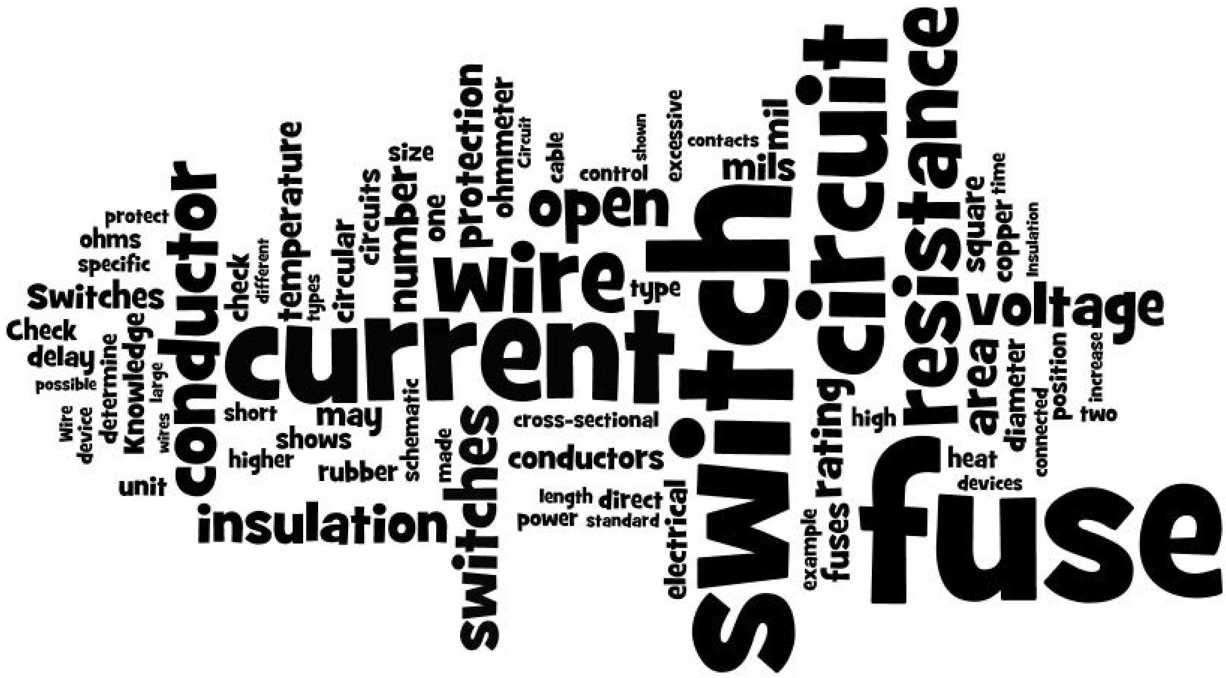
10 Conductors and Circuit Control



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Electrical Conductors

In the previous modules, you have learned about various circuit components. These components provide the majority of the operating characteristics of any electrical circuit. They are useless, however, if they are not connected together. Conductors are the means used to tie these components together.

Many factors determine the type of electrical conductor used to connect components. Some of these factors are the physical size of the conductor, its composition, and its electrical characteristics. Other factors that can determine the choice of a conductor are the weight, the cost, and the environment where the conductor will be used.

Conductor Sizes

To compare the resistance and size of one conductor with that of another, we need to establish a standard or unit size. A convenient unit of measurement of the diameter of a conductor is the **mil** (0.001, or one-thousandth of an inch). A convenient unit of conductor length is the foot. The standard unit of size in most cases is the **mil-foot**. A wire will have a unit size if it has a diameter of 1 mil and a length of 1 foot.

Square Mil

The **square mil** is a unit of measurement used to determine the cross-sectional area of a square or rectangular conductor (views A and B of Figure 1). A square mil is defined as the area of a square, the sides of which are each 1 mil. To obtain the cross-sectional area of a square conductor, multiply the dimension of any side of the square by itself. For example, assume that you have a square conductor with a side dimension of 3 mils. Multiply 3 mils by itself (3 mils x 3 mils). This gives you a cross-sectional area of 9 square mils.

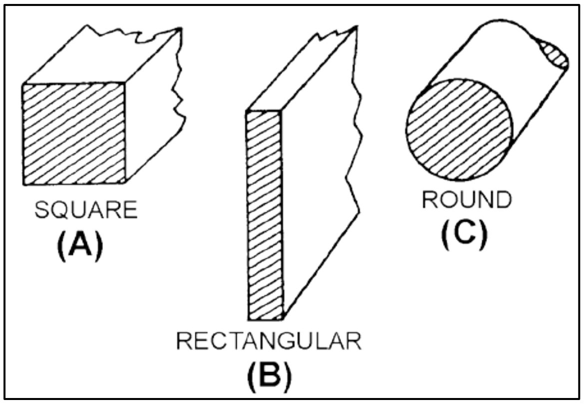


Figure 1: Cross-sectional areas of conductors.

Knowledge Check

1. State the reason for the establishment of a "unit size" for conductors.
2. Calculate the diameter in MILS of a conductor that has a diameter of 0.375 inch.
3. Define a mil-foot.

Circular Mil

The circular mil is the standard unit of measurement of a round wire cross-sectional area (view C of Figure 1). This unit of measurement is found in American and English wire tables. The diameter of a round conductor (wire) used to conduct electricity may be only a fraction of an inch. Therefore, it is convenient to express this diameter in mils to avoid using decimals. For example, the diameter of a wire is expressed as 25 mils instead of 0.025 inch. A circular mil is the area of a circle having a diameter of 1 mil, as shown in view B of Figure 2. The area in circular mils of a round conductor is obtained by squaring the diameter, measured in mils. Thus, a wire having a diameter of 25 mils has an area of 25^2, or 625 circular mils. To determine the number of square mils in the same conductor, apply the conventional formula for determining the area of a circle ($A = \pi r^2$). In this formula, A (area) is the unknown and is equal to the cross-sectional area in square mils, π is the constant 3.14, and r is the radius of the circle, or half the diameter (D). Through substitution, A = 3.14, and $(12.5)^2$; therefore, $3.14 \times 156.25 = 490.625$

square mils. The cross-sectional area of the wire has 625 circular mils but only 490.625 square mils. Therefore, a circular mil represents a smaller unit of area than the square mil.

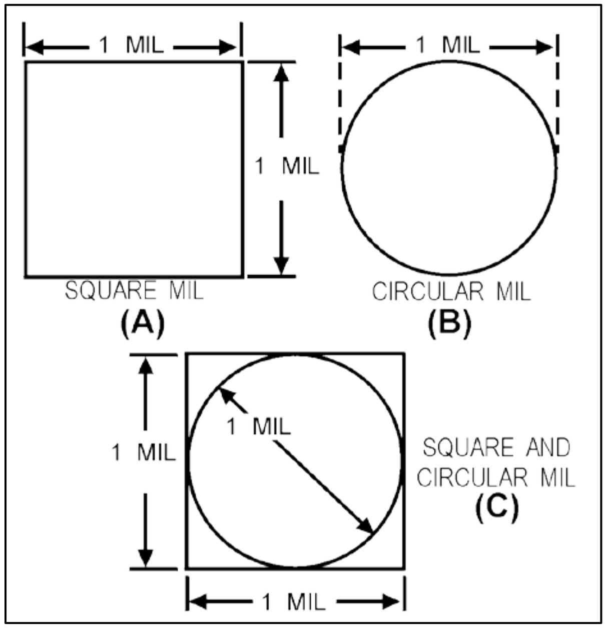


Figure 2: A comparison of circular and square mils.

If a wire has a cross-sectional diameter of 1 mil, by definition, the circular mil area (CMA) is $A = D^2$, or $A = 1^2$, or A = 1 circular mil. To determine the square mil area of the same wire, apply the formula $A = \pi r^2$; therefore, $A = 3.14 \times (0.5)^2$ (0.5 representing half the diameter). When $A = 3.14 \times 0.25$, A = 0.7854 square mil. From this, it can be concluded that 1 circular mil is equal to 0.7854 square mil. This becomes important when square (view A of Figure 2) and round (view B) conductors are compared as in view C of Figure 2.

When the square mil area is given, divide the area by 0.7854 to determine the circular mil area, or CMA. When the CMA is given, multiply the area by 0.7854 to determine the square mil area.

Problem: A 12-gauge wire has a diameter of 80.81 mils. What is (1) its area in circular mils and (2) its area in square mils?

Solution:

(1) $A = D^2 = 80.81^2 = 6{,}530$ circular mils
(2) $A = 0.7854 \times 6{,}530 = 5{,}128.7$ square mils

Problem: A rectangular conductor is 1.5 inches wide and 0.25 inch thick. What is (1) its area in square mils and (2) in circular mils? What size of round conductor is necessary to carry the same current as the rectangular bar?

Solution:

(1) 1.5 inches = 1.5 inches × 1,000 mils per inch = 1,500 mils

0.25 inch = 0.25 inch × 1,000 mils per inch = 250 mils

$A = 1{,}500 \times 250 = 375{,}000$ square mils

(2) To carry the same current, the cross-sectional area of the round conductor must be equal. There are more circular mils than square mils in this area. Therefore:

$$A = \frac{375{,}000}{0.7854} = 477{,}000 \text{ circular mils}$$

A wire in its usual form is a single slender rod or filament of drawn metal. In large sizes, wire becomes difficult to handle. To increase its flexibility, it is stranded. **Strands** are usually single wires twisted together in sufficient numbers to make up the necessary cross-sectional area of the cable. The total area of stranded wire in circular mils is determined by multiplying the area in circular mils of one strand by the number of strands in the cable.

Knowledge Check

1. Define a circular mil.
2. What is the circular mil area of a 19-strand conductor if each strand is 0.004 inch?

Circular-Mil-Foot

A **circular-mil-foot** (Figure 3) is a unit of volume. It is a unit conductor 1 foot in length and has a cross-sectional area of 1 circular mil. Because it is a unit conductor, the circular-mil-foot is useful in making comparisons between wires consisting of different metals. For example, a basis of comparison of the resistivity (to be discussed shortly) of various substances may be made by determining the resistance of a circular-mil-foot of each of the substances.

