable	Dry places	Not hard usage
Twisted, portable cord	PD	18-10	2 or more	Rubber	Cotton	Cotton or rayon	Pendant or portable	Dry places	Not hard usage
Reinforced cord	P-1	18	2 or more	Rubber	Cotton	Cotton over rubber filler	Pendant or portable	Dry places	Not hard usage
	P-2	18-16	2 or more	Rubber	Cotton	Cotton over rubber filler	Pendant or portable	Dry places	Not hard usage
	P	18-10	2 or more	Rubber	Cotton	Cotton over rubber filler	Pendant or portable	Dry places	Hard usage
Braided, heavy-duty cord	K	18-10	2 or more	Rubber	Cotton	Two-cotton, moisture-resistant finish	Pendant or portable	Damp places	Hard usage
Vacuum-cleaner cord	SV, SVO	18	2	Rubber	None	Rubber	Pendant or portable	Damp places	Not hard usage
	SVT, SVTO	18	2	Thermoplastic	None	Thermoplastic	Pendant or portable	Damp places	Not hard usage
Junior hard-service cord	SJ	18-16	2, 3 or 4	Rubber	None	Rubber	Pendant or portable	Damp places	Hard usage
	SJO	18-16	2, 3 or 4	Rubber	None	Oil-resistant compound	Pendant or portable	Damp places	Hard usage
	SJT, SJTO	18-16	2, 3 or 4	Thermoplastic or rubber	None	Thermoplastic	Pendant or portable	Damp places	Hard usage
Hard-service cord	S	18-2	2 or more	Rubber	None	Rubber	Pendant or portable	Damp places	Extra hard usage
	SO	18-2	2 or more	Rubber	None	Oil-resistant compound	Pendant or portable	Damp places	Extra hard usage
	ST	18-2	2 or more	Thermoplastic or rubber	None	Thermoplastic	Pendant or portable	Damp places	Extra hard usage
	STO	18-2	2 or more	Thermoplastic or rubber	None	Oil-resistant thermoplastic	Pendant or portable	Damp places	Extra hard usage

Table B-8. Flexible cords (continued)

Trade Name	Type Letter	AWG	No of Conductors	Insulation	Braid on Each Conductor	Outer Covering	Use		
Rubber-jacketed, heat-resistant cord	AFSJ	18-16	2 or 3	Impregnated asbestos	None	Rubber	Portable	Damp places	Portable heaters
	AFS	18-16-14	2 or 3	Impregnated asbestos	None	Rubber	Portable	Damp places	Portable heaters
Heater cord	HC	18-12	2, 3, or 4	Rubber and asbestos	Cotton	None	Portable	Dry places	Portable heaters
	HPD	18-12	2, 3, or 4	Rubber with asbestos or all neoprene	None	Cotton or rayon	Portable	Dry places	Portable heaters
Rubber-jacketed heater cord	HSJ	18-16	2, 3, or 4	Rubber with asbestos or all neoprene	None	Cotton and rubber	Portable	Damp places	Portable heaters
Jacketed heater cord	HSJO	18-16	2, 3, or 4	Rubber with asbestos or all neoprene	None	Cotton and oil-resistant compound	Portable	Damp places	Portable heaters
	HS	14-12	2, 3, or 4	Rubber with asbestos or all neoprene	None	Cotton and rubber or neoprene	Portable	Damp places	Portable heaters
	HSO	14-12	2, 3, or 4	Rubber with asbestos or all neoprene	None	Cotton and oil-resistant compound	Portable	Damp places	Portable heaters
Parallel heater cord	HPN	18-16	2	Thermosetting	None	Thermosetting	Portable	Damp places	Portable heaters
Heat- and moisture-resistant cord	AVPO	18-10	2	Asbestos and varnished cambric	None	Asbestos, flame-retardant, moisture-resistant	Pendant or portable	Damp places	Not hard usage
	AVPD	18-10	2 or 3	Asbestos and varnished cambric	None	Asbestos, flame-retardant, moisture-resistant	Pendant or portable	Damp places	Not hard usage
Range, dryer cable	SRD	10-4	3 or 4	Rubber	None	Rubber or neoprene	Portable	Damp places	Ranges, dryers
	SRDT	10-4	3 or 4	Thermoplastic	None	Thermoplastic	Portable	Damp places	Ranges, dryers
Elevator cable	E	18-14	2 or more	Rubber	Cotton	Three cotton, outer one flame-retardant and moisture-resistant	Elevator lighting and control	Nonhazardous locations	
	EO	18-14	2 or more	Rubber	Cotton	One cotton and a neoprene jacket	Elevator lighting and control	Hazardous locations	
	ET	18-14	2 or more	Thermoplastic	Rayon	Three cotton, outer one flame-retardant and moisture-resistant	Elevator lighting and control	Nonhazardous locations	

