

# Unit 1. Electronic Principles

<b>1–1. Electronics Fundamentals.....</b>	<b>1–1</b>
201. Metric Notation.....	1–1
202. Electronics Theory.....	1–4
<b>1–2. Electronic Circuits.....</b>	<b>1–12</b>
203. Circuit components.....	1–12
204. Types of circuits .....	1–19
205. Circuit configurations .....	1–20
206. Laws .....	1–22
<b>1–3. Electronics Testing, Troubleshooting, and Repair .....</b>	<b>1–25</b>
207. Electronic test equipment .....	1–25
208. Diagrams.....	1–28
209. Electronics troubleshooting .....	1–34
210. Electronics preventive maintenance and repair .....	1–39

**A**S AN AEROSPACE technician, you will often find yourself working with electrical systems and occasionally having to troubleshoot them as well. Therefore, having a thorough understanding of basic electronic principles will be essential somewhere in your line work. This unit contains lessons designed to help you understand the fundamentals of electronics as well as introduce some of the more common electronic circuits and components you will be dealing with. Our last lesson will introduce some common test equipment as well as circuit analysis and troubleshooting methods used in the field of electronics.

## 1–1. Electronics Fundamentals

Before you can effectively troubleshoot an electronic system, it is vital for you to understand some of the basic concepts and principles of electronics. In this lesson we will be covering metric notation, electronics theory, some common electronics laws, and some basic electronic circuits. Let's begin by looking at some numbering systems that will help make your job a little easier.

### 201. Metric Notation

The field of electronics often involves measurements and mathematic calculations consisting of very large and very small numbers when analyzing electrical circuits. Working with these extremely large or small numbers can be a cumbersome chore; calculations often consist of unwieldy numbers, and decimal fractions can cause errors because of a misplaced decimal point or an accidental omission of a number. Therefore, it is beneficial to convert numbers into different formats so that they are easier to work with.

#### Powers of ten

The powers of ten numbering systems are ways to express very large or very small numbers in more convenient formats. Basically, a whole or mixed number is expressed as the product of a factor and the appropriate positive power of ten. Powers of ten indicate a number's significant digits and its order of magnitude.

Example:  $123,000,000 = 1.23 \times 10^6$

Likewise, a decimal fraction is expressed as the product of a factor and the appropriate negative power of ten.

Example:  $0.000000456 = 4.56 \times 10^{-7}$

Powers of ten numbers are made up of the following parts:

Coefficient	The number before the multiplication symbol. (Example: 6.4 is the coefficient of $6.4 \times 10^2$ ).
Base	The number right after the multiplication symbol that is to be multiplied by itself. When the number 10 is used as the base and matched with an exponent, it is called a power of ten.
Exponent	This is the superscript number next to the 10 and indicates the number of times 10 is multiplied times itself. This number also represents the number of places the decimal point shifts from the original number to where it ends up in the coefficient. If the decimal point moves to the left, the exponent will be positive. If the decimal moves to the right, the exponent will be negative.

For example, the mass of the earth is about 5,973,600,000,000,000,000,000,000 grams (g). That is a pretty big number to work with. To convert that to a power of ten, we first shift the decimal point to the left while counting each number of position changes.

5,973,600,000,000,000,000,000,000

After moving the decimal point 27 places to the *left*, we end up with a coefficient of 5.9736 and a *positive exponent* of 27. When written in scientific notation, it is  $5.9736 \times 10^{27}$  g.

How about an extremely small number? The mass of a proton is 0.00000000000000000000000016726 grams. To convert that to a power of ten, we first shift the decimal to the right while counting each number of position changes.

0.00000000000000000000000016726

After moving the decimal point 24 places to the *right*, we end up with a coefficient of 1.6726 and a *negative exponent* of -24. When written in scientific notation, it is  $1.6726 \times 10^{-24}$  g.

To convert a powers of ten number back to its original format, simply reverse the above steps by counting the appropriate number of decimal spaces right or left of the coefficient, filling in zeros where needed.

For example, to convert  $6.8 \times 10^6$  back to its original number, we would count six decimal spaces to the *right* (remember, move the decimal to the right if the exponent is positive and to the left if the exponent is negative), and we end up with 6,800,000.

### Scientific Notation

Scientific notation is a form of powers of ten numbering. Scientific notation uses the same basic procedures for manipulating numbers as powers of ten with one noticeable difference—the final form expressed has a *coefficient of greater than or equal to 1 but less than 10*. To write a number in scientific notation, put a decimal after the first digit and drop the zeroes. The exponent will be the number of places from the decimal to the end of the number.

Example:  $76.45 \times 10^{-3} = 7.645 \times 10^{-2}$

### Engineering Notation and Prefixes

Engineering notation is another form of the power of ten numbering system that is more commonly used in electronics. Engineering notation is accomplished using the previous methods of moving the decimal point to any convenient position in the numerical coefficient as long as the *resulting exponent is either zero or a multiple of three*. Exponents such as 9, 6, 3, 0, -3, -6, -9, and -12 allow you to express values with the International System of Units' (SI) prefixes. Prefixes such as pico, mega, kilo, and so on simplify written and spoken expressions of electrical quantities. Table 1-1 shows several common powers of ten, their metric prefix, and metric symbol.

Decimals ≥ 1	Positive Exponents	Metric Prefix	Symbol	Decimals <1	Negative Exponents	Metric Prefix	Symbol
1	10 <sup>0</sup>						
10	10 <sup>1</sup>			0.1	10 <sup>-1</sup>		
100	10 <sup>2</sup>			0.01	10 <sup>-2</sup>		
1,000	10 <sup>3</sup>	kilo	K	0.001	10 <sup>-3</sup>	milli	m
10,000	10 <sup>4</sup>			0.0001	10 <sup>-4</sup>		
100,000	10 <sup>5</sup>			0.00001	10 <sup>-5</sup>		
1,000,000	10 <sup>6</sup>	mega	M	0.000001	10 <sup>-6</sup>	micro	μ
10,000,000	10 <sup>7</sup>			0.0000001	10 <sup>-7</sup>		
100,000,000	10 <sup>8</sup>			0.00000001	10 <sup>-8</sup>		
1,000,000,000	10 <sup>9</sup>	giga	G	0.000000001	10 <sup>-9</sup>	nano	n

Table 1-1. Engineering notation and metric prefix.

It's common practice to use prefixes to represent these quantities. Think of the metric prefix as a shorthand way to express a large or small number.

Example:  $26.2 \times 10^2$  watts =  $2.62 \times 10^3$  watts = 2.62 kilowatts

### ***Expressing powers of ten as different numbers***

What if your power of ten number does not contain the exact exponent you need to express it? You must know how to convert numbers between the different powers of ten. For example, let's say you want to express the number  $12.34 \times 10^2$  in kilos ( $10^3$ )?

To do this, you simply subtract the original exponent from the new exponent that you want to end up with.

$$(3) - (2) = 1$$

If the result is positive, you move the decimal point to the left by the number of positions equal to the result.

$$1.234 \times 10^3$$

The same rule applies if you want to express a power of ten number as a regular decimal number. Just subtract the original exponent from the new exponent (remember that  $10^0$  is used to represent the number one).

Example: Express  $6.984 \times 10^4$  as a regular number.

$$(0) - (4) = -4$$

Since the result is negative, you now move the decimal point to the right the number of spaces equal to the result.

$$69,840$$

### **Performing calculations with powers of ten numbers**

The advantage of using power of ten notation is that it makes addition, subtraction, multiplication, and division of very large or small numbers easier.

### ***Addition and subtraction***

To add or subtract numbers expressed in power of ten formats, the decimal point on either or both numbers must be adjusted until the exponents of the power of ten are identical. Addition or

subtraction of the numerical coefficients are performed as usual, and the power of ten will be identical to the common exponent.

### ***Multiplication and Division***

Multiplication and division of numbers expressed in power of ten formats are more straightforward. First, perform the desired calculation on the numerical coefficients as usual. Then calculate the appropriate power of ten. For multiplication calculations, the power of ten for the result is the *sum* of the powers of ten exponents. For division calculations, the power of ten for the result is the *difference* of the divisor and dividend (numerator and denominator) exponents.

## **202. Electronics Theory**

*Electricity* is a general term used for the variety of phenomena resulting from the presence and flow of electrical charge. To better understand this, we will be discussing the following concepts of electricity: atomic structures, electrical charges, electrical potential (voltage), electric current, resistance, electrical energy, and electrical power.

### **Atomic Structure**

The electron theory assumes that all electrical and electronic effects are due to the movement of electrons from one place to another. To see how these electrons move, we first must learn about the structure of the atoms making up electrical circuits. An atom (fig. 1-1) is the smallest particle of a chemical element that retains its chemical properties and is made up of several subatomic particles: electrons, protons, and neutrons. Protons and neutrons make up a dense, massive atomic nucleus in the center of the atom and are collectively called nucleons. Orbiting the nucleus in energy levels, or shells, are the electrons.

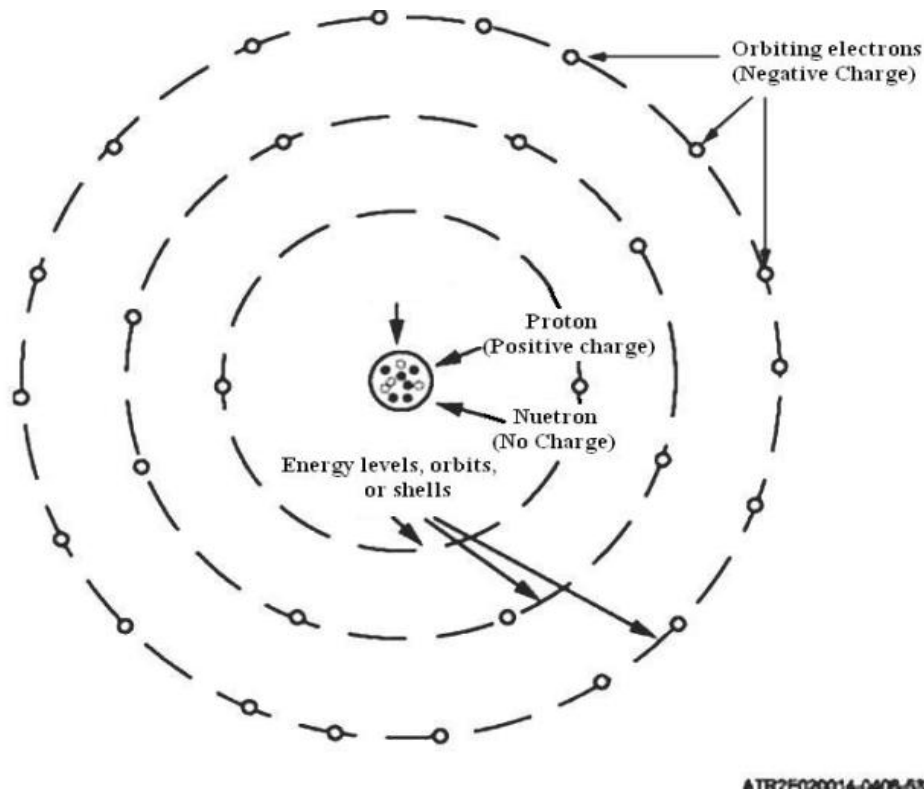


Figure 1-1. Atomic structure.

## Electric Charge

Electric charge is a property of certain subatomic particles that interact with electromagnetic fields and causes attraction and repulsion forces between them. Protons have a positive electrical charge while electrons have a negative electrical charge. Neutrons remain neutral. The atom in figure 1-1 shows that electrons travel around (orbit) the nucleus. When more than one electron is the same distance from the nucleus, those electrons have the same amount of energy as each other and, therefore, are considered to be in the same shell and have the same energy level as each other. When several electrons travel in their own orbit and are the same distance from the nucleus, they have the same amount of energy. The electrons with the same amount of energy are in the same shell or the same energy level (orbit).

The difference between atoms is that they contain different numbers of the same particles. An atom is electrically neutral when it contains the same number of positive charges in the nucleus as it has negative charges in its orbits. If they are not neutral, they are called ions. Ions are either positive or negative.

The atom (shown on the left of fig.1-2) shows six protons in the nucleus and six electrons in the outer shell. Since opposite charges (+ and -) cancel each other, the entire atom itself is considered electrically neutral or balanced.

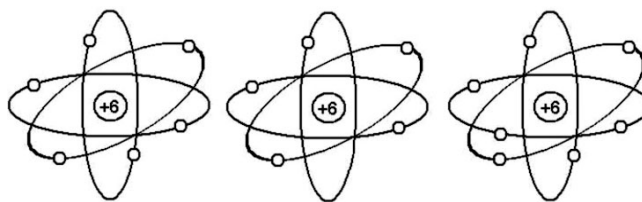


Figure 1-2. Neutral atom, positive ion, negative ion.

The atom (shown in the middle of fig. 1-2) shows six protons in the nucleus, but only five electrons in orbit. The five negative charges do not cancel the six positive charges, so the atom is not neutral. Rather, it has one more proton than electrons, which causes the atom to have a positive charge and is therefore called a positive ion.

The atom (shown on the right of fig.1-2) shows six protons, but now there are seven electrons. Having more electrons than protons causes the atom to have a negative charge and, therefore, is called a negative ion.

So how do atoms give up or receive electrons? In order for an electron to fall to a lower shell, there must be room in the next lower shell, and the electron must give up a definite amount of energy. In certain instances, that energy is given up in the form of light. Similarly, electrons can move from one shell to a higher shell if there is room in the next higher shell, and the electron can absorb enough energy.

The energy needed to cause an electron to move to a higher shell can come from several external sources. Figure 1-3 shows sources like heat energy, light energy, magnetic energy, pressure energy, chemical (dry-cell battery) energy, and friction (static) energy.



Figure 1-3. Sources of energy.

In order for an atom to become an ion, it must lose or gain electrons in its outer shell. This gain or loss is called ionization. Figure 1-4 shows an atom with electrons in four shells. The inner shell (see fig. 1-1) has the most attraction to the nucleus and has the least amount of energy. The outer shell (fig. 1-4) has the least attraction to the nucleus and the most amount of energy. The electrons in the outermost shell are called valence electrons. If a valence electron absorbs sufficient energy, it attempts to move to a higher shell. In the process of moving, it can escape the attraction of the nucleus and becomes a free electron. The amount of energy needed to free an electron from an atom is determined by the type of the atom. Free electrons randomly drift around in the material. Some solid materials such as copper, gold, and silver literally have billions of free electrons randomly drifting about throughout the material.