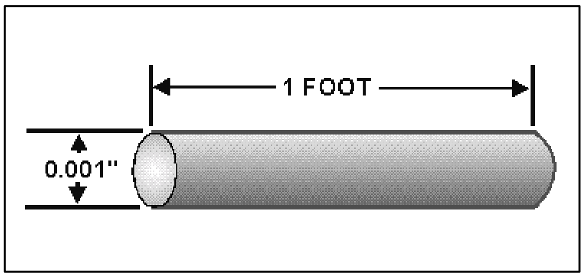


Figure 3: Circular-mil-foot.

In working with square or rectangular conductors, such as ammeter shunts and bus bars, you may sometimes find it more convenient to use a different unit volume. A bus bar is a heavy copper strap or bar used to connect several circuits together. Bus bars are used when a large current capacity is required. Unit volume may be measured as the centimeter cube. **Specific resistance**, therefore, becomes the resistance offered by a cube-shaped conductor 1centimeter in length and 1 square centimeter in cross-sectional area. The unit of volume to be used is given in tables of specific resistances.

Specific Resistance or Resistivity

Specific resistance, or resistivity, is the resistance in ohms offered by a unit volume (the circular-mil- foot or the centimeter cube) of a substance to the flow of electric current. Resistivity is the reciprocal of conductivity. A substance that has a high resistivity will have a low conductivity, and vice versa. Thus, the specific resistance of a substance is the resistance of a unit volume of that substance.

Many tables of specific resistance are based on the resistance in ohms of a volume of a substance 1 foot in length and 1 circular mil in cross-sectional area. The temperature at which the resistance measurement is made is also specified. If you know the kind of metal a conductor is made of, you can obtain the specific resistance of the metal from a table. The specific resistances of some common substances are given in Table 1.

Table 1: Specific Resistances of Common Substances

Substance	Specific resistance at 20° C.	
	Centimeter Cube (cm^3) (microhoms)	Circular-mil-foot (ohms)
Silver	1.629	9.8
Copper (drawn)	1.724	10.37
Gold	2.44	14.7
Aluminum	2.828	17.02
Carbon (amorphous)	3.8 to 4.1	
Tungsten	5.51	33.2
Brass	7.0	42.1
Steel (soft)	15.9	95.8
Nichrome	109.0	660.0

The resistance of a conductor of a uniform cross section varies directly as the product of the length and the specific resistance of the conductor, and inversely as the cross-sectional area of the conductor. Therefore, you can calculate the resistance of a conductor if you know the length, cross-sectional area, and specific resistance of the substance. Expressed as an equation, the "R" (resistance in ohms) of a conductor is:

$$R = \rho \frac{L}{A}$$

Where:

ρ = (Greek rho) the specific resistance in ohms per circular-mil-foot (refer to table 1-1)

L = length in feet

A = the cross-sectional area in circular mils

Problem: What is the resistance of 1,000 feet of copper wire having a cross-sectional area of 10,400 circular mils (No. 10 wire) at a temperature of 20° C?

Solution: The specific resistance of copper (Table 1) is 10.37 ohms. Substituting the known values in the preceding equation, the resistance, R, is determined as:

Given: $\rho = 10.37$ ohms

$L = 1{,}000$ ft

$A = 10{,}400$ circular mils

Solution:

$$R = \rho \frac{L}{A} = 10.37 \times \frac{1{,}000}{10{,}400}$$

$$= 1 \text{ ohm (approximately)}$$

If R, ρ, and A are known, the length (L) can be determined by a simple mathematical transposition. This has many valuable applications. For example, when locating a ground in a telephone line, you will use special test equipment. This equipment operates on the principle that the resistance of a line varies directly with its length. Thus, the distance between the test point and a fault can be computed accurately.

Knowledge Check

1. Define specific resistance.
2. List the three factors used to calculate resistance of a particular conductor in ohms.

Wire Sizes

Wire is manufactured in sizes numbered according to the **AWG** (American Wire Gauge) tables. The various wires (solid or stranded) and the material they are made from (copper, aluminum, and so forth) are published by the National Bureau of Standards. An AWG table for copper wire is shown in table 1-2. The wire diameters become smaller as the gauge numbers become larger. Numbers are rounded off for convenience but are accurate for practical application. The largest wire size shown in the table is 0000 (read "4 naught"), and the smallest is number 40. Larger and smaller sizes are manufactured, but are not commonly used. AWG tables show the diameter in mils, circular mil area, and area in square inches of AWG wire sizes. They also show the resistance (ohms) per thousand feet and per mile of wire sizes at specific temperatures. The last column shows the weight of the wire per thousand feet. An example of the use of table 1-2 is as follows.

Problem: You are required to run 2,000 feet of AWG 20 solid copper wire for a new piece of equipment. The temperature where the wire is to be run is 25° C (77° F). How much resistance will the wire offer to current flow?

Solution: Under the gauge number column, find size AWG 20. Now read across the columns until you reach the "ohms per 1,000 feet for 25° C (77° F)" column. You will find that the wire will offer 10.4 ohms of resistance to current flow. Since we are using 2,000 feet of wire, multiply by 2.

$$10.4\ \text{ohms} \times 2 = 20.8\ \text{ohms}$$

Table 1-2.—Standard Solid Copper (American Wire Gauge)

Gage number	Diameter (mils)	Cross Section		Ohms per 1,000 ft		Ohms per mile	Pounds per 1,000 ft.
		Circular mils	Square inches	25°C.= 77°F.	65°C. = 149°F.	25°C. = 77°F.	
0	460	212,000.00	0.166	0.05	0.0577	0.264	641
0	410	168,000.00	0.132	0.063	0.0727	0.333	508
0	365	133,000.00	0.105	0.0795	0.0917	0.42	403
0	325	106,000.00	0.0829	0.1	0.116	0.528	319
1	289	83,700.00	0.0657	0.126	0.146	0.665	253
2	258	66,400.00	0.0521	0.159	0.184	0.839	201
3	229	52,600.00	0.0413	0.201	0.232	1.061	159
4	204	41,700.00	0.0328	0.253	0.292	1.335	126
5	182	33,100.00	0.026	0.319	0.369	1.685	100
6	162	26,300.00	0.0206	0.403	0.465	2.13	79.5
7	144	20,800.00	0.0164	0.508	0.586	2.68	63
8	128	16,500.00	0.013	0.641	0.739	3.38	50
9	114	13,100.00	0.0103	0.808	0.932	4.27	39.6
10	102	10,400.00	0.00815	1.02	1.18	5.38	31.4
11	91	8,230.00	0.00647	1.28	1.48	6.75	24.9
12	81	6,530.00	0.00513	1.62	1.87	8.55	19.8
13	72	5,180.00	0.00407	2.04	2.36	10.77	15.7
14	64	4,110.00	0.00323	2.58	2.97	13.62	12.4
15	57	3,260.00	0.00256	3.25	3.75	17.16	9.86
16	51	2,580.00	0.00203	4.09	4.73	21.6	7.82
17	45	2,050.00	0.00161	5.16	5.96	27.2	6.2
18	40	1,620.00	0.00128	6.51	7.51	34.4	4.92
19	36	1,290.00	0.00101	8.21	9.48	43.3	3.9
20	32	1,020.00	0.000802	10.4	11.9	54.9	3.09
21	28.5	810	0.000636	13.1	15.1	69.1	2.45
22	25.3	642	0.000505	16.5	19	87.1	1.94
23	22.6	509	0.0004	20.8	24	109.8	1.54
24	20.1	404	0.000317	26.2	30.2	138.3	1.22
25	17.9	320	0.000252	33	38.1	174.1	0.97
26	15.9	254	0.0002	41.6	48	220	0.769
27	14.2	202	0.000158	52.5	60.6	277	0.61
28	12.6	160	0.000126	66.2	76.4	350	0.484
29	11.3	127	0.0000995	83.4	96	440	0.384
30	10	101	0.0000789	105	121	554	0.304
31	8.9	79.7	0.0000626	133	153	702	0.241
32	8	63.2	0.0000496	167	193	882	0.191
33	7.1	50.1	0.0000394	211	243	1,114.00	0.152
34	6.3	39.8	0.0000312	266	307	1,404.00	0.12
35	5.6	31.5	0.0000248	335	387	1,769.00	0.0954
36	5	25	0.0000196	423	488	2,230.00	0.0757
37	4.5	19.8	0.0000156	533	616	2,810.00	0.06
38	4	15.7	0.0000123	673	776	3,550.00	0.0476
39	3.5	12.5	0.0000098	848	979	4,480.00	0.0377
40	3.1	9.9	0.0000078	1,070.00	1,230.00	5,650.00	0.0299

An American Standard Wire Gauge (Figure 4) is used to measure wires ranging in size from number 0 to number 36. To use this gauge, insert the wire to be measured into the smallest slot that will just accommodate the bare wire. The gauge number on that slot indicates the wire size. The front part of the slot has parallel sides, and this is where the wire measurement is taken. It should not be confused with the larger semicircular opening at the rear of the slot. The rear opening simply permits the free movement of the wire all the way through the slot.

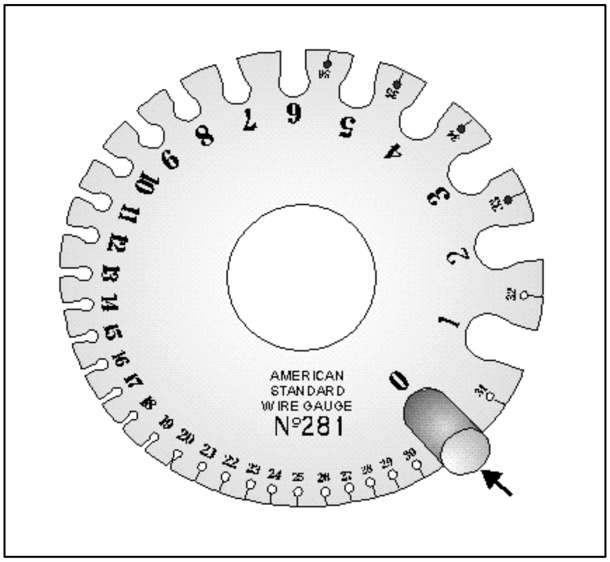


Figure 4: Wire guage.

Knowledge Check

1. Using Table 1, determine the resistance of 1,500 feet of AWG 20 wire at 25º C.
2. When using an American Standard Wire Gauge to determine the size of a wire, where should you place the wire in the gauge to get the correct measurement?