Table B-9. Deep boxes

Box Dimensions, inches	Maximum Number of Conductors			
	No 14	No 12	No 10	No 8
1 1/2 x 3 1/4 octagonal	5	5	4	0
1 1/2 x 4 octagonal	8	7	6	5
1 1/2 x 4 square	11	9	7	5
1 1/2 x 4 11/16 square	16	12	10	8
2 1/8 x 4 11/16 square	20	16	12	10
1 3/4 x 2 3/4 x 2	5	4	4	4
1 3/4 x 2 3/4 x 2 1/2	6	6	5	0
1 3/4 x 2 3/4 x 3	7	7	6	0

Table B-10. Shallow boxes (less than 1 1/2 inches deep)

Box Dimensions, inches	Maximum Number of Conductors		
	No 14	No 12	No 10
3 1/4	4	4	3
4	6	6	4
1 1/4 4 square	9	7	6
4 11/16	8	6	6

Table B-11. Support for nonmetallic conduit runs

Size of Conduit, inches	Maximum Spacing Between Supports, feet
1/2	4
3/4	4
1	5
1 1/4	5
1 1/2	5
2	5
2 1/2	6
3	6
3 1/2	7
4	7
5	7
6	8

Table B-12. Full-load current, single-phase AC motors

HP	115 V	230 V	440 V
1/6	4.4	2.2	—
1/4	5.8	2.9	—
1/3	7.2	3.6	—
1/2	9.8	4.9	—
3/4	13.8	6.9	—
1	16	8	—
1 1/2	20	10	—
2	24	12	—
3	34	17	—
5	56	28	—
7 1/2	80	40	21
10	100	50	26

Table B-13. Full-load current, three-phase AC motors

HP	Induction-Type Squirrel-Cage and Wound Rotor Amperes					Synchronous-Type Unity Power Factor Amperes			
	110 V	220 V	440 V	550 V	2,300 V	220 V	440 V	550 V	2,300 V
1/2	4	2	1	0.8	—	—	—	—	—
3/4	5.6	2.8	1.4	1.1	—	—	—	—	—
1	7	3.5	1.8	1.4	—	—	—	—	—
1 1/2	10	5	2.5	2.0	—	—	—	—	—
2	13	6.5	3.3	2.6	—	—	—	—	—
3	—	9	4.5	4	—	—	—	—	—
5	—	15	7.5	6	—	—	—	—	—
7 1/2	—	22	11	9	—	—	—	—	—
10	—	27	14	11	—	—	—	—	—
15	—	40	20	16	—	—	—	—	—
20	—	52	26	21	—	—	—	—	—
25	—	64	32	26	7	54	27	22	5.4
30	—	78	39	31	8.5	65	33	26	6.5
40	—	104	52	41	10.5	86	43	35	8
50	—	125	63	50	13	108	54	44	10
60	—	150	75	60	16	128	64	51	12
75	—	185	93	74	19	161	81	65	15
100	—	246	123	98	25	211	106	85	20
125	—	310	155	124	31	264	132	106	25
150	—	360	180	144	37	—	158	127	30
200	—	480	240	192	48	—	210	168	40

Table B-14. Standard loads for branch circuits and feeders and demand factors for feeders