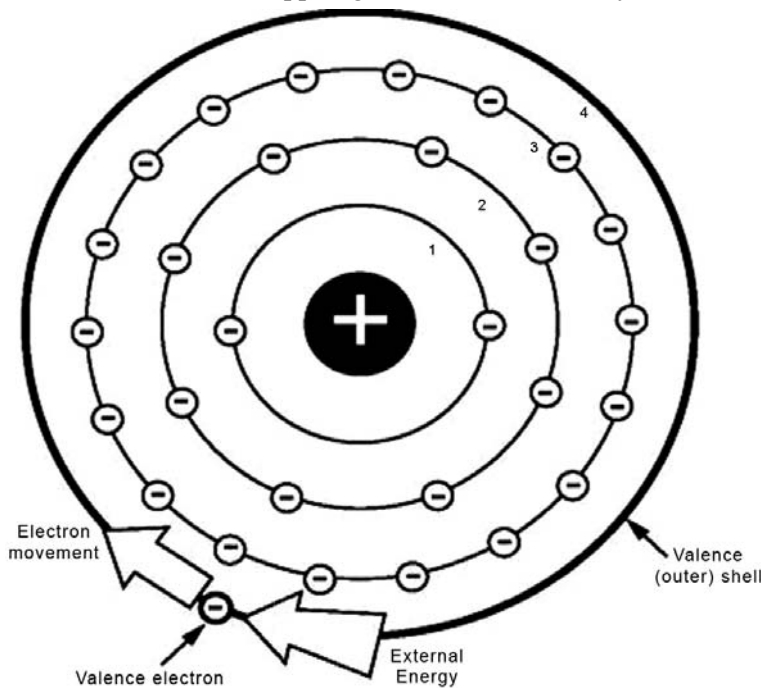


Figure 1-4. Atom.

The movement of electrons transfers energy from point to point. When a valence electron absorbs energy and becomes a free electron, the charge balance of an atom is upset. If one valence electron leaves the shell of a neutral atom, then the atom will be left with more protons (+) than electrons (-). Thus, the overall charge of the atom is now positive making it a positive ion.

Once a valence electron (-) escapes the shell of an atom and becomes free, it no longer has a counterbalancing effect of a corresponding proton (+) in the nucleus. The free electron may lose energy and fall into a shell around a neutral atom. When

this occurs, the atom that the electron falls into will have one additional orbiting electron (-) than corresponding protons (+) in the nucleus. The overall charge on the atom will be negative making it a negative ion.

Positive ions, negative ions, and free electrons are all important concepts in the study of electronics. When an electron moves from one neutral atom to another, the original atom becomes a positive ion, and the receiving atom becomes a negative ion. The free electrons are capable of moving from one atom to another. This movement of free electrons is known as electron flow.

How energy moves from one point to another was briefly explained. Electronics is based on this flow of energy. How a circuit is designed and what a circuit does is dependent on controlling electron flow. A good example is the difference of current flow in conductors, semiconductors, and insulators. In the study of electronics, the association of matter and electricity is important. Since every electronic device is constructed of parts made from ordinary matter, the effects of electricity on matter must be well understood. As a means of accomplishing this, all elements of which matter is made may be placed into one of three categories depending on their ability to conduct electricity: conductors, semiconductors, and insulators. Conductors are elements such as silver, copper, gold, and aluminum, which conduct electricity very readily. Insulators are those materials, such as wood and glass, that oppose the conduction of electricity. All matter between these two extremes may be called semiconductors. Semiconductive materials such as germanium and silicon are widely used in today's

electronic circuits because of their ability to have their electrical properties controlled by external forces such as temperature and voltage.

Conductors have many free electrons that move easily in the material. The electrical conductivity of matter is dependent upon the atomic structure of the material from which the conductor is made. How easily electrons will move through a conductor has to do with the amount of opposition the conductor offers to the movement of electrons. In solid materials such as copper, the atoms which make up the molecular structure are bound firmly together. At room temperature, copper will contain a considerable amount of heat energy. Since heat energy is one method of removing electrons from their orbits, copper will contain many free electrons that can move from atom to atom. Remember, free electrons are those valence electrons that have escaped from their outer orbit.

### Voltage

Electrical potential, or voltage, is the force or electrical energy required to move electrons from one place to another.

Symbol for Voltage: Letter **E**

Unit of measurement: **Volt**

Symbol for unit of measurement: Letter **V**

The difference in electrical potentials between two points in an electric field (the space surrounding an electric charge) is known as the electrical potential difference. This difference is proportional to the electrostatic force that tends to push electrons or other charge carriers from one point to the other. Potential difference, electrical potential, and electromagnetic force are measured in volts, leading to the commonly used term *voltage*.

To have an electrical energy source, such as a battery (fig. 1-5), one terminal must be more positive or more negative than the other. This condition may be referred to as a *difference of potential*, an *electromotive force*, a *potential*, or a *voltage*. All of the terms are correct; however, voltage is the most commonly used.

Battery terminals (or any other points) having unequal electrical charges have the capacity to move electrical charges through a resistance because of this difference of potential energy. An automobile battery has an electromotive force, potential difference, or voltage of 12 volts. It is correct to say that the automobile battery voltage equals 12 volts, or  $E = 12$  Volts.



Figure 1-5. Common batteries.

### Current

Electric current flow is the movement of free electrons through a conductor. The rate of movement is measured in *amperes*. One ampere represents the movement of a specific number of electrons ( $6.28 \times 10^{18}$  electrons = 1 coulomb = unit of electric charge) past a certain point in a conductor in one second.

Symbol for Current: Letter **I**

Unit of measurement: **Ampere**

Symbol for unit of measurement: Letter **A**

When controlled by an external force, the electrons move generally in the same direction. The effect of this movement is felt almost instantly from one end of the conductor to the other. The electron movement is called electric current.

*Electric current*, defined historically as *conventional current*, is the term used for current flow from the most positive part of a circuit to the most negative part. However, to simplify circuit analysis, most electronics illustrations depict “electron current” flow from the most negative part of a circuit to the most positive part since it is only the negatively charged electrons that actually flow.

It should be noted that depending on the conditions, an electric current can consist of a flow of charged particles in either direction or even in both directions at once.

A direct current (DC) is a unidirectional flow, while an alternating current (AC) reverses direction repeatedly.

### **Resistance**

Resistance is the opposition a device or material offers to the movement of electrons and is measured in ohms.

Symbol for resistance: Letter **R**

Unit of measurement: **Ohms**

Symbol for unit of measurement: Greek Letter Omega ( $\Omega$ )

When there is current in a material, the free electrons move through the material and occasionally collide with atoms. These collisions cause the electrons to lose some of their energy and restrict their movement. The more collisions mean the more opposition to the flow of electrons. The higher the resistor value, the greater the opposition to current flow.

### **Impedance**

Electrical impedance, or simply impedance, is a measure of the combined opposing forces to an alternating electric current.

Symbol for impedance: Letter **Z**

Unit of measurement: **Ohms**

Symbol for unit of measurement: Greek Letter Omega ( $\Omega$ )

Unlike electrical resistance even though both are measured in ohms, the impedance of an electric circuit can be a complex number because it is determined by the vector sum of a circuit's resistance, capacitive reactance, and inductive reactance.

### **Power**

Electric power is the rate at which electrical energy is produced or consumed and is measured in watts.

Symbol for Power: Letter **P**

Unit of Measurement: **Watt**

Symbol for unit of measurement: Letter **W**

Energy is typically defined as the ability to do work or, more specifically, the work resulting from a force acting on mass over a distance. Electrical energy is the energy that's stored in an electric field or transported by an electric current. Some examples of electrical energy include:

- The energy that is constantly stored in the earth's atmosphere and is partly released during a thunderstorm in the form of lightning.



- The energy that is stored in the coils of an electrical generator in a power station and is then transmitted by wires to the consumer; the consumer then pays for each unit of energy received.
- The energy that is stored in a capacitor and can be released to drive a current through an electrical circuit.

The operation of electrical circuits involves force (voltage) acting on mass (electrons) over a distance. As mentioned, energy is the capacity to do work, so in electrical circuits, energy is transformed into heat energy. When electrons flow through a conductor, the free electrons lose energy as they collide with atoms in the material. When there is current through a resistor, energy is converted to heat. Power, therefore, can be viewed as the measure of how much energy is being converted to heat.

A common example of this is the light bulb. The current through the filament that produces light also produces heat because the filament has some opposition to current. All electrical devices dissipate or consume power. When an electrical component such as a light bulb or a stereo is connected to and draws current from a voltage source, the component is considered a load on that voltage source. Every load device has a certain amount of resistance. This is load resistance. Load resistance is the resistance or opposition of the load device to current. Load current is the current drawn from the voltage source by the load device.

### **Inductance**

Inductance is an effect which results from the magnetic field that forms around a current-carrying conductor. Electrical current through the conductor creates a magnetic flux proportional to the current. A change in this current creates a change in magnetic flux that, in turn, generates an electromotive force (EMF) that acts to oppose this change in current. Inductance is a measure of the generated EMF for a unit change in current.

Symbol for Inductance: Letter **L**

Unit of Measurement: **Henry**

Symbol for unit of measurement: Letter **H**

### **Capacitance**

Capacitance is a measure of stored energy between two conductive electrodes, or plates, separated by an insulator (otherwise known as a capacitor). A capacitor can store electric energy when disconnected from its charging circuit, so it can be used like a temporary battery.

Symbol for Capacitance: Letter **C**

Unit of Measurement: **Farad**

Symbol for unit of measurement: Letter **F**

### **Reactance**

Reactance is the imaginary part of impedance and is caused by the presence of inductors or capacitors in the circuit. Reactance produces a phase shift between the electric current and voltage in the circuit.

Symbol for Reactance: Letter **X**

Unit of Measurement: **Ohms**

Symbol for unit of measurement: Greek Letter Omega ( **$\Omega$** )

Inductive reactance (symbol  $X_L$ ) is caused by the fact that a current is accompanied by a magnetic field; therefore, a varying current is accompanied by a varying magnetic field—the latter gives an electromotive force that resists the changes in current. The more the current changes, the more an

inductor resists it: the reactance is proportional to the frequency (hence zero for DC). There is also a phase difference between the current and the applied voltage.

Capacitive reactance (symbol  $X_C$ ) reflects the fact that electrons cannot pass through a capacitor, yet effectively alternating current can: the higher the frequency the better. There is also a phase difference between the alternating current flowing through a capacitor and the potential difference across the capacitor's electrodes.

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### **Self-Test Questions**

**After you complete these questions, you may check your answers at the end of the unit.**

#### **201. Metric notation**

1. What is the benefit of converting numbers to the metric notation format?
2. What is a base number?
3. Express the following numbers in powers of ten format:
  - (1) 6,000.
  - (2) 250,000.
  - (3) 0.00038.
  - (4) 0.049.
4. Express the following numbers in decimal format:
  - (1)  $4.6 \times 10^{-4}$ .
  - (2)  $15 \times 10^5$ .
5. What makes scientific notation different than other powers of ten numbers?
6. What makes engineering notation different than other powers of ten numbers?

7. Express the following numbers in engineering notation:

(1)  $1.245 \times 10^2$ .

(2) 68,475.

(3) 0.0000453.

(4)  $9.83 \times 10^{-4}$ .

8. Perform the following calculations:

(1)  $12.34 \times 10^3 + 5.35 \times 10^4$ .

(2)  $6.43 \times 10^5 - 12.1 \times 10^2$ .

(3)  $5.78 \times 10^3 \times 13.5 \times 10^2$ .

(4)  $75.5 \times 10^2 / 2.5 \times 10^{-3}$ .

## 202. Electronics theory

1. Match the description in column A with the item in column B. Items in column B may be used once, more than once, or not at all.

<i>Column A</i>		<i>Column B</i>
____ (1)	The force or electrical energy required to move electrons from one place to another.	a. Ion
____ (2)	Is measured in farads.	b. Atom
____ (3)	Has a neutral electrical charge.	c. Proton
____ (4)	The ability to do work.	d. Energy
____ (5)	The rate at which electrical energy is produced or consumed.	e. Power
____ (6)	Can have either a positive or negative electrical charge.	f. Voltage
____ (7)	The smallest part of a chemical element.	g. Current
____ (8)	The movement of free electrons through a conductor.	h. Neutron
____ (9)	Has a negative electrical charge.	i. Electron
____ (10)	The effect that results from the magnetic field that forms around a current-carrying conductor.	j. Resistance
____ (11)	Its symbol is the Greek letter omega.	k. Inductance
____ (12)	Has a positive electrical charge.	l. Capacitance

## 1-2. Electronic Circuits

Electronic circuits are used in systems to perform a wide variety of tasks. The main uses of electronic circuits are to do the following:

- Control and process data.
- Distribute and convert to/from electric power.

Both of these applications involve the creation and/or detection of electromagnetic fields and electric currents. An electrical circuit is made up of a network of two or more components connected by conductors that has a closed loop, giving a return path for current flow. Let's begin by taking a look at the components that make up electrical circuits.

### 203. Circuit components

An electrical component is any component used in the generation, transmission, distribution, or consumption of electric power. The minimum requirements for a simple circuit (fig. 1-6) are a power source, load device(s), and conductor(s). However, additional circuit components are usually added to provide control, protection, and monitoring capabilities.

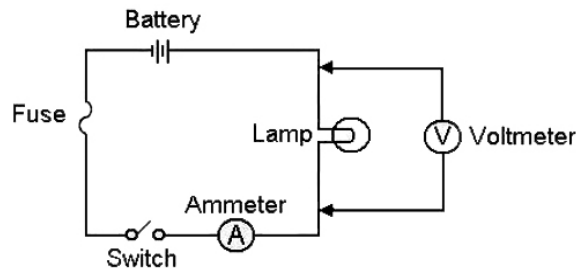


Figure 1-6. Simple circuit.

#### Power sources

All electronic circuits require some source of energy in order to operate. Some of the more common sources for providing power are batteries, generators, and power supplies.

#### Batteries

A battery is a device that converts chemical energy to electrical energy. A multicell battery consists of two or more cells in a series (connected end-to-end). The negative terminal of one cell is connected to the positive terminal of another cell and so on to increase the battery's voltage potential. Batteries can also be wired in parallel to increase their capacity.

#### Generators

An electrical generator is a device that converts mechanical energy to electrical energy, generally using the principle of electromagnetic induction. A force is required to provide the mechanical energy necessary to turn the rotor shaft of the generator and produce an electrical output. The driving force producing this mechanical energy input is called the prime mover. The prime mover can be any source of rotary motion such as that provided by waterfalls, windmills, steam engines, diesel engines, aircraft engines, or nuclear driving sources. Generator output is independent of the type of prime mover used, other than the requirement for a relatively constant rotational speed. A generator's output voltage is controlled by a voltage regulator. A voltage regulator changes the output voltage by varying the resistance of the generator's field circuit. Generators are rated in voltage amperes; in other words, how many volts they can produce at how many amps per phase.

### Power supplies

A power supply, sometimes known as a power supply unit (PSU), is a device or system that supplies electrical or other types of energy to an output load or group of loads. The term is most commonly applied to electrical energy supplies such as rectifiers and inverters. Rectifiers are used to convert AC to DC while inverters are used to convert DC to AC.

### Load devices

A load is any device or circuit that absorbs power. Appliances plugged into a wall outlet are common examples of load devices. There are many electrical components that fit into this category, so we will only discuss a few of the main ones.