Stranded Wire and Cables

A **wire** is a single slender rod or filament of drawn metal. This definition restricts the term to what would ordinarily be understood as "solid wire." The word "slender" is used because the length of a wire is usually large when compared to its diameter. If a wire is covered with insulation, it is an insulated wire. Although the term "wire" properly refers to the metal, it also includes the insulation. A **conductor** is a wire suitable for carrying an electric current. A **stranded conductor** is a conductor composed of a group of wires or of any combination of groups of wires. The wires in a stranded conductor are usually twisted together and not insulated from each other. A **cable** is either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple-conductor cable). The term "cable" is a general one and usually applies only to the larger sizes of conductors. A small cable is more often called a stranded wire or cord (such as that used for an iron or a lamp cord). Cables may be bare or insulated. Insulated cables may be sheathed (covered) with lead, or protective armor. Figure 5 shows different types of wire and cable.

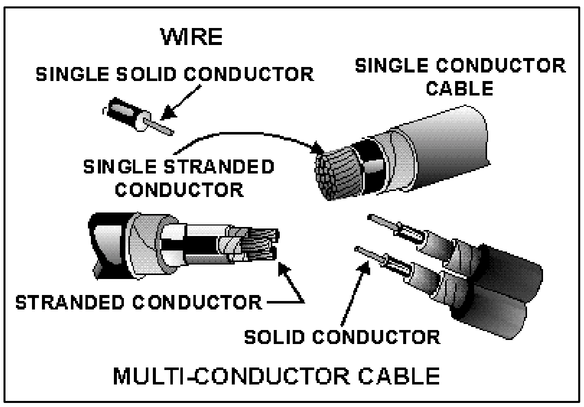


Figure 5: Conductors

Conductors are stranded mainly to increase their flexibility. The wire strands in cables are arranged in the following order:

1. The first layer of strands around the center conductor is made up of six conductors.
2. The second layer is made up of 12 additional conductors.
3. The third layer is made up of 18 additional conductors, and so on.

Thus, standard cables are composed of 7, 19, and 37 strands, in continuing fixed increments. The overall flexibility can be increased by further stranding of the individual strands.

Figure 6 shows a typical cross section of a 37-strand cable. It also shows how the total circular-mil cross-sectional area of a stranded cable is determined.

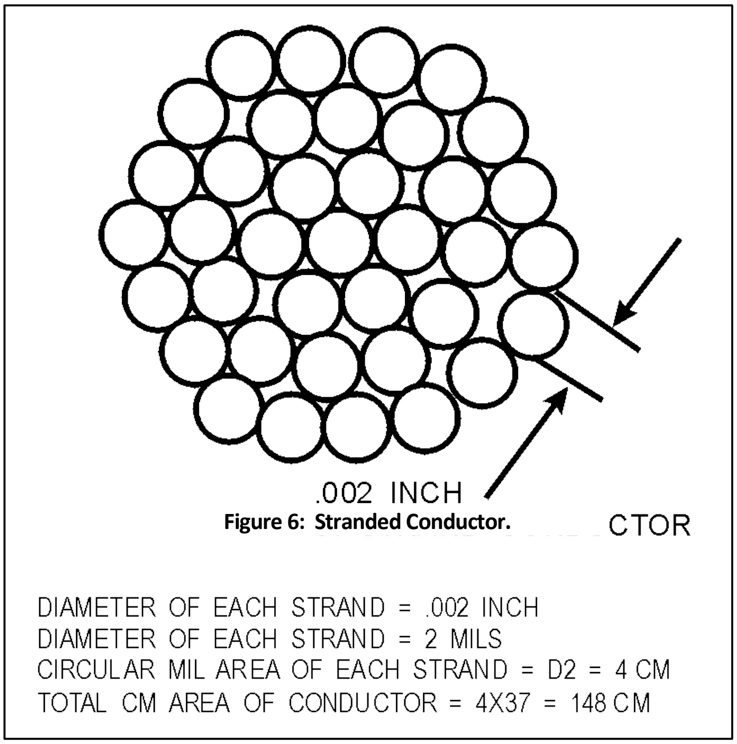


Figure 6: Stranded Conductor.

Selection of Wire Size

Several factors must be considered in selecting the size of wire to be used for transmitting and distributing electric power. These factors will be discussed throughout this section. Each industry will have its own specifications regarding the choice and installation of wiring. An important reason for having these specifications is to ensure uniformity of sizes to reduce the danger of fires caused by the improper selection of wire sizes. Wires can carry only a limited amount of current safely. If the current flowing through a wire exceeds the current-carrying capacity of the wire, excess heat is generated. This heat may be great enough to burn off the insulation around the wire and start a fire.

Factors Governing the Current Rating

The current rating of a cable or wire indicates the current capacity that the wire or cable can safely carry continuously. If this limit, or current rating, is exceeded for a length of time, the heat generated may burn the insulation. The current rating of a wire is used to determine what size is needed for a given load, or current drain.

The factors that determine the current rating of a wire are the conductor size, the location of the wire in a circuit, the type of insulation, and the safe current rating. Another factor that will be discussed later in this chapter is the material the wire is made of. As you have already seen, these factors also affect the resistance in ohms of a wire-carrying current.

Conductor Size

An increase in the diameter, or cross section, of a wire conductor decreases its resistance and increases its capacity to carry current. An increase in the specific resistance of a conductor increases its resistance and decreases its capacity to carry current.

Wire Location

The location of a wire in a circuit determines the temperature under which it operates. A wire may be located in a conduit or laced with other wires in a cable. Because it is confined, the wire operates at a higher temperature than if it were open to the free air. The higher the temperature under which a wire is operating, the greater will be its resistance. Its capacity to carry current is also lowered. Note that, in each case, the resistance of a wire determines its current-carrying capacity. The greater the resistance, the more power it dissipates in the form of heat energy.

Conductors may also be installed in locations where the ambient (surrounding) temperature is relatively high. When this is the case, the heat generated by external sources is an important part of the total conductor heating. This heating factor will be explained further when we discuss temperature coefficient. We must understand how external heating influences how much current a conductor can carry. Each case has its own specific limitations. The maximum allowable operating temperature of insulated conductors is specified in tables. It varies with the type of conductor insulation being used.

Insulation

The insulation of a wire does not affect the resistance of the wire. Resistance does, however, determine how much heat is needed to burn the insulation. As current flows through an insulated conductor, the limit of current that the conductor can withstand depends on how hot the conductor can get before it burns the insulation. Different types of insulation will burn at different temperatures. Therefore, the type of insulation used is the third factor that determines the current rating of a conductor. For instance, rubber insulation will begin deteriorating at relatively low temperatures, whereas varnished cloth insulation retains its insulating properties at higher temperatures. Other types of insulation are fluorinated ethylene propylene (FEP), silicone rubber, or extruded polytetrafluoroethylene. They are effective at still higher temperatures.

Copper versus Aluminum

Although silver is the best conductor, its cost limits its use to special circuits. Silver is used where a substance with high conductivity or low resistivity is needed. The two most commonly used conductors are copper and aluminum. Each has positive and negative characteristics that affect its use under varying circumstances. A comparison of some of the characteristics of copper and aluminum is given in Table 2.

Table 2: Comparitive Characteristics of Copper and Aluminum

CHARACTERISTICS	COPPER	ALUMINUM
Tensile strength (lb/in2).	55,000	25,000
Tensile strength for same conductivity (lb).	55,000	40,000
Weight for same conductivity (lb).	100	48
Cross section for same conductivity (C.M.).	100	160
Specific resistance (n/mil ft).		

Copper has a higher conductivity than aluminum. It is more ductile (can be drawn out). Copper has relatively high tensile strength (the greatest stress a substance can bear along its length without tearing apart). It can also be easily soldered. However, copper is more expensive and heavier than aluminum.

Although aluminum has only about 60 percent of the conductivity of copper, its lightness makes long spans possible. Its relatively large diameter for a given conductivity reduces corona. Corona is the discharge of electricity from the wire when it has a high potential. The discharge is greater when smaller diameter wire is used than when larger diameter wire is used. However, the relatively large size of aluminum for a given conductance does not permit the economical use of an insulation covering.

Knowledge Check

1. State two advantages of using aluminum wire for carrying electricity over long distances.
2. State four advantages of copper over aluminum as a conductor.

Temperature Coefficient

The resistance of pure metals, such as silver, copper, and aluminum, increases as the temperature increases. However, the resistance of some alloys, such as constantan and manganin, changes very little as the temperature changes. Measuring instruments use these alloys because the resistance of the circuits must remain constant to get accurate measurements.

In Table 1, the resistance of a circular-mil-foot of wire (the specific resistance) is given at a specific temperature, 20° C in this case. It is necessary to establish a standard temperature. As we stated earlier, the resistance of pure metals increases with an increase in temperature. Therefore, a true basis of comparison cannot be made unless the resistances of all the substances being compared are measured at the same temperature. The amount of increase in the resistance of a 1-ohm sample of the conductor per degree rise in temperature above 0° C is called the temperature coefficient of resistance. For copper, the value is approximately 0.00427 ohm.

A length of copper wire having a resistance of 50 ohms at an initial temperature of 0° C will have an increase in resistance of 50×0.00427, or 0.214 ohms. This applies to the entire length of wire and for each degree of temperature rise above 0° C. A 20° C increase in resistance is approximately 20×0.214, or 4.28 ohms. The total resistance at 20° C is 50 + 4.28, or 54.28 ohms.

Knowledge Check

1. Define the temperature coefficient of resistance.
2. What happens to the resistance of copper when it is heated?

Conductor Insulation

To be useful and safe, electric current must be forced to flow only where it is needed. It must be channeled from the power source to a useful load. In general, current-carrying conductors must not be allowed to come in contact with one another, their supporting hardware, or personnel working near them. To accomplish this, conductors are coated or wrapped with various materials. These materials have such a high resistance that they are, for all practical purposes, nonconductors. Nonconductors are generally referred to as *insulators* or *insulating material*.

Only the necessary minimum amount of insulation is applied to any particular type of conductor designed to do a particular job. This is done because of several factors. The expense, stiffening effect, and a variety of physical and electrical conditions under which the conductors are operated must be taken into account. Therefore, there is a variety of insulated conductors available to meet the requirements of any job.