Occupancy	Standard Loads, Watts per square foot	Feeder-Demand Factor
Armories and auditoriums	1	100%
Banks	2	100%
Barber shops	3	100%
Churches	1	100%
Clubs	2	100%
Dwellings	3	100% for first 3,000 watts, 35% for next 117,000, 25% for excess above 120,000
Garages	0.5	100%
Hospitals	2	40% for first 50,000 watts, 20% for excess over 50,000
Office buildings	5	100% for first 20,000 watts, 70% for excess over 20,000
Restaurants	2	100%
Schools	3	100% for first 15,000 watts, 50% for excess over 15,000
Stores	3	100%
Warehouses	0.25	100% for first 12,500 watts, 50% for excess over 12,500
Assembly halls	1	100%

Table B-15. Requirements for branch circuits

Type FEP, FEPB, R, RW, RU, RUW, RH-RW, SA, T, TW, RH, RUH, RHW, RHH, THHN, THW, and THWN Conductors in Raceway or Cable					
Circuit Rating	15 amp	20 amp	30 amp	40 amp	50 amp
Conductors (min size): Circuit wires* Taps	 14 14	 12 14	 10 14	 8 12	 6 12
Overcurrent protection	15 amp	20 amp	30 amp	40 amp	50 amp
Outlet devices: Lamp holders permitted Receptacle rating	 Any type 15 max amp	 Any type 15 or 20 amp	 Heavy duty 30 amp	 Heavy duty 40 and 50 amp	 Heavy duty 50 amp
Maximum load	15 amp	20 amp	30 amp	40 amp	50 amp
*These current capacities are for copper conductors with no correction factor for temperature (see Tables B-3 through B-7, pages B-5 through B-9).					

Table B-16. Voltage drop table (based on 3% drop)

Verify Selected Conductor for Current-Carrying Capacity (Tables B-2 through B-7, pages B-2 through B-9)*

For 110 V Circuit Distance to Load, in feet

Load in Amps	50	75	100	125	150	200	250	300	400	500
15	10 12	8 10	8 10	6 8	6 8	4 6	4 6	3 4	2 4	1 3
20	10 12	8 10	6 8	6 8	4 6	4 6	3 4	2 4	1 3	1/0 2
25	8 10	6 8	6 8	4 6	4 6	3 4	2 4	1 3	1/0 2	2/0 1
30	6 10	6 8	4 6	4 6	3 4	2 4	1 3	1/0 2	2/0 1	3/0 1/0
40	6 8	4 6	4 6	3 4	2 4	1 3	1/0 2	2/0 1	3/0 1/0	4/0 2/0
50	4 8	4 6	3 4	2 4	1 3	1/0 2	2/0 1	3/0 1/0	4/0 2/0	300 3/0
60	4 6	2 4	2 4	1 3	1/0 2	2/0 1	3/0 1/0	4/0 2/0	250 3/0	350 4/0
70	4 6	2 4	1 3	1/0 2	2/0 2	3/0 1/0	4/0 2/0	250 2/0	300 4/0	400 250
80	4 6	2 4	1 3	1/0 2	2/0 1	3/0 1/0	4/0 2/0	250 3/0	350 4/0	500 250
90	2 4	1 3	1/0 2	2/0 1	3/0 1	4/0 2/0	250 3/0	300 3/0	400 250	500 300
100	2 4	1 3	1/0 2	2/0 1	3/0 1/0	4/0 2/0	300 3/0	350 4/0	500 250	600 350