### Lamp

A lamp produces light from electricity and is often used to provide a visual indication of current flow. There are a wide variety of lamps used in electronics from standard filament-type lamps to light emitting diodes (LED). Refer to figure 1-6 to see the circuit symbol for a lamp.

### Resistor

A resistor is a passive device used to regulate current in a circuit. Electronic equipment uses a wide variety of resistors made of resistive wire, metal film, or carbon composition. The two most common types of resistors are fixed and variable.

#### Fixed resistor

Many fixed resistors use a pattern of four, five, or six colored stripes (or bands) painted around the body of the resistor to indicate their resistance and tolerance values. The top half of figure 1-7 shows three resistor examples with the four, five, and six colored bands.

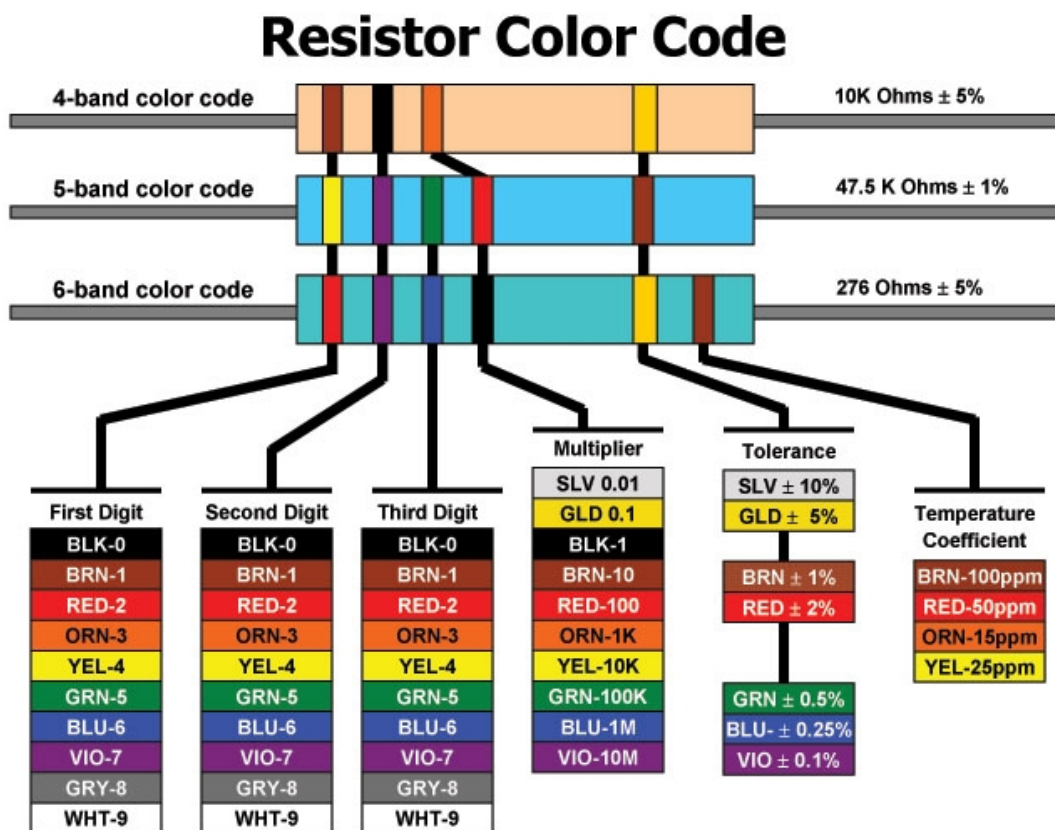


Figure 1-7. Resistor color codes. (Reproduced by permission of University of Colorado, Bolder, CO, <http://www.colorado.edu>.)

Being able to read and understand what these colored bands mean will be important for you as a technician when you troubleshoot and replace components.

To determine a resistor's value from the color bands, you must first know from which end to start reading. For example, let's use the top resistor shown in figure 1-7 with the following colored bands: brown, black, orange, and gold.

First, find the tolerance band of the resistor which will actually be the last band you need to be concerned with. The tolerance band is typically gold or silver; however, on those resistors with five or six bands, it can be any color except black, orange, yellow, or white. Once the tolerance band is found, position the resistor so that the tolerance band is on the right.

Starting from the left side of the component with the first color band brown, use figure 1-7 to find the corresponding number. Since brown corresponds with the number 1, write down the number 1.

Now read the second color band, black, and write down the number 0.

Now read the third color band, orange, and write down that number of zeros (orange is three zeros, so write down three 0's).

We end up with "10,000" or "10K," which is the amount of the resistor's resistance in ohms.

**NOTE:** If the multiplier is black, do not write down any zeros. If the multiplier band is gold, you would move the decimal point one place to the left. If the multiplier band is silver, you would move the decimal point two places to the left.

Notice that the fourth color band is gold. That band is the tolerance band which indicates how close to the previous three color bands the actual resistor's value can be. According to figure 1-7, gold happens to represent 5 percent, so the actual value of the resistor can be anywhere from 9,500 ohms to 10,500 ohms.

Resistors having a sixth color band use that last band to represent the temperature coefficient of the component. The temperature coefficient indicates up to how much the component's resistance can change per degree of temperature change.

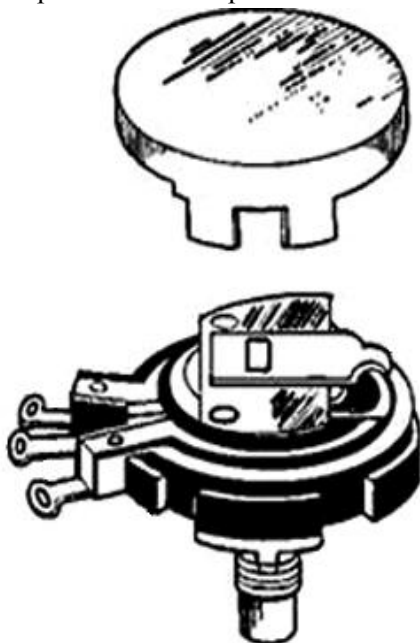


Figure 1-8. Variable resistor.

An easy way to remember which colors equal which numbers is to use a mnemonic. A mnemonic is a memory aid that associates the first letter of a series of words with the first letter of the color codes in ascending order. For example, **B**ad **B**oys **R**avish **O**ur **Y**oung **G**irls **B**ehind **V**ictory **G**arden **W**all. The word "Bad" is associated with the first color black-0, "Boys" with the second color brown-1, and so on up to "Wall" being white-9. There are many variations on the resistor color code mnemonics, but the important thing is to use one that is easy for you to remember.

#### *Variable resistor*

The variable resistor (fig. 1-8) is a resistor whose resistance value can be adjusted, which in turn allows a circuit's current value to be increased or decreased. Variable resistors, also called potentiometers or rheostats, are operated by turning a shaft or sliding a control. A common use of variable resistors is for dimming lights.

***Inductor***

Inductors are passive devices commonly used in signal processing circuits for their property of inductance, which, as you may recall, oppose changes in current. An inductor is usually constructed as a coil of conducting material, typically copper wire, wrapped around a core either of air or of ferromagnetic material. Core materials with a higher permeability than air confine the magnetic field closely to the inductor, thereby increasing the inductance. The opposition offered by a coil to the flow of alternating current is called inductive reactance.

***Capacitor***

A capacitor is a passive electrical device that opposes changes in voltage and can be used to store energy in the electric field between a pair of closely spaced conductors called plates. When voltage is applied to the capacitor, electric charges of equal magnitude, but opposite polarity, build up on each plate. They can also be used to differentiate between high-frequency and low-frequency signals, and this makes them useful in electronic filters.

***Semiconductor devices***

Semiconductor devices are electronic components that exploit the electronic properties of certain semiconductive materials—typically silicon, germanium, and gallium arsenide. They use electronic conduction in the solid state by introduction of an electric field or from exposure to light, pressure, or heat; thus, semiconductors can make excellent sensors.

***Diode***

A diode is an active component that restricts the direction of movement of charge carriers. Essentially, it allows an electric current to flow in one direction but blocks it in the opposite direction. Thus, the diode can be thought of as an electronic version of a check valve.

***Transistor***

A transistor is a semiconductor device that uses a small amount of voltage or electrical current to control a larger change in voltage or current. A transistor can be thought of as an electronic version of a switch and is the fundamental building block of the circuitry that governs the operation of all modern electronics.

***Electromagnetic devices***

Electromagnetic devices exploit the properties of the region of space where electric charges experience a physical influence. This region is commonly called the electromagnetic field. The term *electromagnetism* comes from the fact that electrical and magnetic forces are involved simultaneously. The phenomenon of electromagnetic induction, which provides for the operation of electrical generators, induction motors, and transformers, is based on the principle that a changing electric field generates a magnetic field. Similarly, a changing magnetic field produces an electric field.

***Transformers***

A transformer is a device that is used to transfer electrical energy from one circuit to another by means of an electromagnetic field. One circuit is connected to a power source and is referred to as the primary. The other circuit is connected to a load device and is referred to as the secondary.

Transformers operate using the principles of mutual induction and electromagnetism as there are no direct connections between the primary and secondary windings. A transformer may perform several functions depending on its purpose in the circuit; it may increase (step up) voltage and decrease the current, decrease (step down) voltage and increase current, isolate circuits, match impedance of different circuits, or shift phases between circuits. Accordingly, transformers come in a range of sizes and can be classified in many ways such as by its power level, frequency, voltage class, or by a ratio of the amount of voltage required to step up or down.

### *Relays and Solenoids*

Relays and solenoids are used for controlling or switching electrical circuits from a remote location. The primary circuit is the controlling or actuating circuit. The current flow that energizes the coil of the relay is the primary current. The secondary circuit is the controlled circuit. A relay's contacts are made to close or open. Closed contacts provide continuity in the controlled or secondary circuit of a relay; open contacts remove continuity from the secondary circuit. The configuration of contacts available may offer one or many secondary circuit paths. One possible application of a relay is to use a single primary current path to control several secondary current paths.

### *Motors*

Electric motors convert electrical energy into mechanical energy. They come in many types and sizes that allow them to perform different tasks. They work on the principle that electrical energy develops a magnetic field that produces a mechanical force. The mechanical force of attraction and repulsion rotates a shaft 360 degrees. DC motors are commonly used in battery-operated devices such as drills, shavers, toys, or larger items, such as a golf cart. They are also found in some AC devices after being rectified for use in low-voltage applications such as video cassette recorders and compact disc players.

### **Conductors**

Of course, simply having a power source and load device does not make a circuit. They must be connected for continuity. This is usually accomplished by wiring or soldering the components together resulting in a closed loop. On electronic drawings, or schematics, wires are illustrated as the line(s) that connect two or more components together.

### **Wiring**

A wire is a single, usually cylindrical, elongated strand of drawn metal.

### *Types*

There are several types of wiring used to carry electricity and telecommunications signals.

Solid	Solid wire or solid-core wire consists of one piece of metal wire.
Stranded	Stranded wire is composed of a bundle of small-gauge wires wrapped in a particular pattern inside insulation to make a larger conductor. Stranded wire is more flexible than a solid strand of the same overall gauge.
Cables	Cables are two or more wires that are bound together, typically in a common protective jacket or sheath.
Twisted pairs	Twisted-pair cabling is a form of wiring in which two conductors are wound together for the purposes of canceling out radio frequency interference and electromagnetic interference (RFI/EMI) from external sources and cross talk from neighboring wires.
Coaxial	Coaxial cable is made up of two wires: a wire conductor in the center and a circumferential outer conductor with an insulator separating the two conductors. The dimension and material of the conductors and insulation determine the cables' characteristic impedance and attenuation at various frequencies.
Fiber-optic	Fiber-optic cables are not made out of metal but rather glass or plastic fibers that are designed to guide light along the fiber length by total internal reflection. A layer of cladding surrounds the fiber to redirect light and keep it within the core. Fiber-optic cables are often used as a medium for telecommunication and networking because they offer the advantages of improved bandwidth and noise immunity over traditional types of wiring.



### Sizes

Standard wire sizes are determined by various gauges. The American Wire Gauge (AWG) is commonly used as a standard method of denoting cable and wire diameters. Increasing gauge numbers give decreasing wire diameters. For example, a 22AWG wire has a smaller diameter than an 18AWG wire. The primary consideration when selecting any electric wire or cable size is the cable's current-carrying capacity and its allowable voltage drop. Fiber-optic cables, which will be talked about in more detail later, are rated by size a little differently than standard wires. Fiber-optic cables are sized according to their core and cladding sizes. For example, a number of "62.5/125 micrometers ( $\mu\text{m}$ )" would indicate the cable's core and cladding sizes, respectively, in microns (mc.).

### Soldering

Soldering is a method of joining metal parts using a filler material (solder) that has a low melting point, typically below 450 degrees Celsius ( $450^{\circ}\text{C}$ ) ( $842^{\circ}\text{Fahrenheit [F]}$ ). In the soldering process, heat is applied to the parts to be joined causing the solder to melt and be drawn into the joint by capillary action. The most frequent application of soldering is assembling electronic components to printed circuit boards (PCB). PCBs are used to mechanically support and electrically connect electronic components using conductive pathways, or traces, etched from copper sheets laminated onto a nonconductive substrate.



Figure 1-9. SPST schematic symbol.

### Control devices

Control devices allow the operator to control the aspects of the circuit's operation. The most common control device is the switch. A switch is a device for changing the flow of current in a circuit; a switch, when closed, provides zero resistance to the circuit while an open switch introduces an infinite amount of resistance. Switches are commonly used to apply power or to control a certain function of a circuit. There are several types of switches, but you will primarily be concerned with single-pole single-throw (SPST), single-pole double-throw (SPDT), and double-pole double-throw (DPDT) switches.

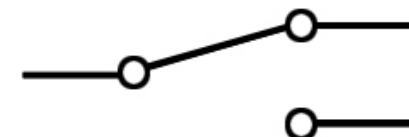


Figure 1-10. SPDT schematic symbol

### Single-pole single-throw switch

An SPST switch is a simple on-off switch, such as a light switch, that either opens or closes the circuit. The **P** refers to the term *pole*, which is the movable portion or arm of the switch. The **T** is the *throw*, which identifies the number of circuits that the pole opens or closes when the switch is operated. The schematic symbol for a SPST switch is shown in figure 1-9.

### Single-pole double-throw switch

An SPDT switch is a toggle switch that provides a continuity path to one of two possible circuits. Figure 1-10 shows the switch, or "bat" that toggles between one of the two circuit paths. An example of a SPDT switch is an AM/FM selector switch on a radio.

### Double-pole double-throw switch

A DPDT switch provides twice the options as a SPDT switch. It could be used to connect two circuits together by throwing one switch that is mechanically connected as illustrated by the dashed line. The schematic symbol for a DPDT switch is shown in figure 1-11.