Two fundamental properties of insulating materials (that is, rubber, glass, asbestos, or plastic) are insulation resistance and dielectric strength. These are two entirely different and distinct properties.

Insulation Resistance

Insulation resistance is the resistance to current leakage through the insulation materials. Insulation resistance can be measured with a megger (ohmmeter able to measure very high resistance) without damaging the insulation. Information so obtained is a useful guide in appraising the general condition of insulation. Clean, dry insulation having cracks or other faults may show a high value of insulation resistance but would not be suitable for use.

Dielectric Strength

Dielectric strength is the ability of an insulator to withstand potential difference. It is usually expressed in terms of the voltage at which the insulation fails because of the electrostatic stress. Maximum dielectric strength values can be measured only by raising the voltage of a *test sample* until the insulation breaks down.

Knowledge Check

1. Compare the resistance of a conductor to that of an insulator.
2. State two fundamental properties of insulating materials.
3. Define insulation resistance.
4. Define dielectric strength.
5. How is the dielectric strength of an insulator determined?

Types of Insulation

The insulating materials used can be dependent on the use and specifications of the application. Covered here is a general overview of the types of insulation an electronics technician may encounter. Two common insulators in use are rubbers and plastics. Properties of rubber and plastic insulators will be covered, as these are the most common. Further investigation on the properties of other insulators will be left to the reader.

Rubber

One of the most common types of insulation is rubber. The voltage that may be applied to a rubber-covered conductor is dependent on the thickness and the quality of the rubber covering. Other factors being equal, the thicker the insulation, the higher the applied voltage can be. Rubber insulation is normally used for low- or medium-range voltage and may have various grades or compositions, but in each case, the rubber serves the same purpose: to confine the current to its conductor.

It is important, however, that you be aware that a thin coating of tin separates the copper conductor from the rubber insulation. If the thin coating of tin were not used, a chemical action would take place and the rubber would become soft and gummy where it makes contact with the copper. When small, solid, or stranded conductors are used, a winding of cotton threads is applied between the conductors and the rubber insulation.

Other Rubber Insulators

Code-Graded Rubber - In this code system, letters are used to signify specific properties and of the rubber insulation, such as voltage level and moisture tolerances.

Latex Rubber – A high-grade compound consisting of 90 percent unmilled grainless rubber. This type of rubber has different grades, similar to code-graded rubber.

Silicone - a rubber compound that can be combined with other insulators depending on the application.

Knowledge Check

1. What is the purpose of coating a copper conductor with tin when rubber insulation is used?

Plastics

Plastic is another of the more commonly used types of insulating material for electrical conductors. It has good insulating, flexibility, and moisture-resistant qualities. Although there are many types of plastic insulating materials, thermoplastic is one of the most common. With the use of thermoplastic, the conductor temperature can be higher than with some other types of insulating materials without damage to the insulating quality of the material. Plastic insulation is normally used for low- or medium-range voltage. Like code-graded rubber, there is a system of alphanumeric identifiers for specific properties such as temperature tolerance and voltage levels.

Other Insulators

Varnished Cambric – able to withstand much higher temperatures than rubber insulation. Varnished cambric is cotton cloth that has been coated with an insulating varnish. It is commonly used on extremely high-voltage conductors used in substations and powerhouses. It is also used in other locations subjected to high temperatures.

Extruded Polytetrafluoroethylene – a high-temperature insulation used extensively in aircraft and equipment installations. It will not burn, but will vaporize when subjected to intense heat and does emit toxic vapors when heated.

Fluorinated Ethylene Propylene (FEP) - properties similar to extruded polytetrafluoroethylene, but will melt at soldering temperatures. There are no known toxic vapors from FEP; however, common sense practice requires that you provide adequate ventilation during any soldering operation.

Asbestos - used extensively in the past for high-temperature insulation. While most public and private structures have undergone asbestos removal, it can still be found in military structures and assets. It is important to be aware of the proper safety precautions when working with this and other hazardous materials.

Paper – when impregnated with a high grade of mineral oil, paper serves as a satisfactory insulation for extremely high-voltage cables. The oil has a high dielectric strength, and tends to prevent breakdown of the paper insulation. The paper must be thoroughly saturated with the oil.

Silk and Cotton – used when a large number of conductors are needed. Each conductor within the cable is insulated from the others by silk and cotton thread. Because the insulation in this type of cable is not subjected to high voltage, the use of thin layers of silk and cotton is satisfactory.

Enamel – used to insulate the magnet wire used in the coils of meters, relays, small transformers, and motor windings. The enamel is a synthetic compound of cellulose acetate (wood pulp and magnesium). Thickness for thickness, enamel has higher dielectric strength than rubber, but cost considerations as well as its fragility make it impracticable for use with large wires.

Mineral Insulated - developed to meet the needs of a noncombustible, high heat- resistant, and water-resistant cable. MI cable has from one to seven electrical conductors. These conductors are insulated in a highly compressed mineral, normally magnesium oxide, and sealed in a liquid tight, gastight metallic tube, normally made of seamless copper.

Conductor Protection

Wires and cables are generally subjected to abuse. The type and amount of abuse depends on how and where they are installed and the manner in which they are used. Cables buried directly in the ground must resist moisture, chemical action, and abrasion. Wires installed in buildings must be protected against mechanical injury and overloading. Wires strung on cross arms on poles must be kept far enough apart so that the wires do not touch. Snow, ice, and strong winds make it necessary to use conductors having high tensile strength and substantial frame structures.

Generally, except for overhead transmission lines, wires or cables are protected by some form of covering. The covering may be some type of insulator like rubber or plastic. Over this, additional layers of fibrous braid or tape may be used and then covered with a finish or saturated with a protective coating. If the wire or cable is installed where it is likely to receive rough treatment, a metallic coat should be added.

The materials used to make up the protection for a wire or cables are grouped into one of two categories: nonmetallic or metallic as shown in the table below.

Nonmetallic Protection	Metallic Protection
• Fibrous Braid	Metallic Sheath
• most commonly used	• watertight protection
• Fibrous Tape	• Metallic Armor
• example: duct tape	• wire-braid
• Woven Covers	• steel tape
• provide abrasion protection	• wire armor
• Rubber and Synthetic Coverings	
• abrasion and moisture protection	
• Jute and Asphalt Coverings	
• cushioning and weather proofing	

Fuses

Electricity, like fire, can be either helpful or harmful to those who use it. It is necessary then, that electricity be kept under control at all times. If for some reason it should get out of control, there must be a method of protecting people and equipment. Devices have been developed to protect people and electrical circuits from currents and voltages outside their normal operating ranges by keeping undesirably large current, voltage, or power surge out of a given part of an electrical circuit.

An electrical unit is built with great care to ensure that each separate electrical circuit is fully insulated from all the others. This is done so that the current in a circuit will follow its intended path. Once the unit is placed into service, however, many things can happen to alter the original circuitry. Some of the changes can cause serious problems if they are not detected and corrected. While circuit protection devices cannot correct an abnormal current condition, they can indicate that an abnormal condition exists and protect personnel and circuits from that condition. In this section, you will learn what circuit conditions require protection devices and the types of protection devices used.

Circuit Conditions Requiring Protection Devices

As has been mentioned, many things can happen to electrical and electronic circuits after they are in use. You have learned how to measure circuit characteristics to help determine the changes that can occur in them. Some of the changes in circuits can cause conditions that are dangerous to the circuit itself or to people living or working near the circuits. These potentially dangerous conditions require circuit protection. The conditions that require circuit protection are direct shorts, excessive current, and excessive heat.

Direct Short or Short Circuit

One of the most serious troubles that can occur in a circuit is a direct short, or short circuit. This is a situation in which some point in the circuit, where full system voltage is present, comes in direct contact with the ground or return side of the circuit. This establishes a path for current flow that contains only the very small resistance present in the wires carrying the current. According to Ohm's law, if the resistance in a circuit is extremely small, the current will be extremely large. Therefore, when a direct short occurs, there will be a very large current through the wires. If the excessive current flow caused by a direct short is left unchecked, the heat in the wire will continue to increase until some portion of the circuit burns.

Excessive Current

It is possible for the circuit current to increase without a direct short. If a resistor, capacitor, or inductor changes value, the total circuit impedance will also change in value. If a resistor decreases in ohmic value, the total circuit resistance decreases. There are any number of conditions that will cause an increase in circuit current. Since the circuit wiring and components are designed to withstand normal circuit current, an increase in current would cause overheating (just as in the case of a direct short). Therefore, excessive current without a direct short will cause the same problems as a direct short.

Excessive Heat

As you have read, most of the problems associated with a direct short or excessive current concern the heat generated by the higher current. The damage to circuit components, the possibility of fire, and the possibility of hazardous fumes being given off from electrical components are consequences of excessive heat. It is possible for excessive heat to occur without a direct short or excessive current. If the bearings on a motor or generator were to fail, the motor or generator would overheat. If the temperature around an electrical or electronic circuit were to rise (through failure of a cooling system for example), excessive heat would be a problem. No matter what the cause, if excessive heat is present in a circuit, the possibility of damage, fire, and hazardous fumes exists.

Knowledge Check

1. Why are circuit protection devices necessary?
2. What are the three conditions that require circuit protection?
3. What is a direct short?
4. What is an excessive current condition?
5. What is an excessive heat condition?

Circuit Protection Devices

All of the conditions mentioned are potentially dangerous and require the use of circuit protection devices. Circuit protection devices are used to stop current flow or open the circuit. To do this, a circuit protection device must ALWAYS be connected in series with the circuit it is protecting. If the protection device is connected in parallel, current will simply flow around the protection device and continue in the circuit.

A circuit protection device operates by opening and interrupting current to the circuit. The opening of a protection device shows that something is wrong in the circuit and should be corrected before the current is restored. When a problem exists and the protection device opens, the device should be shut off and the technician needs to isolate the faulty circuit from the other unaffected circuits, and should respond in time to protect unaffected components in the faulty circuit. The protection device should NOT open during normal circuit operation. This section will focus on one type of circuit protection, the fuse.