For 120 V Circuit Distance to Load, in feet

Load in Amps	100	200	300	400	500	600	700	800	900	1,000
15	12 12	8 10	6 8	4 6	4 6	3 4	2 4	2 4	1 3	1 3
20	10 12	6 8	4 6	4 6	3 4	2 4	1 3	1 3	1/0 2	1/0 2
25	8 10	6 8	4 6	3 4	2 4	1 3	1/0 2	1/0 2	2/0 1	2/0 1
30	6 10	4 6	3 4	2 4	1 3	1/0 2	2/0 2	2/0 1	3/0 1/0	3/0 1/0
40	4 8	4 6	2 4	1 3	1/0 2	2/0 1	3/0 1/0	3/0 1/0	4/0 2/0	4/0 2/0
50	4 8	3 4	1 3	1/0 2	2/0 1	3/0 1/0	4/0 2/0	4/0 2/0	250 3/0	300 3/0
60	4 6	2 4	1/0 2	2/0 1	3/0 1/0	4/0 2/0	250 2/0	250 3/0	300 4/0	350 4/0
70	4 6	1 3	2/0 2	3/0 1/0	4/0 2/0	250 2/0	300 3/0	300 4/0	350 4/0	400 250
80	4 6	1 3	2/0 1	3/0 1/0	4/0 2/0	250 3/0	300 4/0	350 4/0	400 250	500 250
90	2 4	1/0 2	3/0 1/0	4/0 2/0	250 3/0	300 4/0	350 4/0	400 250	500 300	500 300
100	2 4	1/0 2	3/0 1/0	4/0 2/0	300 3/0	350 4/0	400 250	500 250	500 300	600 350

*Example: A building using open wiring required 20 amperes (at 110 V) to be supplied to a load located 150 feet from the circuit breaker. From Tables B-2 and B-7 (assuming R-type copper wire is used), the minimum size wire for this circuit is No 14. From the above table, a No 6 copper wire is required to limit the voltage drop to 3%. Therefore, a No 6 copper wire should be used. If the wire available were aluminum, then the minimum size is No 12, and for a maximum voltage drop of 3%, a No 4 must be used.

Table B-17. Support for rigid metal conduit runs

Size of Conduit, inches	Maximum Distance Between Rigid Metal Conduit Supports, feet
1/2	10
3/4	10
1	12
1 1/4	14
1 1/2	14
2	16
2 1/2	16
3	20

Table B-18. Radius of conduit bends

Size of Conduit, inches	Conductors Without Load Sheath, inches	Conductors With Load Sheath, inches
1/2	4	6
3/4	5	8
1	6	11
1 1/4	8	14
1 1/2	10	16
2	12	21
2 1/2	15	25
3	18	31
3 1/2	21	36
4	24	40
5	30	50
6	36	61

Table B-19. Minimum size (inches) of conduit of electrical metallic tubing to contain a given number of 800-volt conductors

AWG	Number of Conductors (Types R, RW, RH, RU, RUW, TF, T, and TW)								
	1	2	3	4	5	6	7	8	9
18	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4
16	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4	3/4
14	1/2	1/2	1/2	1/2	3/4	3/4	1	1	1
12	1/2	1/2	1/2	3/4	3/4	1	1	1	1 1/4
10	1/2	3/4	3/4	3/4	1	1	1	1 1/4	1 1/4
8	1/2	3/4	3/4	1	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2
6	1/2	1	1	1 1/4	1 1/2	1 1/2	2	2	2
4	1/2	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2	2 1/2
3	3/4	1 1/4	1 1/4	1 1/2	2	2	2	2 1/2	2 1/2
2	3/4	1 1/4	1 1/4	2	2	2	2 1/2	2 1/2	2 1/2
1	3/4	1 1/2	1 1/2	2	2 1/2	2 1/2	2 1/2	3	3
1/0	1	1 1/2	2	2	2 1/2	2 1/2	3	3	3
2/0	1	2	2	2 1/2	2 1/2	3	3	3	3 1/2
3/0	1	2	2	2 1/2	3	3	3	3 1/2	3 1/2
4/0	1 1/4	2	2 1/2	3	3	3	3 1/2	3 1/2	4

Table B-20. Size conduit of electrical metallic tubing for combinations of conductors (percentage of cross-sectional area of conduit or tubing)

Conductors	Number of Conductors				
	1	2	3	4	4+
Not lead covered	53	31	40	40	40
Lead covered	55	30	40	38	35
For rewiring existing conduits	60	40	40	50	50

Table B-21. Dimensions and percent of area of conduit and tubing for combinations