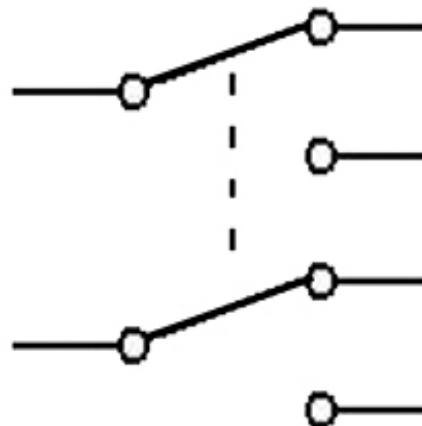


Figure 1-11. DPDT schematic symbol.

## Protective devices

Protective devices provide current limiting with the purpose of protecting circuits from the harmful effects of excess current flow. Excess current, if permitted to flow, can cause circuitry to become hot and melt, resulting in an open circuit and possibly damaging components along the way. Current limiters can reduce the peak current flowing in a circuit by taking the excess current for a short period until the fault clears or until additional protective devices activate. The most common protective devices are fuses and circuit breakers.

### Fuses

A fuse is a type of overcurrent protection device. Its critical component is a thin metal wire that will melt when heated by a prescribed electric current, opening the circuit of which it is a part, and so protecting the circuit from an overcurrent condition. Fuses are rated with current and voltage ratings that indicate the maximum circuit current and voltage in which the fuse can be used. Fuses should be replaced with only suitable substitutes even though many fuses are physically the same size. You can replace a blown (open) fuse with another having the same size, voltage, and current characteristics, or it is permissible to use one with a larger voltage rating and/or a smaller current rating. For example, fuses carrying a 250V rating can be safely used in a 125V circuit, but a 125V fuse cannot be used in a 250V circuit as the fuse may not be capable of safely interrupting the arc in a circuit of a higher voltage. Conversely, fuses carrying a 2 amp rating can be safely used in a 5 amp circuit, but a 5 amp fuse cannot be used in a 2 amp circuit.

### Circuit breakers

A circuit breaker serves the same purpose as a fuse, but it works a little differently. When excessive current passes through a circuit breaker, it energizes and creates a break in the circuit. When this happens, the circuit breaker is said to have “tripped” or “popped.” An advantage of the circuit breaker over the fuse is the ability to reset and reuse the circuit breaker after the overload has been removed, while the fuse must be replaced.



Figure 1-12. Chassis ground.

### Ground

Ground is a point in a circuit used as a common reference point from which voltages are measured. Voltages may be either positive or negative with respect to ground, which has a potential of zero volts. You are probably familiar with the electrical ground on an automobile where the chassis is the common reference point. Ground may be either an earth ground, which means that point has been connected to a metal stake driven into the earth; or as in the case of most electronic equipment, the ground symbol denotes the metal chassis. When completing each electrical circuit, common points are connected directly to the metal chassis; current flows through the metal chassis (conductor) to reach other points of the circuit. A schematic example of using the chassis as ground is illustrated in figure 1-12.

**Putting it all together**

From our previous discussion we know that there are three basic requirements for current flow:

- There must be a source of electromotive force (voltage), such as a battery.
- There must be a conductor material, such as copper wire.
- There must be continuity, meaning there is a complete path for current flow.

Once these requirements are met, recall how current flows. Remember, the electron is the basic unit of electric charge. An atom with an equal number of electrons and protons is neutral but becomes electrically charged when it either gains or loses electrons. Charged matter either attracts or repels other matter as stated in the Law of Electric Charges:

- Like charges repel each other.
- Unlike charges attract each other.

In the conductor, electrons always move from the most negative point to the most positive. Current flow results when the movement of free electrons moves in the same direction from the negative terminal through a circuit to the positive terminal of the battery. This basic understanding of current flow can now be applied to each type of circuit configurations.

**204. Types of circuits**

There are three types of circuits: analogue, digital, and mixed signal.

**Analogue Circuits**

Analogue circuits use a continuous range of voltage as opposed to discrete voltage levels as in digital circuits. Most analogue electronic appliances, such as radio receivers, are constructed from combinations of a few types of basic circuits. The number of different analogue circuits so far devised is huge, especially because a circuit can be defined as anything from a single component, to systems containing thousands of components.

***Advantages***

Analogue circuits are several times faster than their digital counterparts. Depending on the operation, analogue circuits can be several hundreds, or hundreds of thousands, of times faster than digital circuits.

***Disadvantages***

The primary disadvantage of analogue circuits is that any such system has noise—random disturbances or variations—in it. As the signal is copied and recopied, or transmitted over long distances, these random variations become dominant and lead to signal degradation. Because of the way information is encoded in analogue circuits, they are much more susceptible to noise than digital circuits, since a small change in the signal can represent a significant change in the information present in the signal and can cause the information present to be lost, corrupted, or otherwise made useless.

**Digital circuits**

Digital circuits are electric circuits based on a number of discrete voltage levels. Digital circuits are the most common physical representation of Boolean algebra and are the basis of all digital computers. To most engineers, the terms *digital circuit*, *digital system*, and *logic* are interchangeable in the context of digital circuits. In most cases, the number of different states of a node is two, represented by two voltage levels labeled “low” and “high.” Often “low” will be near zero volts and “high” will be at a higher level depending on the supply voltage in use.

### Advantages

Digital systems offer some key advantages over analogue circuits in that they interface well with computers and are easy to control with software. It is often possible to add new features to a digital system without changing hardware and to do this remotely just by uploading new software. Design errors or bugs can be worked around with a software upgrade after the product is in customer hands.

Information storage is also much easier in digital systems than in analogue ones. In particular, the great noise immunity of digital systems makes it possible to store data and retrieve it later without degradation. In an analogue system, aging and wear and tear will degrade the information in storage, but in a digital system, as long as the wear and tear is below a certain level, the information can be recovered perfectly. Digital signals can thus be regenerated to achieve lossless data transmission, within certain limits. Analogue signal transmission and processing, by contrast, always introduces noise. Theoretically, there is no data loss when copying digital data. This is a great advantage over analogue systems, which faithfully reproduce every bit of noise that makes its way into the signal.

### Disadvantages

Digital circuits tend to use more energy than analogue circuits to accomplish the same calculations and signal processing tasks, thus producing more heat as well. In portable or battery-powered systems, this can be a major limiting factor, but in a situation where power is plentiful, a digital system is often preferred because of all the advantages listed above, especially that of (re)programmability and ease of upgrading without requiring hardware changes.

Another disadvantage of digital circuits is that they are sometimes more expensive, especially in small quantities. Fragility is also a potential disadvantage of digital systems, in that if a single piece of digital data is lost or misinterpreted, the meaning of large blocks of related data can completely change.

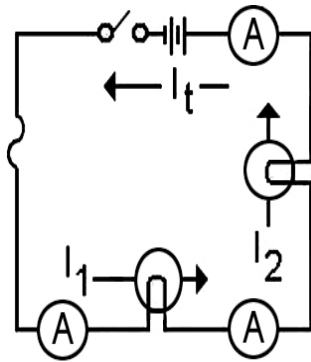


Figure 1-13. Series circuit.

### Mixed signal

Mixed circuits contain both analogue and digital components. Some analogue circuitry these days may use digital or even microprocessor techniques to improve upon the basic performance of the circuit. This type of circuit is usually called mixed signal.

Typically, mixed-signal chips perform some whole function or subfunction in a larger assembly such as the radio subsystem of a cell phone or the read-data path and laser-sled control logic of a DVD player. They often contain an entire system on a chip.

Because of the use of both digital signal processing and analogue circuitry, mixed-signal integrated circuits (IC) are usually designed for a very specific purpose, and their design requires a high level of expertise.

## 205. Circuit configurations

There are three basic types of circuit configurations: series, parallel, and series-parallel circuits. The ability to identify the circuit characteristics of each and how it operates is a must to understand circuit operation in the electronic career field.

### Series circuits

The most basic circuit configuration is the series circuit as shown in figure 1-13. It is called a series circuit, or sometimes called a cascade-coupled or daisy-chain-coupled circuit, because all of the components are connected end to end, resulting in only one possible path for current to flow.

Once the switch is closed, current is shown flowing from the negative side of the battery or power source, through the switch, the fuse, and the lamp back to the positive side of the battery. A conductor/wire connects the components in series (end to end).

Because there is only one path for current to flow, *all elements in a series connection have equal currents*. This can be expressed in formula as:

$$I_{total} = I_{L1} = I_{L2}$$

Each lamp, however, offers a certain amount of opposition or resistance to current flow. Therefore, the total resistance in a series circuit is the sum of all of the individual resistances. This is expressed in formula as:

$$R_{total} = R_{L1} + R_{L2}$$

### Parallel circuits

The parallel circuit is a little more complicated than the series circuit. In a parallel circuit, the load devices are connected in parallel with each other and the voltage source. It is often necessary to connect electrical devices so the entire source of voltage is across each device. This forms multiple paths or branches for current to flow. This physical electrical interface where many devices share the same electric connection is sometimes called an electrical bus.

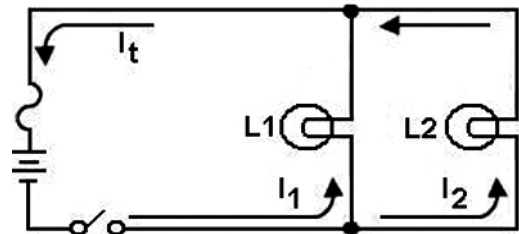


Figure 1-14. Parallel circuit.

Figure 1-14 shows a practical DC parallel circuit. Notice at the top of the circuit, L1 and L2 are showed connected together and are electrically one point when the switch is closed. Similarly the bottoms of L1 and L2 comprise another electrical point. The applied voltage appears between the top and bottom of both lamps. This is an important point to remember about parallel circuits. When components are connected in parallel across a voltage source, each branch has the same voltage. Therefore, *voltage is common among branches in a parallel circuit*. The voltages in this parallel circuit can be expressed as follows:

$$E_{Source} = E_{L1} = E_{L2}$$

As shown in figure 1-14, there are two separate and complete paths for current to flow. Current will divide among the branches in the parallel circuit in a manner depending on the amount of resistance in each branch and then come back together after they go through the branches. Branches with low resistance will draw more current than branches with high resistance as current will follow the path of least resistance.

The total current in the parallel circuit shown is the sum of the currents in the individual branches and may be expressed mathematically as follows:

$$I_{total} = I_{L1} + I_{L2}$$

Example: If  $I_{L1}$  is  $2A$  and  $I_{L2}$  is  $3A$ , then  $I_{total} = 2A + 3A = 5A$ .

The total resistance of all the components in a parallel circuit is the reciprocal of the sum of the individual reciprocals of each resistance of each component. This is mathematically expressed as follows:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

Example:  $R_{L1} = 10K\Omega$  and  $R_{L2} = 20K\Omega$

$$1/R_{total} = 1/10K\Omega + 1/20K\Omega$$

$$1/R_{total} = 0.0001 + 0.00005$$

$$R_{total} = 1/(0.0001 + 0.00005)$$

$$R_{total} = 6666.67\Omega$$

### Series-parallel circuits

The series-parallel circuit is a combination of series and parallel circuits. It is a group of parallel resistances connected in series with other resistances, meaning current has both single and multiple paths for electron flow. A series resistance is the one with total current ( $I_{total}$ ) flowing through it, so it is easy to locate. The current distribution in a series-parallel circuit is shown in figure 1-15.

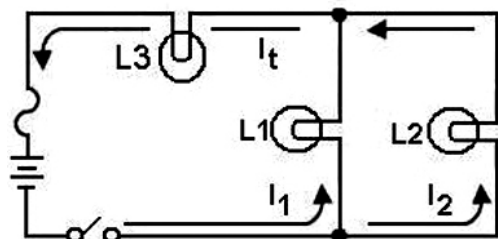


Figure 1-15. Series-parallel circuit.

The total current leaves the negative side of the battery and divides into currents  $I_{L1}$  and  $I_{L2}$ . It recombines after passing through both branches to become total current through  $I_{L3}$  and returns to the positive side of the battery.

Since a series-parallel circuit is a combination of both the series and the parallel circuits, the voltage distributions are going to be determined using the characteristics of both circuits. Since the series

component is between the power source and the parallel circuit, some of the applied voltage will be dropped across the series component. What is left is distributed across all of the parallel components just as in a parallel circuit.

The total resistance is also figured out using a combination of the same formulas and calculations used for series and parallel circuits. For example, in order to find the total resistance of the above, we would have to first figure out the total resistance of the parallel circuit, and then add that value to the resistance of the series portion of the circuit.

Example:  $R_{L1} = 50\Omega$

$R_{L2} = 75\Omega$

$R_{L3} = 100\Omega$

$R_{Total} = 100\Omega + [1 / (1/50\Omega) + (1/75\Omega)] = 130\Omega$

## 206. Laws

A number of electrical laws apply to all electrical networks. The most common of these include Ohm's Law and Kirchhoff's Current and Voltage Laws.

### Ohm's Law

Ohm's Law states that in an electrical circuit, the current passing through a conductor is directly proportional to the potential difference applied across them provided all physical conditions are kept constant.

In mathematical terms, this is mathematically written as:  $I = \frac{V}{R}$

As you may recall,  $I$  is the current,  $V$  is the voltage or potential difference (also known as the voltage drop), and  $R$  is the resistance. To illustrate the use of Ohm's Law, let's say we wanted to find the current flowing in the circuit depicted in figure 1-16 once the switch is closed. In order to find the total current ( $I_t$ ), we must find the circuit's total resistance. Recall that total resistance ( $R_t$ ) in a series circuit equals the sum of the individual resistances.

Stated as a formula:  $R_t = 5\Omega + 10\Omega = 15\Omega$

With the battery or applied voltage ( $E_{Source}$ ) at 30V, and total resistance ( $R_t$ ) of 15 ohms, total current ( $I_t$ ) now can be calculated by using this formula:

$$I_t = 30V / 15\Omega = 2A$$

As long as two of the three values are known, Ohm's Law can be manipulated to solve for the unknown value. For example, to find the actual voltage drop across each resistor in figure 1-16 (since  $R1$  and  $R2$  are of different values), we would use the formula ( $E = I \times R$ ), or in this case  $E_{R1} = I_{R1} \times R1$ . By substituting  $2A$  and  $5\Omega$  for  $R1$  or  $10\Omega$  for  $R2$  into the formula, the voltage drops across  $R1$  and  $R2$  can be calculated as follows:

$$E_{R1} = 2A \times 5\Omega = 10V$$

$$E_{R2} = 2A \times 10\Omega = 20V$$

Notice the larger the resistance, the larger the voltage drop. Remember, *voltage follows resistance*. The individual voltage drops add together to equal the total, or applied, voltage.

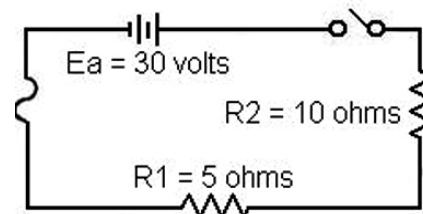


Figure 1-16. Series circuit 2.