Fuses

A **fuse** is the simplest circuit protection device. It derives its name from the Latin word "fusus," meaning "to melt." Fuses have been used almost from the beginning of the use of electricity. The earliest type of fuse was simply a bare wire between two connections. The wire was smaller than the conductor it was protecting and, therefore, would melt before the conductor it was protecting was harmed. Some "copper fuse link" types are still in use, but most fuses no longer use copper as the fuse element (the part of the fuse that melts). After changing from copper to other metals, tubes or enclosures were developed to hold the melting metal. The enclosed fuse made possible the addition of filler material, which helps to contain the arc that occurs when the element melts. Figure 7 shows several fuses and the symbols used on schematics.

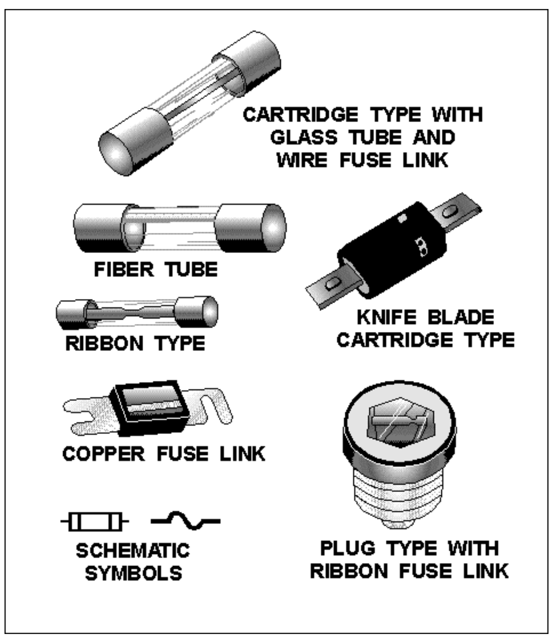


Figure 7: Typical fuses and schematic symbols

Fuse Ratings

You can determine the physical size and type of a fuse by looking at it, but you must know other things about a fuse to use it properly. Fuses are rated by current, voltage, and time-delay characteristics to aid in the proper use of the fuse. To select the proper fuse, you must understand the meaning of each of the fuse ratings.

Current Rating

The current rating of a fuse is a value expressed in amperes that represents the current the fuse will allow without opening. The current rating of a fuse is always indicated on the fuse. To select the proper fuse, you must know the normal operating current of the circuit. If you wish to protect the circuit from overloads (excessive current), select a fuse rated at 125 percent of the normal circuit current. In other words, if a circuit has a normal current of 10 amperes, a 12.5-ampere fuse will provide overload protection. If you wish to protect against direct shorts only, select a fuse rated at 150 percent of the normal circuit current. In the case of a circuit with 10 amperes of current, a 15 ampere fuse will protect against direct shorts, but will not be adequate protection against excessive current.

Voltage Rating

The voltage rating of a fuse is NOT an indication of the voltage the fuse is designed to withstand while carrying current. The voltage rating indicates the ability of the fuse to quickly extinguish the arc after the fuse element melts and the maximum voltage the open fuse will block. In other words, once the fuse has opened, any voltage less than the voltage rating of the fuse will not be able to "jump" the gap of the fuse. You must always select a fuse with a voltage rating equal to or higher than the voltage in the circuit you wish to protect.

Time Delay Rating

There are many kinds of electrical and electronic circuits that require protection. In some of these circuits, it is important to protect against temporary or transient current increases. Sometimes the device being protected is very sensitive to current and cannot withstand an increase in current. In these cases, a fuse must open very quickly if the current increases.

Some other circuits and devices have a large current for short periods and a normal (smaller) current most of the time. An electric motor, for instance, will draw a large current when the motor starts, but normal operating current for the motor will be much smaller. A fuse used to protect a motor would have to allow for this large temporary current, but would open if the large current were to continue.

Fuses are time delay rated to indicate the relationship between the current through the fuse and the time it takes for the fuse to open. The three time delay ratings are delay, standard, and fast.

Delay - A delay, or slow-blowing, fuse has a built-in delay that is activated when the current through the fuse is greater than the current rating of the fuse. This fuse will allow temporary increases in current (surge) without opening. Some delay fuses have two elements; this allows a very long time delay. If the over- current condition continues, a delay fuse will open, but it will take longer to open than a standard or a fast fuse. Delay fuses are used for circuits with high surge or starting currents, such as motors, solenoids, and transformers.

Standard - Standard fuses have no built-in time delay, nor are they designed to be fast acting. Standard fuses are sometimes used to protect against direct shorts only. They may be wired in series with a delay fuse to provide faster direct short protection. For example, in a circuit with a 1-ampere delay fuse, a 5-ampere standard fuse may be used in addition to the delay fuse to provide faster protection against a direct short. A standard fuse can be used in any circuit where surge currents are not expected and a very fast opening of the fuse is not needed. A standard fuse opens faster than a delay fuse, but slower than a fast rated fuse.

Fast - Fast fuses are designed to open very quickly when the current through the fuse exceeds the current rating of the fuse. Fast fuses are used to protect devices that are very sensitive to increased current. A fast fuse will open faster than a delay or standard fuse. Fast fuses can be used to protect delicate instruments or semiconductor devices.

Figure 8 will help you understand the differences between delay, standard, and fast fuses. Figure 8 shows that, if a 1-ampere rated fuse had 2 amperes of current through it, (200% of the rated value), a fast fuse would open in about 0.7 second, a standard rated fuse would open in about 1.5 seconds, and a delay rated fuse would open in about 10 seconds. Notice that in each of the fuses, the time required to open the fuse decreases as the rated current increases.

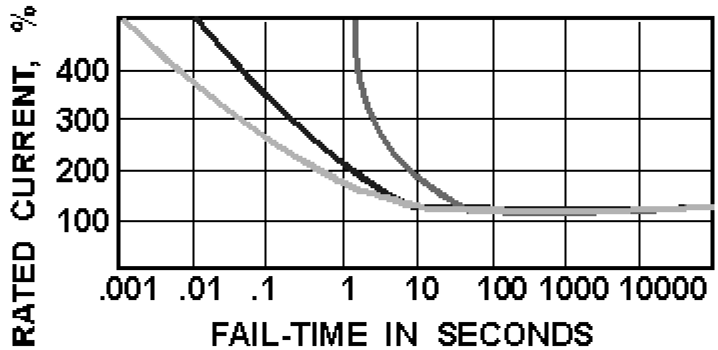


Figure 8: Time required for fuse to open.

Knowledge Check

Q11. In what three ways are fuses rated?

Q12. What does the current rating of a fuse indicate? Q13. What does the voltage rating of a fuse indicate? Q14. What are the three time delay ratings of fuses?

Q15. Give an example of a device you could protect with each type of time delay fuse.

Fuseholders

For a fuse to be useful, it must be connected to the circuit it will protect. Some fuses are "wired in" or soldered to the wiring of circuits, but most circuits make use of fuseholders. A fuseholder is a device that is wired into the circuit and allows easy replacement of the fuse.

Fuseholders are made in many shapes and sizes, but most fuseholders are basically either clip-type or post-type. Figure 9 shows a typical clip-type and post-type fuseholder.

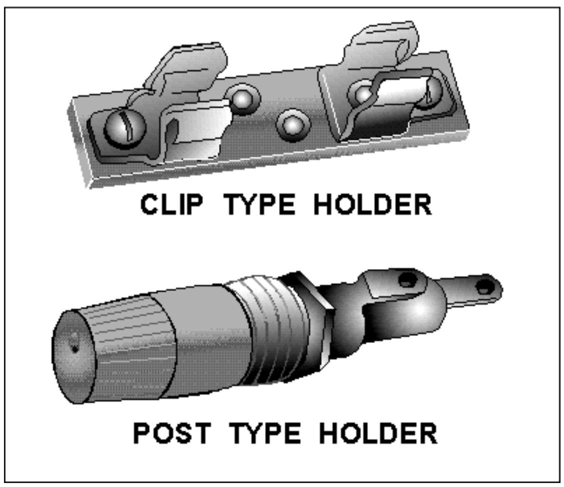


Figure 9: Typical fuseholders

The **clip-type fuseholder** is used for cartridge fuses. The ferrules or knife blade of the fuse are held by the spring tension of the clips. These clips provide the electrical connection between the fuse and the circuit. If a glass-bodied fuse is used, the fuse can be inspected visually for an open without removing the fuse from the fuse holder. **Post-type fuseholders** are made for cartridge fuses. The post-type fuseholder is much safer because the fuse and fuse connections are covered with insulating material. The disadvantage of the post-type fuseholder is that the fuse must be removed to visually check for an open.

Troubleshooting Fuses

A fuse, if properly used, should not open unless something is wrong in the circuit the fuse is protecting. When a fuse is found to be open, you must determine the reason the fuse is open. Replacing the fuse is not enough. Before you look for the cause of an open fuse, you must be able to determine if the fuse is open.

Checking for an Open Fuse

There are several ways of checking for an open fuse. Some fuses and fuseholders have indicators built in to help you find an open fuse; also, a multimeter can be used to check fuses. The simplest way to check glass-bodied fuses, and the method you should use first, is visual inspection. If the fuse element is not complete, or if the element has been melted onto the glass tube, the fuse is open. However, sometimes a fuse will look good, but will, in fact, be open. Therefore, while it is sometimes possible to know if a fuse is open by visual inspection, it is not possible to be sure a fuse is good just by looking at it. Some fuses and fuseholders have built-in indicators to show when a fuse is open, such as a spring loaded indicator, or an indicating lamp in the fuse cap. However, just as in visual checking, you cannot be sure a fuse is good just because there is no open-fuse indication.

The only sure method of determining if a fuse is open is to use a meter. An ohmmeter can be used to check for an open fuse by removing the fuse from the circuit and checking for continuity through the fuse (0 ohms). If the fuse is not removed from the circuit, and the fuse is open, the ohmmeter may measure the circuit resistance. This resistance reading might lead you to think the fuse is good. You must be careful when you use an ohmmeter to check fuses with small current ratings (such as 1/32 ampere or less), because the current from the ohmmeter may be larger than the current rating of the fuse. For most practical uses, a small current capacity fuse can be checked out of the circuit through the use of a resistor. The ohmic value of the resistor is first measured and then placed in series with the fuse. The continuity reading on the ohmmeter should be of the same value, or close to it, as the original value of the resistor. This method provides protection for the fuse by dropping the voltage across the resistor. This in turn decreases the power in the form of heat at the fuse. Remember, it is heat which melts the fuse element.