Size of Conduit, inches	Internal Diameter, inches	Area, square inches									
		Total 100%	Not Lead Covered				Lead Covered				
			1 Cond 53%	2 Cond 51%	3 Cond 43%	4+ Cond 40%	1 Cond 55%	2 Cond 30%	3 Cond 40%	4 Cond 38%	4+ Cond 35%
1/2	0.622	0.30	0.16	0.09	0.13	0.12	0.17	0.09	0.12	0.11	0.11
3/4	0.824	0.53	0.28	0.16	0.23	0.21	0.29	0.16	0.21	0.20	0.19
1	1.049	0.86	0.46	0.27	0.37	0.34	0.47	0.26	0.34	0.33	0.30
1 1/4	1.380	1.50	0.80	0.47	0.65	0.60	0.83	0.65	0.60	0.57	0.53
1 1/2	1.610	2.04	1.08	0.63	0.88	0.82	1.11	0.61	0.82	0.78	0.71
2	2.067	3.36	1.78	1.04	1.44	1.34	1.85	1.01	1.34	1.28	1.18
2 1/2	2.469	4.79	2.54	1.48	2.06	1.92	2.63	1.44	1.92	1.82	1.68
3	3.068	7.38	3.91	2.29	3.17	2.95	4.06	2.21	2.95	2.80	2.58
3 1/2	3.548	9.90	5.25	3.07	4.26	3.96	5.44	2.97	3.96	3.76	3.47

Table B-22. Dimensions of rubber-covered and thermoplastic-covered conductors

AWG	Types R, RH, RW		Types T, TW, TF, RU	
	Approximate Diameter, inches	Approximate Area, square inches	Approximate Diameter, inches	Approximate Area, square inches
18	0.146	0.0167	0.100	0.0088
16	0.158	0.0196	0.118	0.0109
14	0.171	0.0230	0.131	0.0135
12	0.188	0.0278	0.148	0.0172
10	0.242	0.0460	0.168	0.0224
8	0.311	0.0760	0.228	0.0471
6	0.397	0.1238	0.323	0.0819
4	0.452	0.1605	0.372	0.1087
3	0.481	0.1817	0.401	0.1263
2	0.513	0.2067	0.433	0.1473
1	0.508	0.2715	0.508	0.2027
1/0	0.629	0.3107	0.549	0.2367
2/0	0.675	0.3578	0.505	0.2781
3/0	0.727	0.4151	0.647	0.3288
4/0	0.785	0.4810	0.705	0.3904

Table B-23. Characteristics of wire

Size AWG or MCM	No Wires	Diameter		Resistance, ohms per 1,000 feet	
		Inches	Millimeters	Copper	Aluminum
14	Solid	0.0641	1.63	2.57	4.22
12	Solid	0.0808	2.05	1.62	2.66
10	Solid	0.102	2.59	1.02	1.67
8	Solid	0.129	3.27	0.640	1.05
6	7	0.184	4.67	0.410	0.674
4	7	0.232	5.89	0.260	0.424
3	7	0.260	6.60	0.205	0.336
2	7	0.292	7.41	0.162	0.266
1	19	0.332	8.42	0.129	0.211
1/0	19	0.373	9.46	0.102	0.168
2/0	19	0.418	10.6	0.0811	0.133
3/0	19	0.470	11.9	0.0642	0.105
4/0	19	0.528	13.3	0.0509	0.0836
250	37	0.575	14.6	0.0431	0.0780
300	37	0.630	16.0	0.0360	0.0590
350	37	0.681	17.3	0.0308	0.0505
400	37	0.728	18.5	0.0270	0.0442
500	37	0.814	20.6	0.0216	0.0354
600	61	0.893	22.7	0.0180	0.0295
700	61	0.964	24.5	0.0154	0.0253
150	61	0.998	25.4	0.0144	0.0236

APPENDIX C

Metric Conversion Chart

Table C-1. Metric conversion chart

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square feet	0.0929	centares
square inches	6.452	square centimeters
°F	0.5556	°C
gallons	3.785	liters
pounds	0.4536	kilograms