### Kirchhoff's Laws

Kirchhoff's Voltage and Current Laws are used to find unknown quantities of current and voltage in any part of a series circuit.

#### Voltage law

Kirchhoff's Voltage Law states that the directed sum of the electrical potential differences around a circuit must be zero. In other words, the sum of all voltage drops across the loads in the circuit will equal the source voltage. This can be seen using the previous example:

$$E_{Source} = E_{R1} + E_{R2}$$

$$E_{Source} = 10V + 20V = 30V$$

#### Current law

Kirchhoff's Current Law states that the sum of all currents entering a node is equal to the sum of all currents leaving the node.

The three ammeters shown in figure 1-17 would show how much current is flowing at various points in the circuit. Since this is a series circuit, all the ammeters will read the same amount of current.

Remember that current is common in a series circuit. In other words, the total circuit current equals the current through Lamp1, which equals the current through Lamp 2. It doesn't matter how many lamps are in the circuit.

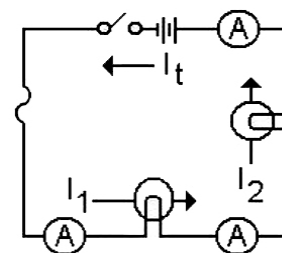


Figure 1-17. Series Circuit 3.

## Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

### 203. Circuit Components

1. What are the minimum requirements for a simple circuit?
2. What is the value of a resistor with the following color bands: yellow, blue, red, and silver?

3. Match the description in column A with the component in column B. Items in column B may be used once, more than once, or not at all.

*Column A**Column B*

- |   |                |
|---|----------------|
| ____ (1) Converts mechanical energy to electrical energy.   | a. Fuse        |
| ____ (2) Provides visual indication of current flow.  | b. Lamp        |
| ____ (3) A passive device used to regulate current.   | c. Relay       |
| ____ (4) A passive device used to oppose current.   | d. Motor       |
| ____ (5) A passive device that opposes changes in voltage.  | e. Diode       |
| ____ (6) Allows current to flow in only one direction.  | f. Switch      |
| ____ (7) Uses a small amount of voltage or current to control a larger change in voltage or current.          | g. Battery     |
| ____ (8) Used to transfer electrical energy from one circuit to another by means of an electromagnetic field. | h. Ground      |
| ____ (9) Used for controlling or switching electrical circuits from a remote location.                        | i. Resistor    |
| ____ (10) Converts electrical energy into mechanical energy.  | j. Inductor    |
| ____ (11) A device used for changing the flow of current in a circuit.  | k. Capacitor   |
| ____ (12) Device used to protect circuits from overcurrent conditions.  | l. Generator   |
| ____ (13) Commonly used as a reference point in a circuit.  | m. Transistor  |
|   | n. Transformer |

4. Explain the standard used for sizing wires.
5. What is soldering?
6. What is the most common control device?
7. What does the Law of Electric Charges state about charged matter?

**204. Circuit Types**

1. What are the three types of circuits?
2. What are the advantages and disadvantages of analogue circuits as compared with digital circuits?
3. What are the advantages and disadvantages of digital circuits as compared with analogue circuits?

**205. Circuit Configurations**

1. What are the three basic types of circuit configurations?



2. Why do all elements in a series circuit have equal current flowing through them?
3. What is important to note about voltage in parallel circuits?
4. How is the total resistance calculated in a parallel circuit?
5. How is a series resistance located in a series-parallel circuit?
6. How is total resistance calculated in a series-parallel circuit?

#### **206. Circuit laws**

1. What is Ohm's law?
2. What is the current flowing in a circuit with a power source of 12 volts and a total resistance of 4K ohms?

### **1-3. Electronics Testing, Troubleshooting, and Repair**

Has a piece of equipment ever failed and you did not even know where to begin to repair it? As a technician, knowing which piece of test equipment to use and why, along with having some basic troubleshooting and repair skills, will be essential for you to perform your job efficiently and correctly. This lesson will go over some common test equipment you will likely be using on the job as well as some basic fault analysis and repair procedures.

#### **207. Electronic test equipment**

Electronic test equipment is used to create stimulus signals and capture responses from electronic devices under test (DUT). In this way, the proper operation of the DUT can be proven or faults in the device can be traced and repaired. Use of electronic test equipment is essential to any serious work on electronic systems. Electrical test equipment can be broken up into two broad categories: stimuli and measurement.

##### **Stimuli test equipment**

Stimuli test equipment is used to provide operating power, signals, or other inputs to the DUT. Stimuli equipment includes power supplies, signal/function generators, and pulse generators.

##### ***Power supplies***

As mentioned in our previous lesson, power supplies are used to supply electrical or other types of energy to an output load or group of loads by converting one form of electrical power to another

## Signal/function generators

### *Pulse generators*

## Measurement test equipment

### *Meters*

Meters are used to take measurements and provide visual indications of circuit operation.

*Voltmeter*

A voltmeter is an instrument used for measuring the potential difference, or voltage, between two points in an electric circuit.

*Ohmmeter*

An ohmmeter is an electrical measuring instrument that measures electrical resistance.

*Ammeter*

An ammeter, also known as a galvanometer, is an instrument used to measure the flow of electric current in a circuit. Ammeters must be inserted into the circuit and become part of it in order to measure current. However, a clamp meter, or clamp-on ammeter, is a type of ammeter that measures electrical current without the need to disconnect the wiring through which the current is flowing.

*Multimeter*

Multimeters, also commonly called volt-ohm-milliammeters (VOM) as shown in figure 1–20, digital voltmeters (DVM) or digital multimeters (DMM) as shown in figure 1–21, typically combine the capabilities of the three meters listed above and can measure voltage, resistance, and current. Some multimeters are capable of measuring frequency as well.



Figure 1–21. Digital multimeter. (Reproduced by permission of Fluke Corp., Everett, WA, <http://www.fluke.com>.)

*Time domain reflectometer*

A time domain reflectometer (TDR) is an electronic instrument used to characterize and locate faults in metallic cables. Optical TDRs are used for locating faults in optical-fiber lines. Basically a TDR transmits a pulse along the conductor. If the conductor is working correctly and is properly terminated, the entire transmitted pulse will be absorbed in the far-end termination, and no signal will be reflected back to the TDR. But where impedance discontinuities exist, each discontinuity will create an echo that is reflected back to the reflectometer.

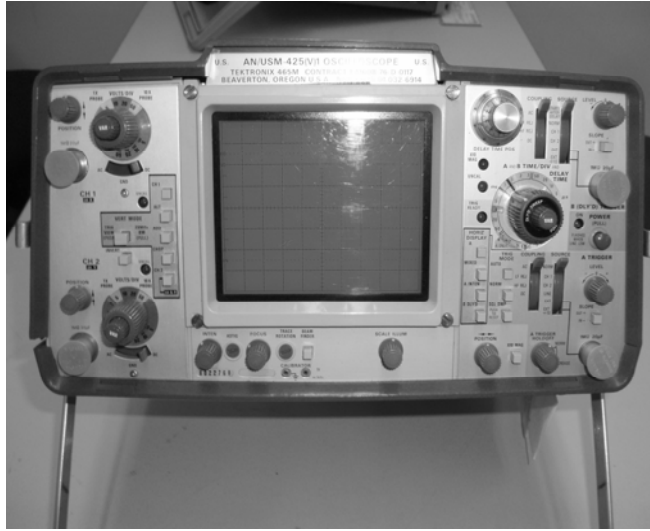


Figure 1-22. Oscilloscope.

### Oscilloscopes

An oscilloscope (fig. 1-22), sometimes abbreviated CRO for cathode-ray oscilloscope, or commonly just scope or O-scope, is a piece of electronic test equipment that allows electrical signals to be viewed, usually as a two-dimensional graph.

In most applications, the graph (fig. 1-23) shows how signals change over time. The vertical (Y) axis represents voltage and the horizontal (X) axis represents time. The intensity or brightness of the display is sometimes called the Z axis.

### Counters

A counter measures signal frequency and the number of events occurring within a specific period of time.

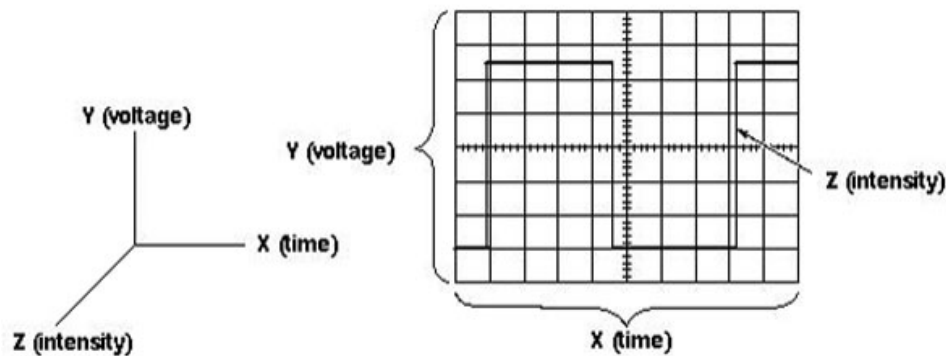


Figure 1-23. Oscilloscope graph.

### Logic probes

A logic probe is a hand-held pen-like probe used for analyzing and troubleshooting the logical states (Boolean 0 or 1) of a digital circuit. There are typically three lights on the probe's chassis; two of the lights represent the two possible voltage states (high/low) while the third light is for pulses or single-occurring events.

## 208. Diagrams

This lesson begins by stating, "It is one thing to look at wiring diagrams and another to be able to read and interpret them." What category are you? As a technician, you may use many different types of wiring diagrams to depict the electrical circuits and components in portable generators and power plants, as well as automatic transfer panels. Do you really understand what these diagrams are telling you? In this lesson you will be provided information to help you in your wiring diagram endeavors.

Wiring diagrams are identified according to the degree of detail they show. They have a threefold purpose:

1. Show system components.
2. Allow you to understand system operation.
3. Aid in the troubleshooting of electrical systems.

CONTACTORS AND RELAYS - INCLUDING TIMING RELAYS AND DASHPOT CONTACTORS											WIRING																																															
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WITH BLOWOUT		WITHOUT BLOWOUT		TIME OPENING		TIMED CLOSING																																																				
N.O.	N.C.	N.O.	N.C.	N.O.	N.C.	N.O.	N.C.																																																			
OVERLOAD RELAYS						LIMIT SWITCHES		DISCONNECTS				FUSE																																														
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PUSH BUTTONS								FOOT SWITCHES		PRESSURE FLOAT & VACUUM SWITCHES																																																
MOMENTARY CONTACT				MAINTAINED CONTACT		SHOW CONTACTS WITH SWITCH NOT DEPRESSED		SHOW CONTACTS AT ATMOSPHERIC PRESSURE OR WITH FLOAT NOT SUPPORTED BY LIQUID																																																		
SINGLE CIRCUIT		DOUBLE CIRCUIT		MUSHROOM HEAD	TWO SINGLE CONTACTS					ONE DOUBLE CONTACT																																																
N.O.	N.C.	N.O.	N.C.						N.O.	N.C.	N.O.	N.C.																																														
SELECTOR SWITCHES						PILOT LIGHT		TRANSFORMERS			INDUCTORS																																															
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Figure 1-24. Common electrical symbols.

The first time you ever looked at a wiring diagram you probably thought, “I will never understand these things!” As you have progressed in your career, you probably found that the first step to understanding wiring diagrams is to identify the power source and what energizes the various components. Then, you must know what components are in the circuit and how they operate. The best place to find this information is in an equipment manual.

### **Understanding diagram symbols**

The most important key to reading and understanding wiring diagrams is an ability to read symbols. There is no getting around the fact; you must be able to identify and read wiring diagram symbols in order to successfully interpret wiring diagrams. In a way, symbols are the language of diagrams. To be able to read diagrams, you must know the language. With a sound knowledge of these symbols, you can install and/or trace circuits and locate malfunctions with ease.

Space is often at a premium in diagramming, so abbreviations are used. Figure 1-24 shows the typical symbology for circuit components. By using symbols and abbreviations, you can make wiring diagrams tell the story of the circuitry.

### **Diagram types**

Wiring diagrams are detailed drawings that show how the wires of a circuit connect the components. As such, they are the “roadmaps” for electrical circuitry. There are three basic types of wiring diagrams you will use as an electronics technician. They are as follows:

1. One-line or block diagram.
2. Schematic/elementary diagram.
3. Interconnection diagrams.

Each diagram is classified according to its function.

#### ***One-line (block) diagram***

The most basic of the diagrams is the one-line type. This type of diagram is also called a block or flow diagram. It gives you a general view of the entire system. An example of a block diagram is shown in figure 1-25. The lines show the general functional scheme that connects each box or circle and the arrows show the path of the signal. You can use this diagram along with a schematic diagram for a better understanding of a system’s operation when you are troubleshooting or extracting circuits. Remember the one-line diagram does not show the connections or internal wiring of devices.

#### ***Schematic/elementary diagram***

Of all the wiring diagrams, the schematic, or elementary, is the most important and most useful for troubleshooting and extracting circuits. The schematic, or elementary, diagram continues the idea of showing all circuit components in a straight line, without regard for physical location or relationship. Along with the one-line diagram, it is one of the simplest forms of diagrams. As such, it gives you an overall view of a particular system, shows circuit operations, and shows where the functions within a circuit occur in an exact sequence. Figure 1-26 is an example of a schematic diagram. A schematic diagram usually includes different elements (solenoids, relays, contacts, meters, and mechanical linkage); it is easier to trace the circuit and its operation. The schematic diagram can also contain a legend that identifies the device numbers.

A thorough understanding of schematic diagrams can simplify troubleshooting of any electrical system. Keep in mind that some schematic diagrams do not have the internal wires numbered, but they do contain the connections for all contacts numbered. Partial wire numbers may also be included on some, but not on all, schematic diagrams.

**NOTE:** The internal wiring of devices is usually separate from the schematic diagram, and it does not show the source of power to the device.