A voltmeter can also be used to check for an open fuse. The measurement is taken between each end of the fuse and the common or ground side of the line. If voltage is present on both sides of the fuse (from the voltage source and to the load), the fuse is not open. Another method commonly used, is to measure across the fuse with the voltmeter. If NO voltage is indicated on the meter, the fuse is good, (not open). Remember there is no voltage drop across a straight piece of wire. Some plug-type fuseholders have test points built in to allow you to check the voltage. To check for voltage on a clip-type fuseholder, check each of the clips. The advantage of using a voltmeter to check for an open fuse is that the circuit does not have to be deenergized and the fuse does not have to be removed.

Safety Precautions When Checking a Fuse

Since a fuse has current through it, you must be very careful when checking for an open fuse to avoid being shocked or damaging the circuit. The following safety precautions will protect you and the equipment you are using.

- Turn the power off and discharge the circuit before removing a fuse.
- Use a fuse puller (an insulated tool) when you remove a fuse from a clip-type fuseholder.
- When you check a fuse with a voltmeter, be careful to avoid shocks and short circuits.
- When you use an ohmmeter to check fuses with low current ratings, be careful to avoid opening the fuse by excessive current from the ohmmeter.

Replacing Fuses

After an open fuse is found and the trouble that caused the fuse to open has been corrected, the fuse must be replaced. Before you replace the fuse, you must be certain the replacement fuse is the proper type and fits correctly.

- Proper Type of Replacement Fuse
- To be certain a fuse is the proper type, check the technical manual for the equipment. The parts list will show you the proper fuse identification for a replacement fuse. Obtain the exact fuse specified, if possible, and check the identification number of the replacement fuse against the parts list.
- If you cannot obtain a direct replacement, use the following guidelines:
- Never use a fuse with a higher current rating, a lower voltage rating, or a slower time delay rating than the specified fuse.
- The best substitution fuse is a fuse with the same current and time delay ratings and a higher voltage rating.
- If a lower current rating or a faster time delay rating is used, the fuse may open under normal circuit conditions.
- Substitute fuses must have the same style (physical dimensions) as the specified fuse.

Knowledge Check

1. What are three methods for determining if a fuse is open?
2. You have just checked a fuse with an ohmmeter and find that the fuse is shorted. What should you do?
3. You have just checked a 1/500-ampere fuse with an ohmmeter and find it is open. Checking the replacement fuse shows the replacement fuse is open also. Why would the replacement fuse indicate open?
4. How could you check a 1/500-ampere fuse with an ohmmeter?
5. List the safety precautions to be observed when checking fuses.

Switches

Circuit control devices are used everywhere that electrical or electronic circuits are used. They are found in houses, automobiles, submarines, computers, aircraft, televisions, ships, space vehicles, medical instruments, and many other places. In this section you will learn what circuit control devices are, how they are used, and some of their characteristics.

Circuit control, in its simplest form, is the application and removal of power. This can also be expressed as turning a circuit on and off or opening and closing a circuit. Before you learn about the types of circuit control devices, you should know why circuit control is needed.

If a circuit develops problems that could damage the equipment or endanger personnel, it should be possible to remove the power from that circuit. The circuit protection devices discussed in the previous section will remove power automatically if current or temperature increase enough to cause the circuit protection device to act. Even with this protection, a manual means of control is needed to allow you to remove power from the circuit before the protection device acts.

Switch types

Circuit control takes many forms, such as switches, relays, and solenoids. For this section, we are going to focus primarily on switches. There are thousands and thousands of switch applications found in home, industry, and the military. Hundreds of electrical switches work for you every day to perform functions you take for granted. Some switches operate by the touch of a finger and many others are operated automatically.

Switches are used in the home to turn off the alarm clock, to control the stove, to turn on the refrigerator light, to turn on and control radios and televisions, hair dryers, dishwashers, garbage disposals, washers and dryers, as well as to control heating and air conditioning.

Industry uses switches in a wide variety of ways. They are found in the business office on computers, copy machines, and other equipment. A factory or shop may use thousands of switches and they are found on almost every piece of machinery. Switches are used on woodworking machinery, metal working machinery, conveyors, automation devices, elevators, hoists, and lift trucks.

Switches are designed to work in many different environments from extreme high pressure, as in a submarine, to extreme low pressure, as in a spacecraft. Other environmental conditions to consider are high or low temperature, rapid temperature changes, humidity, liquid splashing or immersion, ice, corrosion, sand or dust, fungus, shock or vibration, and an explosive atmosphere. It would not be possible to describe all the different switches used. This section will describe the most common types of switches, including manual switches, automatic switches, and multi-contact switches.

Manual Switches

A manual switch is a switch that is controlled by a person. In other words, a manual switch is a switch that you turn on or off. Examples of common manual switches are a light switch, the ignition switch on a motor vehicle, and selector switches.

Automatic Switch

An automatic switch is a switch that is controlled by a mechanical or electrical device. You do not have to turn an automatic switch on or off. Two examples of automatic switches are a thermostat and the distributor in a motor vehicle. The thermostat will turn a furnace or air conditioner on or off by responding to the temperature in a room. The distributor electrically turns on the spark plug circuit at the proper time by responding to the mechanical rotation of a shaft. Even the switch that turns on the light in a refrigerator when the door is opened is an automatic switch.

Automatic switches are not always as simple as the examples given above. Limit switches, which sense some limit such as fluid level, mechanical movement, pressure (altitude or depth under water), or an electrical quantity, are automatic switches. Computers use and control automatic switches that can be quite complicated. Basically, any switch that will turn a circuit on or off without human action is an automatic switch. Automatic switches will be discussed in greater detail in future courses.

Multicontact Switch

Switches are sometimes used to control more than one circuit or to select one of several possible circuits. An example of a switch controlling more than one circuit is the AM/FM selector on a radio. This switch enables you to control either the AM or FM portion of the radio with a single switch.

These switches are called **multicontact** switches because they have more than one contact or multi(ple) contacts.

Poles and Throws

Multicontact switches (other than rotary switches, which will be covered later) are usually classified by the number of poles and number of throws. **Poles** are shown in schematics as those contacts through which current enters the switch; they are connected to the movable contacts. Each pole may be connected to another part of the circuit through the switch by "throwing" the switch (movable contacts) to another position. This action provides an individual conduction path through the switch for each pole connection. The number of **throws** indicates the number of different circuits that can be controlled by each pole. By counting the number of points where current enters the switch (from the schematic symbol or the switch itself), you can determine the number of poles. By counting the number of different points each pole can connect with, you can determine the number of throws.

Figure 10 will help you understand this concept by showing illustrations of various multicontact switches and their schematic symbols.

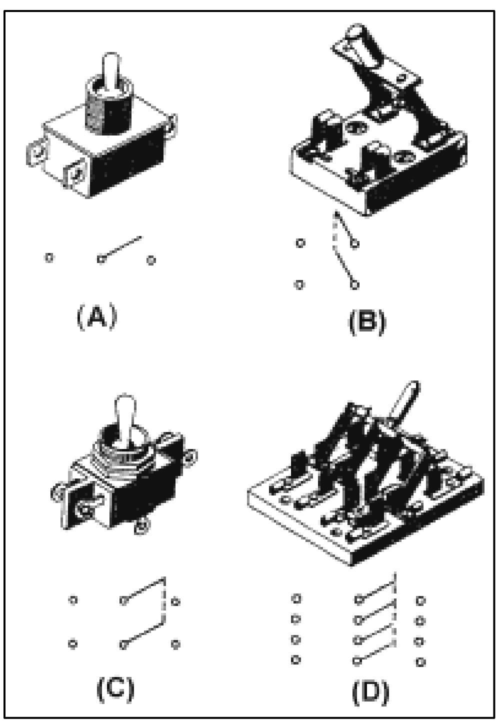


Figure 10: Multicontact switches.

Figure 10(A) shows a single-pole, double-throw switch, abbreviated SPDT. The illustration shows three terminals (connections) on this switch. The schematic symbol for the switch is also shown. The center connection of the schematic symbol represents the point at which current enters the switch. The left and right connections represent the two different points to which this current can be switched. From the schematic symbol, it is easy to determine that this is a single-pole, double-throw switch.

Now look at Figure 10(B). The switch is shown with its schematic symbol. The schematic symbol has two points at which current can enter the switch, so this is a double-pole switch. Each of the poles is mechanically connected (still electrically separate) to one point, so this is a single-throw switch. Only one throw is required to route two separate circuit paths through the switch. This would be designated as a DPST, or double pole single throw, switch.

Figure 10(C) shows a double-pole, double-throw switch (DPDS) and its schematic symbol.Figure 10(D) shows a four-pole, double-throw switch (4PDT) and its schematic symbol. It might help you to think of switches with more than one pole as several switches connected together mechanically. For example, the knife switch shown in Figure 10(D) could be thought of as four single-pole, double-throw switches mechanically connected together.

Knowledge Check

1. What is the difference between a manual and an automatic switch?
2. What is one example of a manual switch?
3. What is one example of an automatic switch?
4. Why are multicontact switches used?
5. Label the schematic symbols shown in Figure 11 as to number of poles and number of throws.

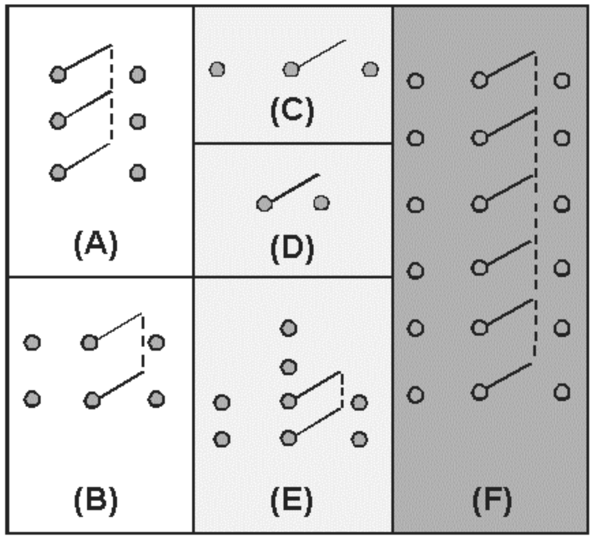


Figure 11: Schematic symbols of switches.