Glossary

A	ampere(s)
AC	alternating current
AFM	Air Force manual
amp	ampere(s)
ARNG	Army National Guard
ASTM	American Society for Testing Materials
ATTN	attention
AWG	American Wire Gauge
C	Celsius
CB	circuit breaker
commo	communications
cond	conduit
cont	contract
CPR	cardiopulmonary resuscitation
DA	Department of the Army
DC	direct current
DOD	Department of Defense
DPW	Department of Public Works
EM	engineer manual
EMF	alternating electromotive force
EMT	electrical metallic tubing
est	estimate
F	Fahrenheit
FM	field manual
FSN	federal stock number
ft	foot, feet
FTX	field training exercise
gen	generator
GFCI	ground-fault circuit interrupter
hgt	height
HP	horsepower
HQ	headquarters
in	inch(es)
insp	inspection
IPCEA	Insulated Power Cable Engineer Association
inc	incorporated
kVA	kilovolt-amperes
kW	kilowatt(s)
lb	pound(s)
lg	length

max maximum

MCM 1,000 circular mils

mfd manufactured

min minimum

mtd mounted

NA not applicable

NAV Navy

NAVFAC Navy Facilities Engineering Command

NC national coarse

NEC National Electrical Code

No number

PMCS preventive maintenance checks and services

PVC polyvinyl chloride

qty quantity

recp receptacle

reg registration

rpm revolutions per minute

rqr requirement

ser serial

TAMMS The Army Maintenance Management System

TM technical manual

TM Marine Corps technical manual

TO theater of operations

TO Air Force technical order

TO technical order

US United States

USAES United States Army Engineer School

USAR United States Army Reserves

V volts

var-cam varnished-cambric

W watt(s)

w width

wt weight

° degrees

∆ delta

Y wye

number

' foot, feet

" inch(es)

% percent

References

SOURCES USED

These are the sources quoted or paraphrased in this publication.

JOINT AND MULTISERVICE PUBLICATIONS

TM 5-704. *Construction Print Reading in the Field* {AFM 85-27}. 2 January 1969.

TM 5-6115-271-14. *Operator's, Organizational, Direct Support and General Support Maintenance Manual for Generator Set, Gasoline Engine Driven, Skid Mtd, Tubular Frame. . .* {TO 35C2-3-386-1; TM 05926A-14; NAVFAC P-8-613-14}. 3 August 1976.

TM 5-6115-275-14. *Operator's, Organizational, Intermediate (Field) (Direct Support and General Support) and Depot Maintenance Manual: Generator Set, Gasoline-Engine Driven, Skid Mounted, Tubular Frame. . .* {TO 35C2-3-452-1; NAVFAC P-8-615-14}. 16 June 1977.

TM 5-6115-323-14. *Operator/Crew, Organizational, Intermediate (Field) (Direct Support and General Support) and Depot Maintenance Manual for Generator Set, Gasoline Engine Driven, Skid Mounted, Tubular Frame. . .* {TO 35C2-3-385-1}. 23 July 1976.

TM 5-6115-329-14. *Operator, Organizational, Intermediate (Field) (Direct Support and General Support) and Depot Maintenance Manual for Generator Sets, Gasoline Engine Driven. . .* {TO 35C2-3-440-1}. 11 October 1977.

TM 5-6115-332-14. *Operator, Organizational, Intermediate (Field), Direct Support, General Support, and Depot Level Maintenance Manual: Generator Set, Tactical, Gasoline Engine: Air Cooled. . .* {NAVFAC P-8-614-14; TO 35C2-3-424-1}. 9 December 1977.

TM 5-6115-457-12. *Operator and Organizational Maintenance Manual: Generator Set, Diesel Engine Driven, Tactical, Skid Mtd. . .* {TO 35C2-3-442-1; NAVFAC P-8-627-12; TM-07464A-12}. 15 June 1973.

TM 5-6115-458-12. *Operator/Crew and Organizational Maintenance Manual Generator Set, Diesel Engine Driven, Tactical, Skid Mtd. . .* {TO 35C2-3-443-1; NAVFAC P-8-629-12; TM-07536A-12}. 15 January 1974.

TM 5-6115-465-12. *Operator's and Organizational Maintenance Manual for Generator Set, Diesel Engine Driven, Tactical Skid Mtd. . .* {NAVFAC P-8-625-12; TO 35C2-3-446-1; TM-06858B/06859D-12}. 31 January 1975.