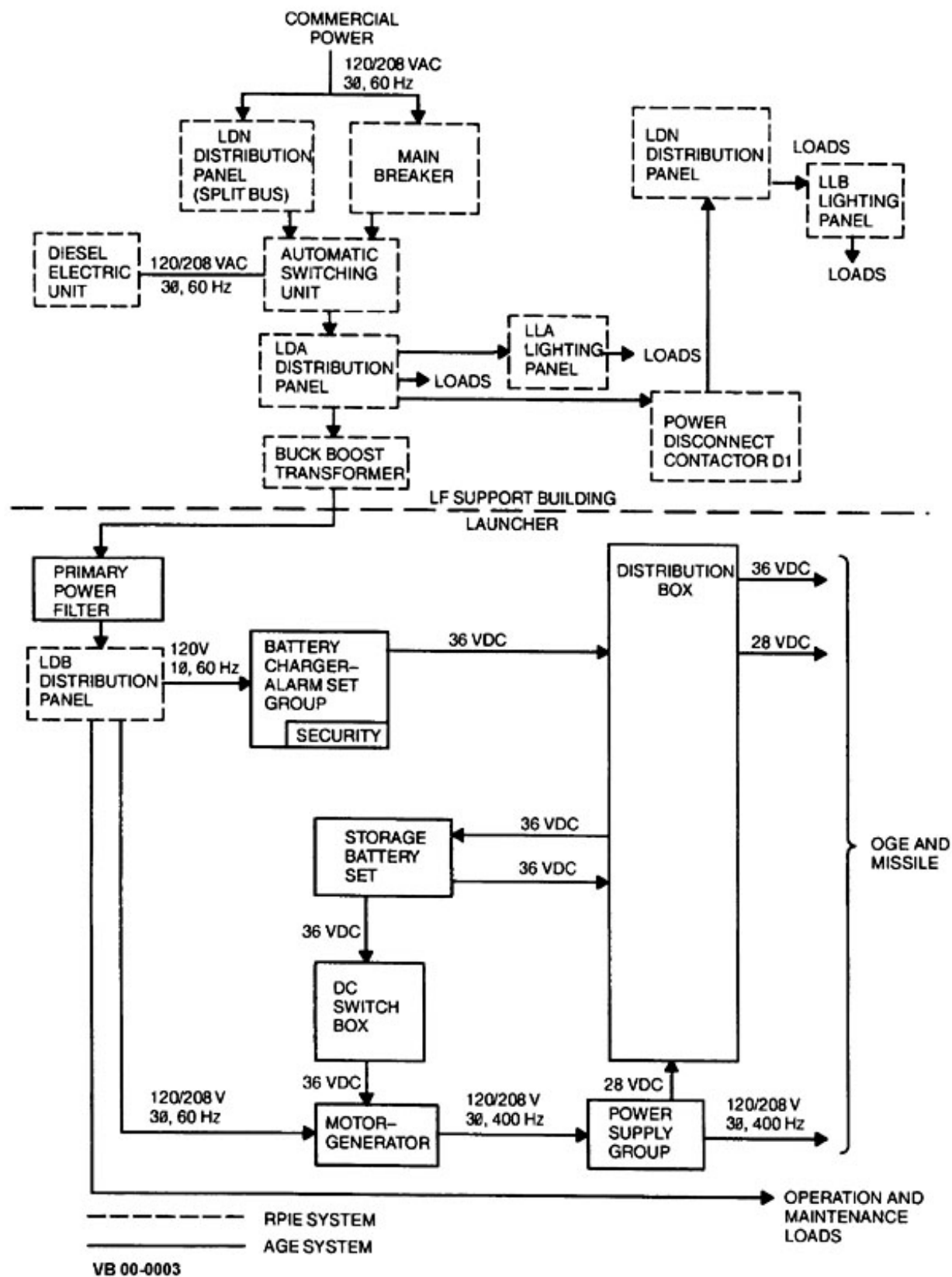


Figure 1-25. Block diagram.

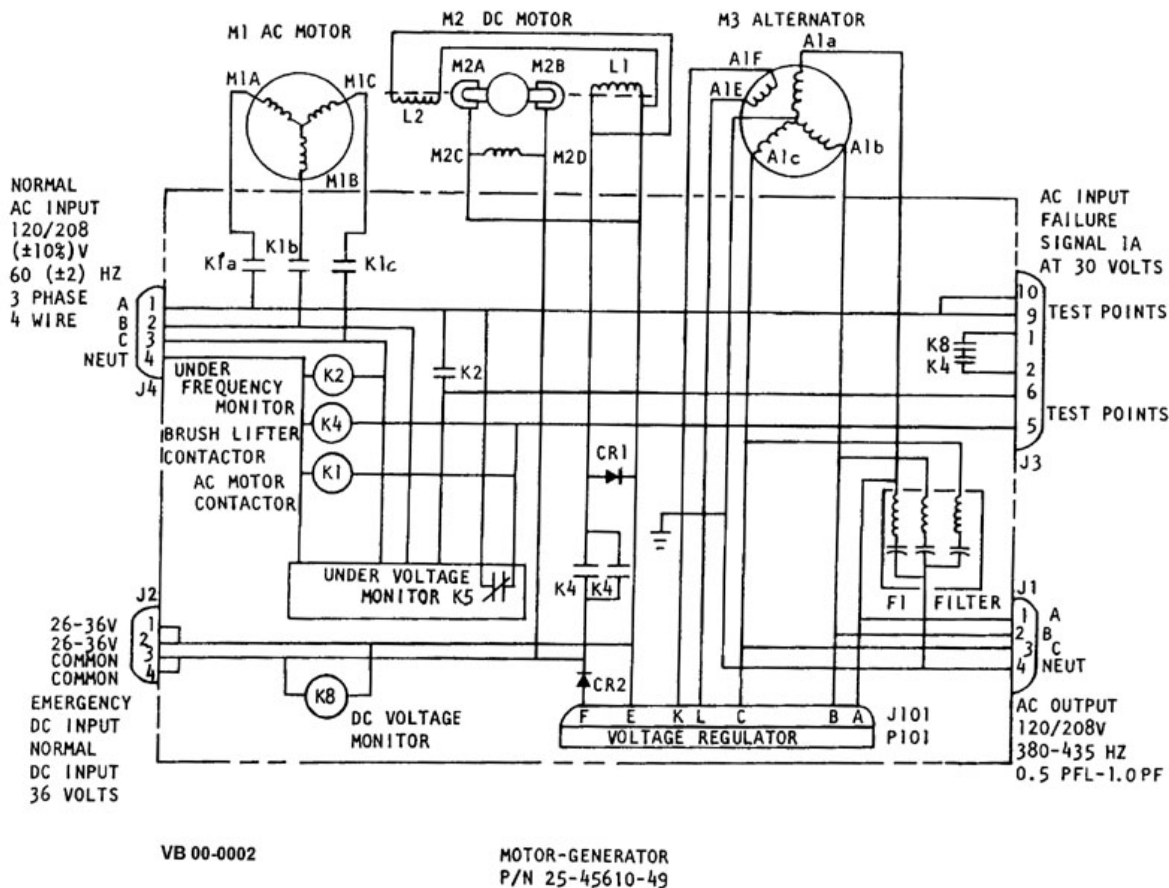


Figure 1-26. Schematic/elementary diagram.

### Interconnection diagram

An interconnection diagram (fig. 1-27) shows complete connections between equipment units, unit assemblies, and associated apparatus. It is a complete diagram, using pin numbers for transistors, integrated circuits and color-coded designators, and part numbers for all components. This diagram also uses standard circuit symbols showing all equipment or circuit connections. Heavy lines normally show the main power circuits, medium lines show exciter and field circuits, and light lines show the smaller wiring. Dotted/dashed lines outline the panel sections. Circuit tracing and extracting

The ability to trace and extract circuits is indispensable when you troubleshoot the electrical circuitry of this equipment. By using wiring diagrams, you can trace electrical circuitry and determine where to connect test equipment for checking electrical operation.

### Tracing circuits

In tracing circuits on a schematic or wiring diagram for troubleshooting or repairing, it is often easier to extract (make a simple drawing) only the specific circuit in which you are interested. It is easier to work on a system with this simple drawing than with a large bulky wiring diagram. As you follow the circuit operation explanation in the appropriate manual, trace the circuit on the schematic diagram. It is a good idea to color code the circuit for easy identification and a clear understanding of that particular circuit. Include on your drawing all wire numbers, device code numbers, and area designations.





The following are three well-established rules for tracing electrical circuits.

Rule 1	Use the appropriate technical reference to understand circuit operation. This is the most important step in circuit extractions. If you do not understand how the circuit operates, you will encounter numerous problems during the extraction and troubleshooting process. Understanding circuit operation includes an understanding of how each component operates, the identification of the power source and units of resistance, and electron flow in the circuit.
Rule 2	Identify or highlight all circuit components on the schematic diagram. This enables you to locate the components when you begin the actual tracing.
Rule 3	Trace the circuit on the schematic diagram as you are reading the circuit operation. This procedure allows you to gain a clear understanding of the circuit. First, locate the power source of the circuit. Next, locate the unit or units of resistance on the schematic. A unit of resistance is defined as the component or components that provide action. Normally, the name of the circuit identifies the unit of resistance. For example, in a panel light circuit, the unit or units of resistance are the panel lights.

It is important to remember all switches, contacts, relays, and other electrical devices can be shown in the “energized” or “de-energized” position. Eventually, you will trace the circuit through contacts of relays. To maintain circuit (tracing) continuity back to the power source, the contacts must be closed. This means the relay controlling the normally open contacts must be energized for the contacts to close. Trace the relay circuit from one side of the power source, through the relay, to the other side of the power source. Once the relay circuit is traced back to the power source, hypothetically, the relay is energized. This allows the normally open contacts of the relay to close, thus allowing you to continue circuit tracing of the circuit. This situation may repeat itself every time you trace through open contacts of relays.

### ***Extracting circuits***

Now that you have traced the circuit on the schematic diagram, you can extract the circuit. Both the schematic and interconnection diagrams are very important when extracting circuits. The schematic diagram is your guide through the interconnection diagram. The schematic shows where you are, where you are going, and from where you came. When one of these factors is not known, extraction of complex circuits becomes difficult or almost impossible. There are three rules to follow when extracting circuits.

Rule 1	Identify and label all circuit components, conductors, wire numbers, connection points, terminal boards, and contacts. Identify and label the state of relays, solenoids, and switches in the circuit as either normally open (NO) or normally closed (NC) until they are acted upon.
Rule 2	Set all switches to the desired position and close the appropriate contacts of all relays. When tracing through switches that have several contacts, you need to know which contacts close when the switch is repositioned. Some diagrams provide switch schematics showing this information.
Rule 3	Know how meters are energized and connected to the source of power. Let's assume you need to trace a circuit through a meter. Meter circuits are perhaps the hardest circuits to trace on a wiring diagram because most meters are connected through multiple selector switches. For example, you know that a voltmeter is connected in parallel with the source of power, but when the same meter is used to measure different phase voltages, the circuit gets complex, requiring a selector switch. The legend on the diagram shows the contact positions of the switch and must be consulted when you trace this circuit. Often, the source of power is not readily apparent in an AC power system. That is why it's sometimes better to start at the meter and trace back through the switch to the power connection.

## **209. Electronics troubleshooting**

Now that you have learned how to interpret wiring diagrams, you must be able to apply this knowledge to the electrical/electronic troubleshooting process. Troubleshooting is a form of problem solving where a systematic method is used to find the source of a fault or to gain an understanding of why a component failed, or is failing. In this lesson we will be discussing the basic steps of analytical

troubleshooting, some of the more common electrical malfunctions you will be dealing with, and preventative measures to eliminate damage caused from electrostatic discharge events.

### **Basic troubleshooting steps**

The purpose of troubleshooting is to enable you, the technician, to maintain equipment in peak operating condition. Electrical troubleshooting is defined as a step-by-step procedure of analyzing, locating, and correcting electrical malfunctions. The five fundamental steps of troubleshooting are as follows:

1. Perform an operational check.
2. Analyze the malfunction.
3. Locate the malfunction.
4. Perform corrective action.
5. Perform an operational check.

Since troubleshooting is a step-by-step procedure, its effectiveness depends on a good understanding of basic electrical theory and an understanding of the specific equipment on which you are working. A person can be taught everything, but the actual troubleshooting. The ability to troubleshoot depends on the capability to think clearly and apply basic electrical theory.

To troubleshoot effectively, you must follow a systematic procedure. It is systematic because it is based on a plan of action, not on haphazard “here-and-there” checking. It is a plan that helps you track down the trouble in a minimum amount of time. Your first step is to study the symptoms of the problem thoroughly and ask yourself these questions:

1. What were the warning signs preceding the problem?
2. What recent repair has been done?
3. Has a similar problem occurred before?

### ***Perform an operational check***

The first step in troubleshooting is to perform an operational check of the equipment to determine if an actual problem exists. In starting and operating the equipment you are troubleshooting, there are certain checks and procedures that must be accomplished to prevent further malfunctions and damage to the equipment.

Proper inspections and correct operating procedures ensure efficient operation and a long life for equipment. On the other hand, improper inspections and incorrect operating procedures could cause electrical troubles, inefficient operation, and possible damage or destruction of equipment. In your inspections and operating procedures, you must follow the step-by-step procedures in the systems or technical manual for your particular item of equipment.

A thorough visual inspection of the electrical components often reveals minor discrepancies that can be corrected and prevented from developing into major electrical problems. Check such items as the wiring harness for breaks, worn or cracked insulation, or any signs of rubbing against any metal parts. Check transformers, resistors, relays, and terminals for loose connections, evidence of overheating, cracks, corrosion, or any signs of damage. Inspect other components for obvious damage from overheating, wear, or abuse. Make a listing of all symptoms you note so that the chances of overlooking possible malfunctions are reduced.

### ***Analyze the malfunction***

The second step in troubleshooting is to analyze the malfunction. Using your senses, such as sight, sound, smell, or feel can help detect the trouble. Once you are aware of a malfunction, consult the proper systems or technical manual for normal circuit operation. This will help you get a clearer picture of how the circuit involved should be working normally. Also, check the troubleshooting

flowchart or table in the manual for probable causes and remedies. This step alone could reduce your efforts to a few simple checks—instead of a long and hard search throughout the entire circuit.

If the troubleshooting chart or table proves to be of no help, use the circuit description and wiring diagrams to extract that particular circuit. After you have extracted the circuit, you must then check this circuit with the proper test equipment. It is in this step that you must determine the type of trouble in order to determine the type of test equipment to use.

### ***Locate the malfunction***

Once you have analyzed the malfunction and have determined what type of test equipment to use, you will need to extract the suspected circuit or component in order to avoid erroneous readings and begin locating the cause of the malfunction. Locating the cause of a problem is usually the most difficult task you have to accomplish and requires much thinking. However, if you extract the circuit, select the proper test equipment, and have a complete understanding of what you are doing, finding the cause of a trouble can be easy.

### ***Perform corrective action***

After you find the cause of the problem, a neat, permanent-type repair is a necessity. Slipshod repair can only worsen a situation. Use original replacement-type parts, not something “jerry-rigged.” If you do not intend to properly repair the cause of the trouble, then why go to the effort of hunting for the problem in the first place?

### ***Perform an operational check***

Performing a final operational check is required to prove your work and to ensure the equipment is in proper working order before you return it to service. If you do not prove the work you have accomplished, you can never be sure that you fixed the problem. Also, there may be another problem with the equipment that requires attention before the unit can be placed back in service.

Let’s take a look at some of the most common types of electrical malfunctions.

### **Electrical malfunctions**

The most common types of electrical malfunctions are opens, shorts, grounds, and low power. In this area, you will learn each malfunction in depth to include causes, symptoms, and procedures for locating each malfunction.