Single-Break and Double-Break Switches

Switches can also be classified as single-break or double-break switches. This refers to the number of places in which the switch opens or breaks the circuit. All of the switches shown so far have been single-break switches. A double-break switch is shown in Figure 12 The schematic symbol shown in Figure 12(A) shows that this switch breaks the circuit in two places (at both terminals). The upper part of the schematic symbol indicates that these contacts are in the open position and the circuit will close when the switch is acted upon (manually or automatically). The lower symbol shows closed contacts. These contacts will open the circuit when the switch is acted upon.

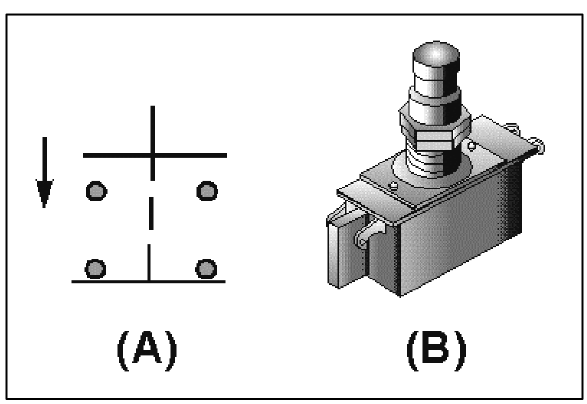


Figure 12: Double-break pushbutton switch.

Figure 12(B) is a picture of the switch. This switch is called a pushbutton switch because it has a button that must be pushed to change the switch contact connections. Notice that the switch has four terminals. The schematic symbol in Figure 12(A) shows that when one set of contacts is open, the other set of contacts is closed. This switch is a double-pole, single-throw, double-break switch.

The number of poles in a switch is independent of the number of throws and whether it is a single or double break switch. The number of throws in a switch is independent of the number of poles and whether it is a single or double break switch. In other words, each characteristic of a switch (poles, throws, break) is not determined by either of the other characteristics. Figure 13 shows the schematic symbols for several different switch configurations.

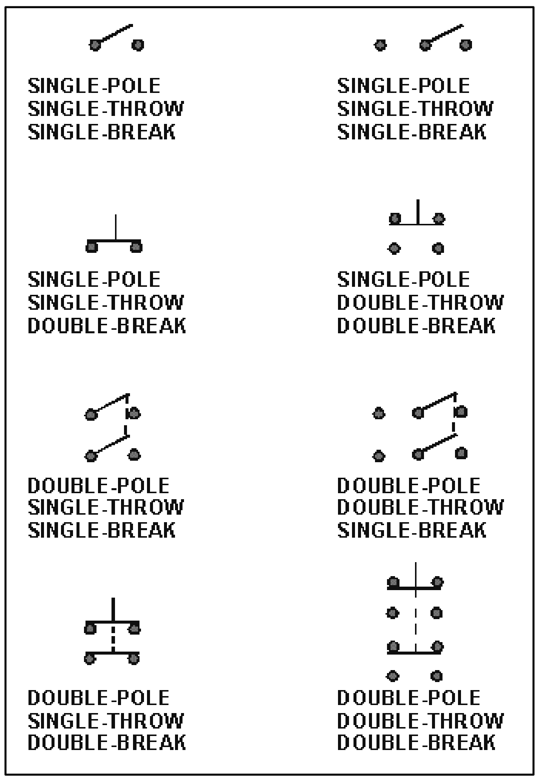


Figure 13: Schematic symbols of switch configurations.

Rotary Switches

A rotary switch is a midcontact switch part of the schematic with the contacts arranged in a full or partial circle. Instead of a pushbutton or toggle, the mechanism used to select the contact moves in a circular motion and must be turned. Rotary switches can be manual or automatic switches. An automobile distributor, the ignition switch on a motor vehicle, and some selector switches are rotary switches.

Some rotary switches are made with several layers or levels. The arrangement makes possible the control of several circuits with a single switch. Figure 14 is an illustration of a rotary switch with two layers. Each layer has a selector and 20 contacts. As this switch is rotated, both layers select a single circuit (contact) of the 20. It is also called a wafer switch. In a wafer switch, each layer is known as a wafer.

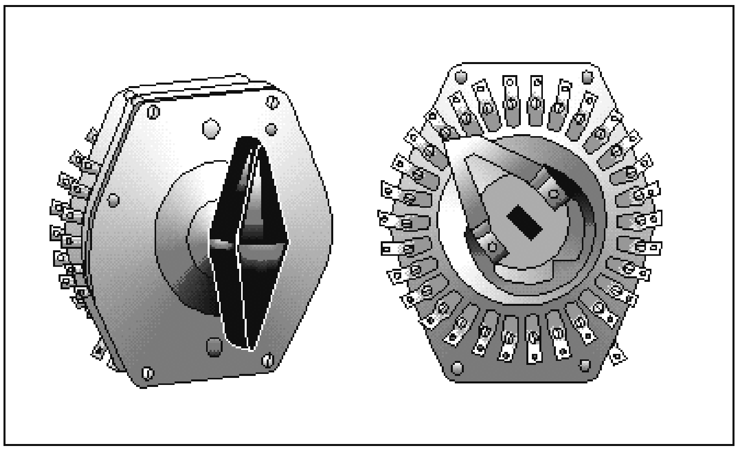


Figure 14: Two-layer rotary switch.

Other Types of Switches

You have learned that switches are classified by the number of poles, throws, and breaks. There are other factors used to describe a switch such as the type of actuator and the number of positions. In addition, switches are classified by whether the switch has momentary contacts or are locked into or out of position and whether or not the switch is snap-acting. Below, the more relevant switch configurations are discussed.

Type of Actuator

In addition to the pushbutton, toggle, and knife actuated switches already described, switches can have other actuators. There are rocker switches, paddle switches, keyboard switches, and mercury switches (in which a small amount of mercury makes the electrical contact between two conductors).

Number of Positions

Switches are also classified by the number of positions of the actuating device. Figure 15 shows three toggle switches, the toggle positions, and schematic diagrams of the switch. Figure 15(A) is a single-pole, single-throw, two-position switch. The switch is marked to indicate the ON position (when the switch is closed) and the OFF position (when the switch is open). Figure 15(B) is a single-pole, double-throw, three-position switch. The switch markings show two ON positions and an OFF position. When this switch is OFF, no connection is made between any of the terminals. In either of the ON positions, the center terminal is connected to one of the outside terminals. (The outside terminals are not connected together in any position of the switch.) Figure 15(C) is a single-pole, double-throw, two-position switch. There is no OFF position. In either position of this switch, the center terminal is connected to one of the outside terminals.

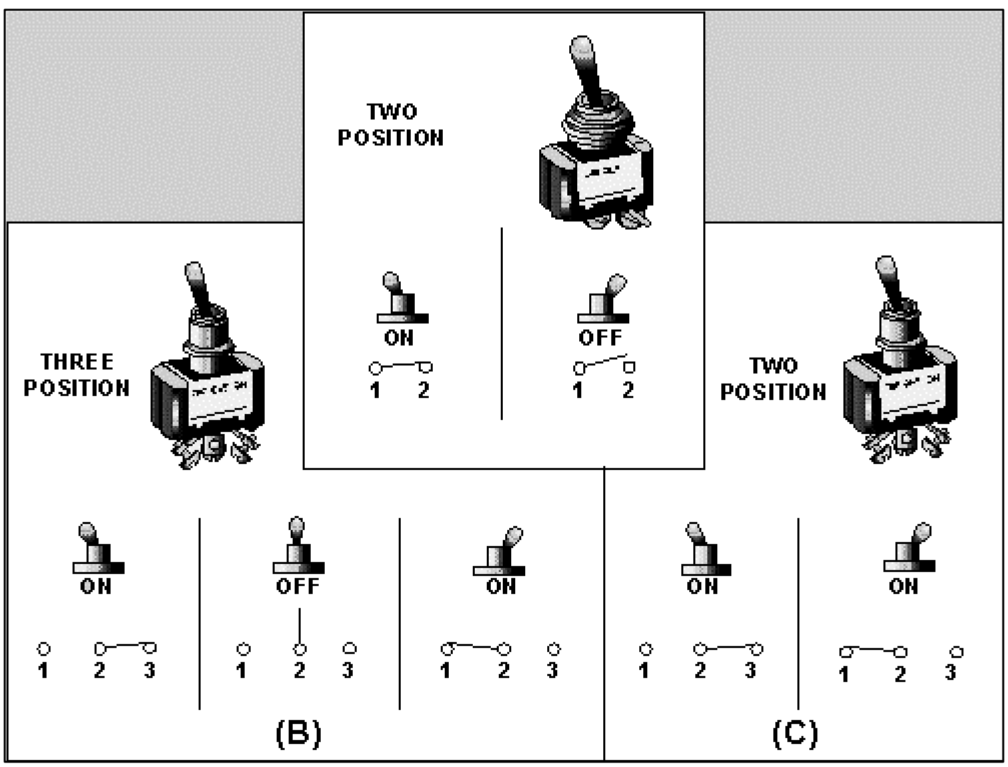


Figure 15: Two- and three-position switches.

Momentary Switches

In some switches, one or more of the switch positions are **momentary**. This means that the switch will only remain in the momentary position as long as the actuator is held in that position. As soon as you let go of the actuator, the switch will return to a non-momentary position. The starter switch on an automobile is an example of a momentary switch. As soon as you release the switch, it no longer applies power to the starter.

Normally Open or Normally Closed

Some switches, such as momentary or push-buttons, are configured to be normally open (NO) or normally closed (NC). As an example, a NO push-button switch is open (or on). When the button is pressed, the contacts will open and no current will flow. This type of switch can be used as a reset switch where one wants to disconnect power briefly. In a NC push-button, the switch is considered closed until pressed.