TM 5-6115-545-12. *Operator's and Organizational Maintenance Manual for Generator Set, Diesel Engine Driven, Tactical Skid Mtd. . .* {TO 35C2-3-444-1; NAVFAC P-8-626-12; TM 00038G-12}. 10 June 1973.

TM 5-6115-584-12. *Operator and Organizational Maintenance Manual for Generator Set, Diesel Engine Driven, Tactical Skid Mtd. . .* {NAVFAC P-8-622-12; TO 35C2-3-456-1; TM 05682C-12}. 22 July 1977.

TM 5-6115-585-12. *Operator and Organizational Maintenance Manual for Generator Set, Diesel Engine Driven, Tactical Skid Mtd. . .* {NAVFAC P-8-623-12; TO 35C2-3-455-1; TM-05684C/05685B-12}. 25 July 1977.

TM 5-6115-593-12. *Operator and Organizational Maintenance Manual for Generator Set, Diesel Engine Driven, Tactical Skid Mtd. . .* {TO 35C2-3-463-1}. 17 July 1990.

TM 5-6115-603-12. *Operator's and Organizational Maintenance Manual for Generator Set, Gas Turbine Engine Driven, Transportable, Skid Mtd. . .* {TO 35C2-3-466-1; NAFACP 8-644-12; TM 6115-12/B}. 15 December 1982.

TM 9-243. *Use and Care of Hand Tools and Measuring Tools* {M6290-AJ-MAN-010; TO 32-1-101; TM-10209-10/1}. 12 December 1983.

ARMY PUBLICATIONS

DA Pam 738-750. *Functional Users Manual for the Army Maintenance Management System (TAMMS).* 1 August 1994.

EM 385-1-1. *US Army Corps of Engineers Safety and Health Requirements Manual*. 1 October 1992.

FM 5-422. *Engineer Prime Power Operations*. 7 May 1993.

FM 21-11. *First Aid for Soldiers*. 27 October 1988.

TM 5-301-1. *Army Facilities Components System -- Planning (Temperate)*. 27 June 1986.

TM 5-301-2. *Army Facilities Components System -- Planning (Tropical)*. 27 June 1986.

TM 5-301-3. *Army Facilities Components System -- Planning (Frigid)*. 27 June 1986.

TM 5-301-4. *Army Facilities Components System -- Planning (Desert)*. 27 June 1986.

TM 5-302-1. *Army Facilities Components System: Design*. 28 September 1973.

TM 5-302-2. *Army Facilities Components System: Design*. 28 September 1973.

TM 5-302-3. *Army Facilities Components System: Design*. 28 September 1973.

TM 5-302-4. *Army Facilities Components System: Design*. 28 September 1973.

TM 5-302-5. *Army Facilities Components System: Design*. 28 September 1973.

TM 5-303. *Army Facilities Components System - Logistic Data and Bills of Materiel*. 1 June 1986.

TM 5-682. *Facilities Engineering: Electrical Facilities Safety*. 1 June 1983.

TM 9-6140-200-14. *Operator's, Unit, Direct Support and General Support Maintenance Manual for Lead-Acid Storage Batteries*. 13 July 1989.

OTHER SOURCES

Sunset Basic Home Wiring, Lane Publishing Company, Menlo Park, California, 1987.

DOCUMENTS NEEDED

These documents must be available to the intended users of this publication.

DA Form 2028. *Recommended Changes to Publications and Blank Forms*. 1 February 1974.

DA Form 2404. *Equipment Inspection and Maintenance Worksheet*. 1 April 1979.

READINGS RECOMMENDED

These readings contain relevant supplemental information.

Summers, Wilford I., *American Electricians' Handbook*. McGraw-Hill, Inc. 1987.

FM 5-424
25 June 1997

By Order of the Secretary of the Army:

DENNIS J. REIMER
General, United States Army
Chief of Staff

Official:

JOEL B. HUDSON
Administrative Assistant to the
Secretary of the Army
03557

DISTRIBUTION:

Active Army, Army National Guard, and U. S. Army Reserve: To be distributed in accordance with initial distribution number 115486, requirements for FM 5-424.

PIN: 075463-000