#### ***Opens***

The cause for an open is an incomplete path for current flow within the circuit. Opens can occur when a conductor becomes broken, a fuse opens, relay or switch contacts fail to close properly, or when any other device in the circuit fails to provide a complete path for current flow.

Naturally, if there is an open, there can be no current flow. Consequently, the unit will not operate. If the fault is an open, the following applies:

1. Circuit is inoperative.
2. Protective device will not activate.
3. Indicator lamps do not illuminate.

The possible location of an open can be anywhere in the circuit; however, using a digital multimeter can help you find the open. Remember a multimeter is connected in parallel with the circuit or component. When using a digital multimeter, set the meter to read voltage; the meter should indicate the difference in potential voltage when connected across two points that are positive and negative. This is because one connecting lead is attached to a potential of, let’s say, 24 volts, while the other lead is connected to 0-volts potential. With a difference in potential between the two points, a reading of 24 volts will be indicated on the multimeter.

A multimeter connected from negative to negative or from positive to positive indicates 0 volts. This is because there is no difference in potential between the two connection points. When both meter leads are connected on the conductor at 24-volts potential, or 0-volts potential, there is no difference of potential for the meter to indicate.

When using a multimeter to locate an open, the equipment you are troubleshooting must have its power supply turned on. Place the black lead on the negative conductor or frame. Place the red lead on the positive conductor of the main unit of resistance in the circuit. Check the remaining positive terminals in sequence, moving towards the power source until the voltage indication on the voltmeter changes from the applied voltage to 0 volts. The open electrical malfunction is located between the last applied voltage reading and the first point 0 voltage reading.

Using the multimeter setup to read resistance can also find opens. With this setup, you must observe the following two very important precautions:

1. Turn the power to the circuit being tested to “off.” This is to prevent damage to the meter. Because multimeters have their own power supply, any voltage or current that is encountered by the meter causes damage to its internal components.
2. Isolate the circuit components and conductors to prevent erroneous readings. If you do not isolate the circuit, the multimeter detects any devices that contain an appreciable amount of resistance. The resistance reading could fool you into thinking you have located the problem.

The multimeter indicates continuity (uninterrupted good connection) when the display reads 0.00 and “OL,” meaning out of limits or overload, when the circuit is open. When using a multimeter to locate an open in a circuit, place the meter leads across segments of the circuit until you find the open. The open is located between the last 0.00 indication and the first OL indication. Remember, whenever you use a multimeter to measure resistance, the power to the circuit must always be “off.”

### ***Shorts***

There are three types of electrical shorts: (1) direct, (2) cross, and (3) shorted control.

There are certain basic symptoms that indicate some type of short has occurred. They are as follows:

1. Circuit inoperative.
2. Protective device actuated.
3. Two or more circuits operate from one control device.
4. Circuits can't be turned off.

#### ***Direct short***

Positive and negative conductors making direct contact cause a direct short. The short provides a shortcut for the current back to the power source, bypassing the unit of resistance. As the unit of resistance is bypassed, current flow increases to a point at which the protective device is actuated.

The indications of a direct short are an inoperative circuit and the protective device has actuated. Also, if the excessive current remains in the circuit long enough, the insulation on the wires may begin to melt or even burn. You may smell smoke and see burnt conductors.

The location of direct shorts is between the positive and negative conductors and between the power source and unit of resistance. Use either a digital multimeter or an ohmmeter in order to locate all shorts, as these are the only true methods of isolating the exact location of the short. When symptoms indicate a direct short, isolate the positive conductors in the circuit. Turn off the power to the circuit. Using the multimeter, place one meter lead on the negative conductor and move the other lead from one positive conductor to another in the circuit until the direct short is found. An OL display on the multimeter indicates a good (no short) component. A 0.00 reading on the multimeter indicates the location of the direct short.

### *Cross short*

The positive conductors of two or more independent circuits making contact cause a cross short. The contact causes units in all the shorted circuits to operate when only one control device is turned on.

The symptom of a cross short is when two or more independent circuits operate from one control device. In addition, the protective device may or may not actuate. This depends on the current rating of each circuit. Cross-short malfunctions are not as common as direct shorts but are more complex to troubleshoot because they can affect more than one circuit.

The possible location of a cross short is between the control devices and units of resistance of two or more independent circuits. When you use multimeters (setup for resistance) for locating electrical short malfunctions, the power to the circuit must be off. Isolate the positive conductors of the circuits involved. Place one meter lead on a positive conductor of one circuit and the other lead on the positive conductors of the other circuit or circuits, one at a time. If you do not find the cross short, move the first meter lead to another positive conductor in the first circuit, and then move the other lead through the other circuit as you did before. Repeat these procedures until the location of the cross short is isolated. A 0.00 indication on the meter indicates the location of the cross short.

### *Shorted control*

The contacts of a switch or relay being welded cause a shorted control. Shorted controls are usually the result of overcurrent conditions or dirty contacts. The symptoms of a shorted control are that the circuit continues to operate with the control device in the OFF position and the protective device does not actuate.

When the symptoms indicate a shorted control, turn off power to the circuit and isolate control devices. Using a multimeter setup to read resistance, place the leads across the contacts of the control device or switch, with the control device or switch in the OFF position. An OL indication on the meter indicates proper switch or control device operation. A 0.00 display on the meter indicates a shorted control device or switch.

### *Ground*

If the positive conductor in a one-wire circuit makes contact with the conduit, frame, chassis, or any other metallic part of the wiring system, the circuit is grounded.

A ground has the same symptoms as a direct short; that is, the circuit is inoperative and the protective device is actuated—power bypasses the unit of resistance and goes to ground, causing the protective device to actuate.

The location of a ground can be between the positive conductor and the frame, somewhere between the power source and unit of resistance. The procedures for locating a ground are identical to the procedures for locating a direct short with one exception—the frame is substituted for the negative conductor.

### *Low power*

Weak batteries are the common cause of low power, although a loose connection, dirty switch contacts, or conductors too small to carry the load can also cause low power. The symptoms of a low-power condition can be an electric motor that's running sluggishly, dim lights, or chattering relays. The possible location of a low-power condition could be anywhere in the circuit. When locating a low-power condition, supply power to the circuit. Use a multimeter to measure the voltage drop across each wire, component, and connection in the circuit. A 0-volt reading on the meter indicates the wire, component (provided it does not normally have a voltage drop), or connection being tested is good. A voltage reading indicates the location of the low power.

## 210. Electronics preventive maintenance and repair

The best troubleshooting technique is often the prevention of trouble. By following procedures step-by-step and performing all maintenance and repair actions in accordance with the systems or technical manuals, you can avoid most electrical troubles. Proper inspections and correct operating procedures ensure efficient operation and a long life for the equipment. On the other hand, improper inspections, incorrect operating procedures, and poor repair jobs usually end up causing more electrical troubles, inefficient system operation, and could possibly end up causing damage to the equipment and even possible injury to the operator.

This final lesson will go over some common maintenance procedures that you, as an aerospace technician working on electronics, should be familiar with. Let's begin by going over electrostatic discharge and how to effectively minimize its associated risks to electronic equipment.

### Electrostatic discharge

Recall from our earlier lesson on atomic structure that an object's electrical charge is determined by its makeup of electrons. This electrical charge can be altered when two items are rubbed together (friction) causing one item to lose electrons and the other item to gain them. This changing of electrons can result in a positive or negative electrical charge depending on whether the item was gaining or losing electrons. A conductive material will evenly dissipate this charge over its surface, but a nonconductive material will not. This inability to dissipate the electrons causes the item to stay charged. When an unbalanced amount of electrons is built up and has nowhere to go, the electrical charge is said to be at rest and is commonly called "static electricity."

An electrostatic discharge (ESD) event occurs when the static electricity suddenly flows from one object having a built-up electrical charge to another object having a different electrical potential. A common example of an ESD event is the spark that you sometimes feel when you touch a metal doorknob after walking across a carpeted room. While this sudden transfer of electrons can be a minor discomfort to you, it can cause severe damage to certain electronic components that are sensitive to low voltages and currents. The threshold of sensitivity or the level of voltage required for a human being to feel a static discharge is approximately 3,500 volts while some of today's circuits are sensitive to voltages as low as three volts. This means ESD damage can be done to devices by personnel without them even knowing it.

### ESD sources

Personnel working on electrostatic discharge sensitive (ESDS) components need to be aware of what materials and activities pose hazards as sources of static electricity. Typically, nonconductors (insulators) such as plastics and other synthetic materials are capable of generating large amounts of electrostatic voltages. Remember, this is because the generated charge is not distributed over the entire surface of the material as is the case with conductors. Recall that conductors allow electrons to move easily in the material; therefore, charges generated on conductors are rapidly distributed over their entire surfaces.

### Failure mechanisms

ESD damage to electronic and electrical devices can be caused by either voltage or current depending on the composition and construction of the device.

Voltage-induced failures	Dielectric breakdown is the failure mechanism. Dielectric breakdown of the component occurs when the threshold or maximum electric-field strength of the dielectric medium is reached, and bonded electrons within the medium break free and flow within the dielectric.
Current-induced failures	Thermal secondary breakdown and metallization melt are the failure mechanisms. Basically, this means that the device cannot dissipate the power associated with the ESD event. The heat generated by the discharge melts the device substructures.

### ***Defect types***

When a defect is attributed to component damage caused by ESD, it can be categorized in three ways: catastrophic, intermittent, and latent.

Catastrophic	Total failure of electronic parts, assemblies, and equipment. These defects are the easiest to diagnose and repair.
Intermittent	Intermittent or erroneous signals. These defects are the hardest to troubleshoot because the fault seems to keep moving.
Latent (soft)	Items already having been partially damaged by an ESD event can check out electrically on a repair/test bench but fail when subjected to stresses of wide temperature ranges, mechanical shock, high g-forces, or by applying normal operating voltages. These faults are considered the most dangerous because the failure is not detected until it occurs during the item's operation.

### ***ESD control***

An effective ESD control program consists of the proper handling and storage of ESDS components.

#### ***Handling ESDS items***

Any time you are required to handle an ESD-sensitive item, you must first ensure your work area is set up for this type of work. In order to safely handle these sensitive components, your work area must be set up as follows:

- The worktable must have a conductive work surface.
- Flooring that you will stand on while working must also be conductive.
- Both the work surface and floor surface must be grounded to the facility ground with a minimum series resistance of 250,000 ohms. This is not just a straight ground to the earth; the resistance is roughly that of the human body and is required to ensure there is not a difference in potential between the workstation and the person working at the workstation.
- Anyone working within three feet of ESDS items must use wrist straps or leg straps that will limit current to 5 milliamps maximum for personnel safety. This is accomplished by a 1-megohm resistor in the wrist strap that makes direct contact with your skin. The method of ensuring the strap will limit current is to design it with a fuse or with a very small wire that will burn out above the 5-milliamp level.
- Hand tools must have insulating material removed.
- Remove any static-producing materials such as plastic, vinyl, or foam packaging material from the work area.
- Before touching an ESD-sensitive item or any component containing one, touch the test leads to the ground.

Another issue you must be concerned with is humidity. As the air gets dryer, the likelihood of static electricity grows. The ideal humidity for working with ESD-sensitive items is between 40 percent and 60 percent relative humidity. Any level higher than this is conducive to corrosion problems and anything lower than this is too dry.

These guidelines are commonly accepted by all who handle ESD-sensitive items although you should become familiar with your work area's local requirements and ensure they are followed.

#### ***Storing ESDS items***

One of the handling procedures for ESD-sensitive items is the method of packaging. The procedure required to properly protect an ESD-sensitive item is as follows:

1. Install a shunt or shorting bar on the connectors of components or circuit boards.
2. Place item in a conductive shielded bag.



3. Place item (inside conductive bag) into an antistatic bag.
4. Label the bag with an “ESD-sensitive” label.
5. Protect packaged item with conductive foam.
6. Place item in standard shipping container.
7. Label the container with another “ESD-sensitive” label.

These steps are the commonly accepted methods of packaging ESD-sensitive items. You should consult your work area’s policies or manufactures’ recommendations for further guidance.

### **Soldering**

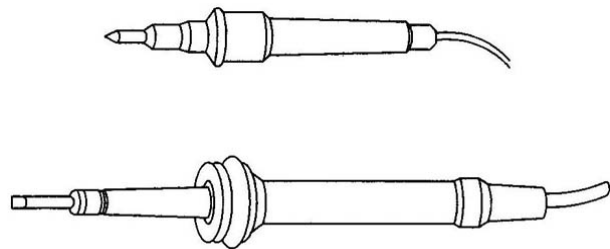
Recall from our previous discussion that soldering is a method of joining metal parts using a filler material (solder) that has a low melting point. Soldering can be accomplished in a number of ways, but you as a technician will be primarily concerned with the use of an electric soldering iron as a heat source.

#### ***Basic soldering equipment***

Proper soldering of connections in electronic equipment requires the basic tools and equipment listed below.

##### ***Soldering Iron***

Soldering irons (fig. 1–28) are available in a variety of sizes and wattage ratings. The size and shape of the connection being made primarily determines wattage ratings of the soldering iron. Ratings of 25–100 watts are commonly used for soldering electrical connections, while ratings of 100–450 watts are used for soldering large terminals and metal chassis. Soldering irons must be temperature controllable within  $\pm 10^{\circ}\text{F}$  and set to a temperature of heat level that will allow an acceptable solder connection to be made in a maximum of five seconds.

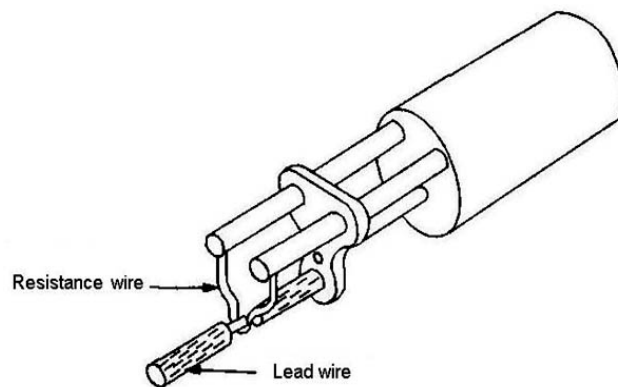


**Figure 1–28. Soldering irons.**

##### ***Insulation strippers***

Thermal-type insulation strippers (fig. 1–29) are temperature controllable and are used to melt a break in the insulation so it can be slid off of the conductor. They shall be used whenever practical because they pose the least amount of risk of damage to the conductor.

When mechanical wire strippers (fig. 1–30), sometimes referred to as hand- or precision-cutting-type strippers, are used, extreme care must be taken not to nick or otherwise damage the conductor. Mechanical wire strippers must have fixed dies in order to ensure a precision cut on the insulation.