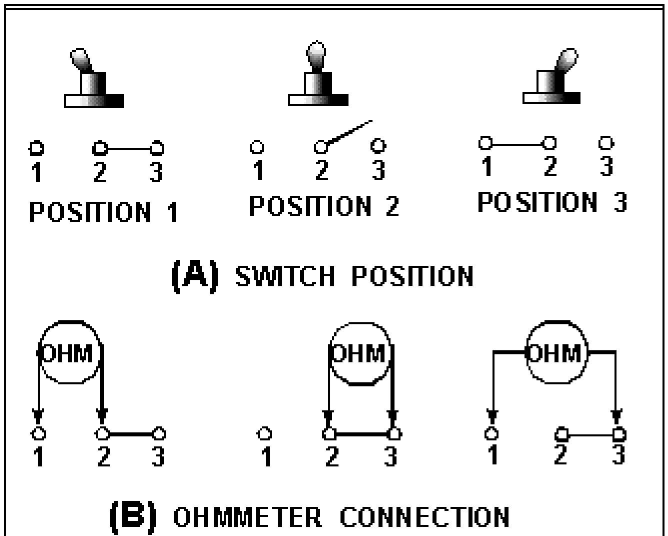
Current and Voltage Rating of Switches

Switches are rated according to their electrical characteristics. The rating of a switch is determined by such factors as contact size, contact material, and contact spacing. There are two basic parts to a switch rating-the current and voltage rating. The **current rating** of a switch refers to the maximum current the switch is designed to carry. This rating is dependent on the voltage of the circuit in which the switch is used. The **voltage rating** of a switch refers to the maximum voltage allowable in the circuit in which the switch is used. The voltage rating may be given as an ac voltage, a dc voltage, or both. The voltage rating of a switch should never be exceeded.

If current rating is exceeded, the contacts may "weld" together making it impossible to open the circuit. If a voltage higher than the voltage rating of the switch is applied to the switch, the voltage may be able to "jump" the open contacts of the switch. This would make it impossible to control the circuit in which the switch was used.

Troubleshooting Switches

Switches are usually a very reliable electrical component. This means, they do not fail very often, if the current and voltage ratings are not exceeded. Even so, switches do fail. The following information will help you in maintaining and changing switches.



SWITCH POSITION	OHMMETER CONNECTION	CORRECT READING
1	1 - 2	∞
1	2 - 3	0
1	1 - 3	∞
2	1 - 2	∞
2	2 - 3	∞
2	1 - 3	∞
3	1 - 2	0
3	2 - 3	∞
3	1 - 3	∞

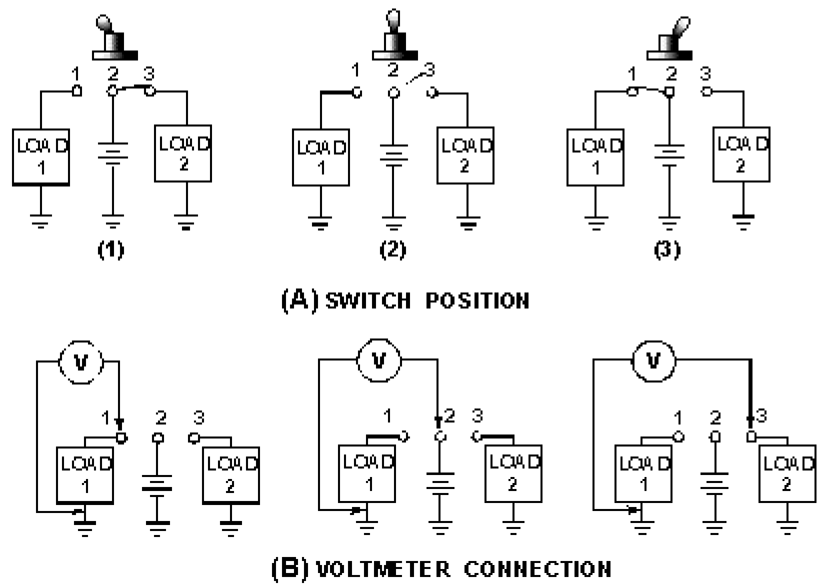
(C) TABLE OF CORRECT READINGS

Figure 16: Checking a switch with an ohmmeter.

Switches can be checked using two basic methods. You can use an ohmmeter or a voltmeter. Figure 16 is used to explain the method of using an ohmmeter to check a switch. Figure 16(A) shows the toggle positions and schematic diagrams for the three switch positions. Figure 16(B) shows the ohmmeter connections used to check the switch while the toggle is in position 1. Figure

16(C) is a table showing the switch position, ohmmeter connection, and correct ohmmeter reading for those conditions.

As an example, with the switch in position 1 and the ohmmeter connected to terminals 1 and 2 of the switch, the ohmmeter should indicate (∞). When the ohmmeter is moved to terminals 2 and 3, the ohmmeter should indicate zero ohms. With the ohmmeter connected to terminals 1 and 3, the indication should be (∞).



SWITCH POSITION	VOLTMETER CONNECTION	CORRECT READING
1	1	0V
1	2	VOLTAGE
1	3	VOLTAGE
2	1	0V
2	2	VOLTAGE
2	3	0V
3	1	VOLTAGE
3	2	VOLTAGE
3	3	0V

(C) TABLE OF CORRECT READINGS

Figure 17: Checking a switch with a voltmeter.

Recall that when using the ohmmeter, power must be removed from the circuit and the component being checked should be isolated from the circuit. Because this is not always practical, and because sometimes it is necessary to check a switch while there is power applied to it, you can check the switch by the use of a voltmeter.

Figure 17(A) shows a switch connected between a power source (battery) and two loads. In Figure 17(B), a voltmeter is shown connected between ground and each of the three switch terminals while the switch is in position 1. Figure 17(C) is a table showing the switch position, voltmeter connection, and the correct voltmeter reading. The table in Figure 17(C) will show you the correct readings for each switch position.

Replacing Switches

When a switch is faulty, it must be replaced. The technical manual for the equipment will specify the exact replacement switch. If it is necessary to use a substitute switch, the following guidelines should be used. The substitute switch must have all of the following characteristics:

- At least the same number of poles.
- At least the same number of throws.
- The same number of breaks.
- At least the same number of positions.
- The same configuration in regard to momentary or locked positions.
- A voltage rating equal to or higher than the original switch.
- A current rating equal to or higher than the original switch.
- A physical size compatible with the mounting.

In addition, the type of actuator (toggle, pushbutton, rocker, etc.) should be the same as the original switch. (This is desirable but not necessary. For example, a toggle switch could be used to replace a rocker switch if it were acceptable in all other ways.)

Knowledge Check

1. What two types of meters can be used to check a switch?
2. If a switch must be checked with power applied, what type of meter is used?
3. What should you check when performing preventive maintenance on a switch?

Answers to Knowledge Checks

Electrical Conductors Section

Electrical Conductors

1. To allow comparisons between conductors of different sizes and resistance.
2. 375 mils (move the decimal three places to the right).
3. A circular conductor with a diameter of 1 mil and a length of 1 foot.

Circular Mil

1. The cross-sectional area of a circular conductor with a diameter of 1 mil.
2. Circular mil Area (CMA) = D^2 (in mils) * number of strands. 0.0004 inch = 4 mils , therefore CMA = 4^2 * 19 strands = 16 * 19 = 304 mils.

Specific Resistance

1. The resistance of a unit volume of a substance.
2. Length, cross-sectional area, and specific resistance of a unit volume of the substance from which the conductor is made.

Wire Sizes

1. 1,000 ft = 10.4 ohms1,500 ft = 1.5 0.4 = 15.6 ohms In the parallel walled slot not the circular area.
2. Conductor size, the material it is made of the location of the wire in a circuit, and the type of insulation used.

Copper vs. Aluminum

1. It is light and reduces corona.
2. It has higher conductivity, it is more ductile, it has relatively high tensile strength, and it can be easily soldered.

Temperature Coefficient

1. The amount of increase in the resistance of a 1-ohm sample of the conductor per degree of temperature rise above 0º C
2. It increases.

Conductor Insulation

1. Conductors have a very low resistance and insulators have a resistance that is so great that, for all practical purposes, they are nonconductors.
2. Insulation resistance and dielectric strength.
3. The resistance to current leakage through the insulation.
4. The ability of the insulation material to withstand potential difference.
5. By raising the voltage on a test sample until it breaks down.

Types of Insulation

1. To prevent the rubber insulation from deteriorating due to chemical action.

Fuse Section

Circuit Conditions

2. To protect people and circuits from possible hazardous conditions.
3. A direct short, excessive current, and excessive heat.
4. A condition in which some point in the circuit where full system voltage is present comes in contact with the ground or return side of the circuit.
5. A condition that is not a direct short but in which circuit current increases beyond the designed current carrying ability of the circuit.
6. A condition in which the heat in or around the circuit increases to a higher than normal level

Fuse Ratings

1. Current, voltage, and time delay.
2. The amount of current the fuse will allow without opening.
3. The ability of the fuse to quickly extinguish the arc after the fuse element melts and the maximum voltage that cannot jump across the gap of the fuse after the fuse opens.
4. Delay, standard, and fast.
5. Delay-Motors, solenoids, or transformers. Standard-Automobiles, lighting or electrical power circuits. Fast-Delicate instruments or semiconductor devices.

Troubleshooting Fuses

1. Visual inspection, indicators, and using a meter.
2. Put it back in the circuit. A good fuse will have zero ohms of resistance.
3. The ohmmeter causes more than 1/500 ampere through the fuse when you check the fuse, thus it opens the fuse.
4. Use a resistor in series with the fuse when you check it with the ohmmeter.
5. Turn the power off and discharge the circuit before you remove fuses. Use a fuse puller (an insulated tool) when you remove fuses front clip-type fuse holders. When you check fuses with a voltmeter, be careful to avoid shocks and short circuits.

Switches Section

Switch Types

1. A manual switch must be turned on or off by a person. An automatic switch turns a circuit on or off without the action of a person (by using mechanical or electrical devices).
2. A light switch, an ignition switch, television channel selector, etc.
3. A thermostat, an automobile distributor, a limit switch, etc.
4. Multicontact switches make possible the control of more than one circuit or the selection of one of several possible circuits with a single switch.
5. Answers Below

a. Three-pole, single-throw (triple-pole, single-throw)
b. Double-pole, double-throw
c. Single-pole, double-throw
d. Single-pole, single-throw
e. Double-pole, triple-throw
f. Six-pole, double-throw

Troubleshooting Switches

1. An ohmmeter and a voltmeter.
2. A voltmeter.
3. The switch operation for smooth and correct operation, the terminals for corrosion, and the physical condition of the switch.

Additional Resources

Physics Resources

Georgia State University – HyperPhysics

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

Video Resources

Khan Academy – Electricity and magnetism

https://www.khanacademy.org/science/physics/electricity-and-magnetism

References

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Table of Figures

Source of figures: United State Navy NEETs, some modifications by Olympic College.