**Figure 1–29. Thermal wire stripper.**

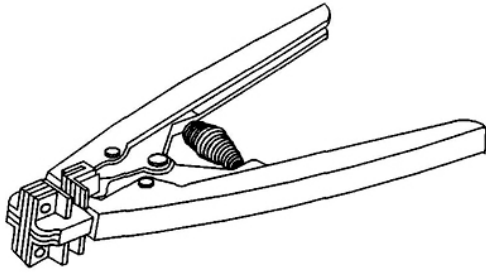


Figure 1-30. Mechanical wire stripper.

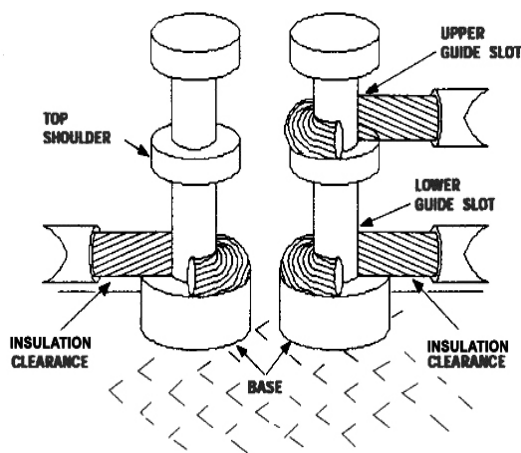


Figure 1-31. Turret terminal connections

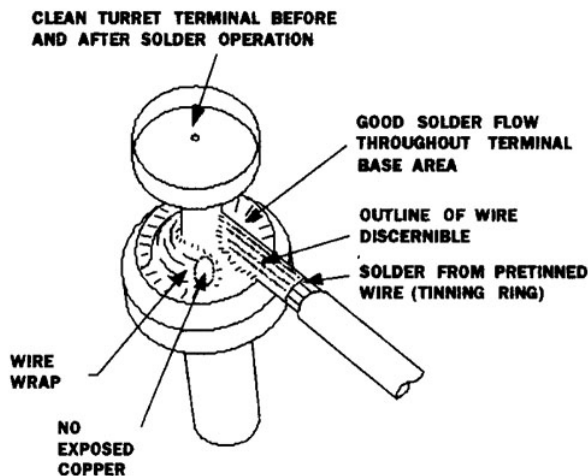


Figure 1-32. Acceptable turret terminal solder connection

### Wire-bending tools

Wire-bending tools used to connect wires to terminals should have a smooth bending surface that will bend wires and part leads without nicking, ringing, or causing other damage to the lead part.

### Solder

General soldering of electronic connections shall be accomplished using flux-cored-wire solder with an approximate ratio of 60 percent tin and 40 percent lead.

### Flux

Flux is used to remove any surface oxidation, provide a protective cover to prevent surface reoxidation, and to promote wetting action of the molten solder.

### Basic solder connections

There are several types of solderable terminal connections you may come across. We will discuss some of the more common types of terminals as well as some post-solder-connection inspection criteria that you should be familiar with. Keep in mind that the minimum insulation clearance for wire connected to all terminal types is such that the insulation does not become damaged or otherwise imbedded in the solder joint. The maximum insulation clearance of wires connected to all terminals shall be no more than two wire diameters, including the insulation.

### Turret

Wires or part leads attached to turret terminals shall wrap around the turret a minimum of 180 degrees as shown in figure 1-31.

A properly soldered turret terminal connection will look like the illustration shown in figure 1-32.

### Bifurcated

Wires can be attached to bifurcated terminals by way of bottom, top, and side (fig. 1-33) routes.

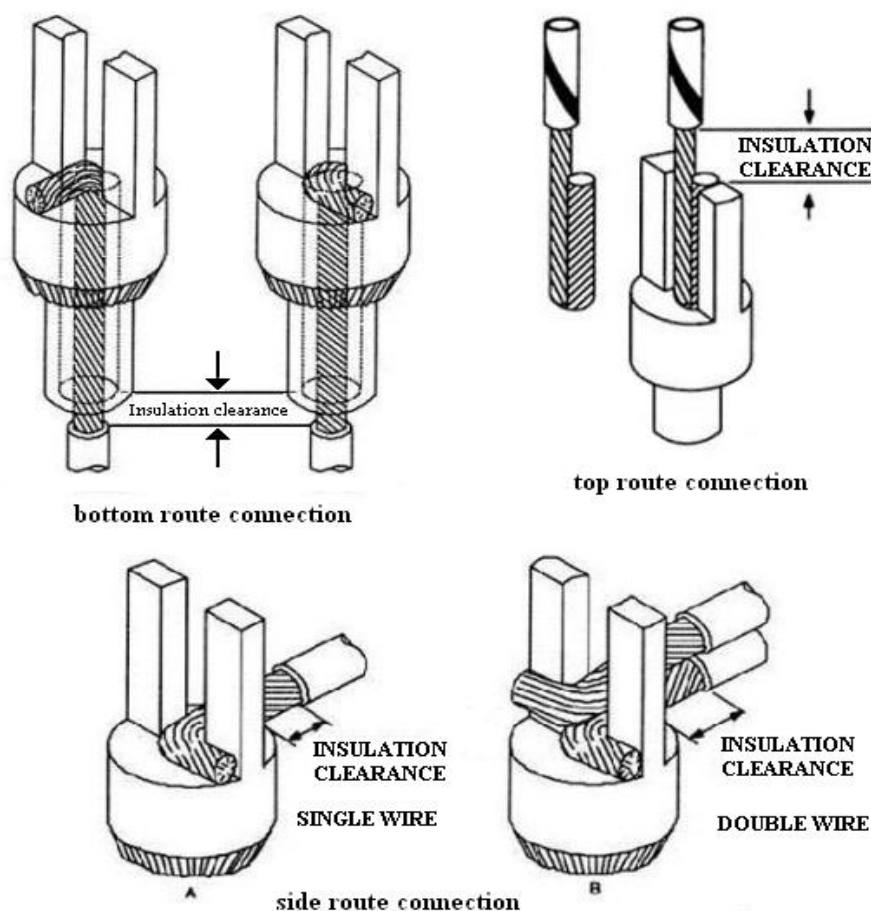


Figure 1-33. Bottom, top, and side route connection on bifurcated terminal.

A properly soldered side-routed bifurcated terminal connection should look like the illustration shown in figure 1-34.

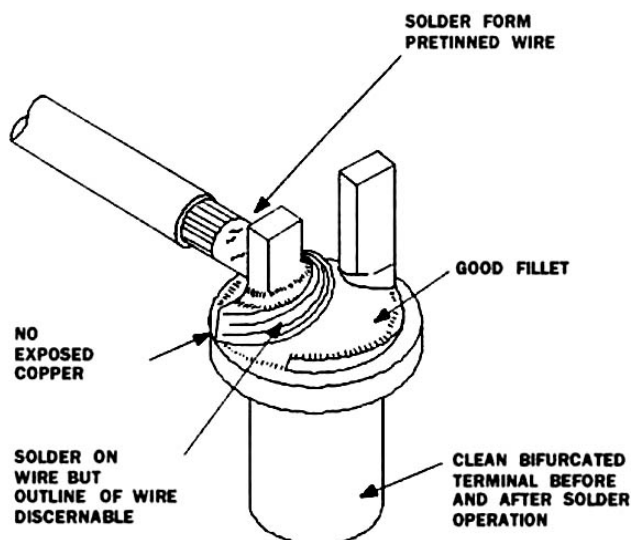


Figure 1-34. Acceptable bifurcated terminal solder connection.

*Hook*

Wires attached to hook terminals (fig. 1-35) shall wrap around the terminal a minimum of 180 degrees and a maximum of 270 degrees.

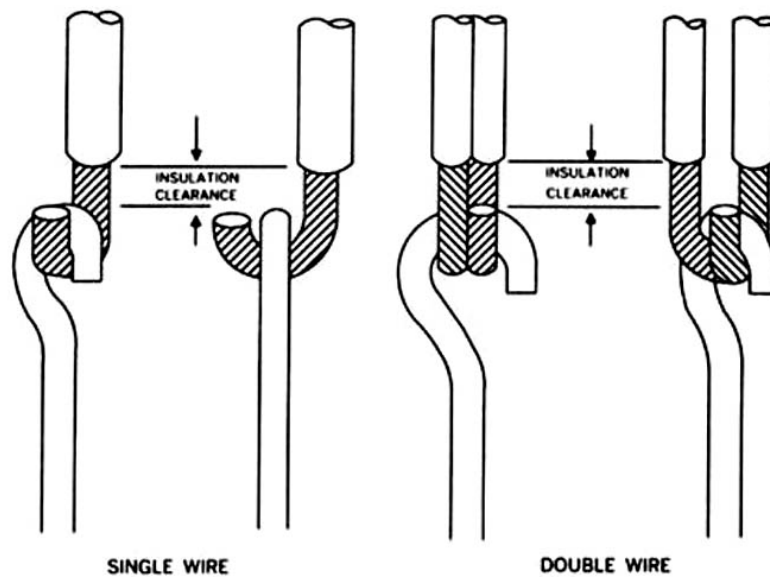


Figure 1-35. Hook terminal connections.

A properly soldered hook connection should look like the illustration shown in figure 1-36.

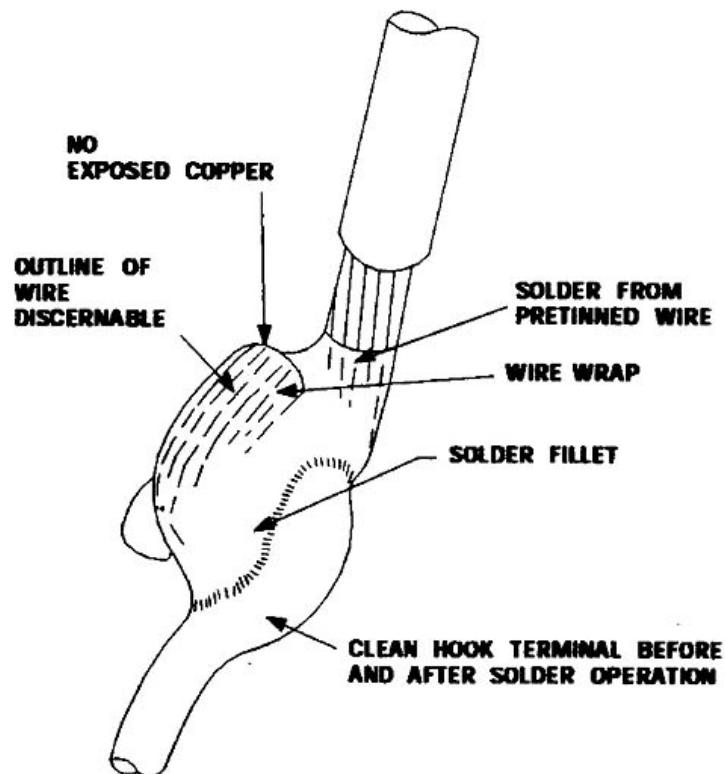


Figure 1-36. Acceptable hook terminal solder connection.

### Surface mounts

Wires or component leads mounted flat must make contact with the terminal, and the contour of the wire must be visible under the solder coating. The solder must also form a concave fillet, called a “knee fillet,” on each side of the wire, and the fillet must blend into the terminal surface in a smooth, continuous feathered edge. Figure 1-37 shows the cross section of an acceptable solder connection on a flat surface.

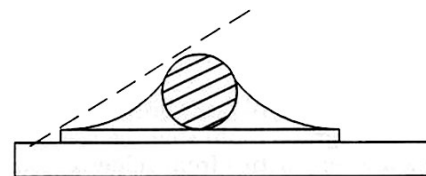


Figure 1-37. Cross section of acceptable solder connection.

### Cups

When soldering a stranded wire into a cup, ensure that the wire bottoms out in the cup as depicted in figure 1-38.

Note that the contour of the wire is visible from the insulation termination to the point of entry into the cup as shown in figure 1-39.

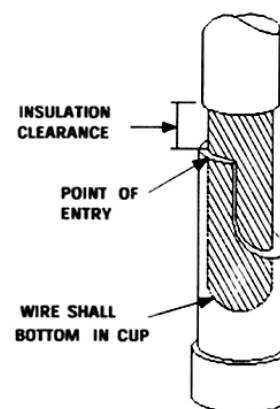


Figure 1-38. Wire placement in solder cup terminal.

### Basic soldering techniques

All solder pads and device terminals must be clean in order for good wetting and heat transfer to occur. Always clean the terminal or pad using an abrasive material such as a pencil-style typewriter eraser until the surface is bright and shiny and wash the cleaned surface with a solvent immediately prior to wire or part lead attachment and soldering. This will help ensure a secure solder connection. The soldering iron, as well as any stranded wire to be soldered, must be clean and pretinned with solder; otherwise, components may heat up excessively due to poor heat transfer. If component exteriors are insulated or will not come in contact with any wires or traces on the printed wiring board (PWB), they may be mounted flush with the PWB. Component leads can be bent up to 30 degrees in order to help retain the part during soldering, or you may use plastic mounting clips or holders for large devices to reduce mounting stresses. The end result is that they must then be permanently mounted on the circuit board properly. Use heat sinks on the leads of sensitive devices to prevent heat damage. Apply the soldering iron to both the component lead and terminal or pad to equally heat both. Apply solder to both lead and terminal or pad but never directly to the tip of soldering iron or gun. Direct contact of solder with the iron will cause the molten solder to flow over the gun rather than the joint. The moment the solder melts and begins to flow, remove the solder supply immediately but do not remove the iron just yet. The remaining solder will then flow over the junction of the lead and terminal or pad, assuming both are free of dirt. Let the iron heat the junction until the solder flows and then remove the iron tip. This will ensure a good solid junction. Remove the iron from the junction and let the junction cool.

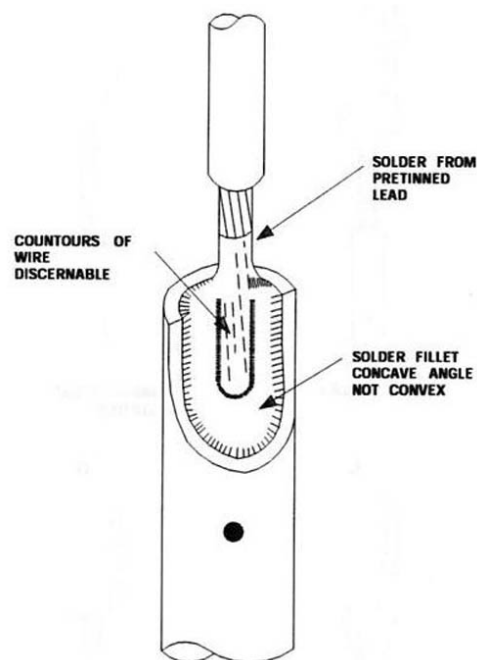


Figure 1-39. Acceptable solder cup terminal connection.

Be sure not to move the joint while it is cooling. Doing so will result in a fractured joint. Do not blow air onto the joint while it is cooling; instead, let it cool naturally, which will occur fairly rapidly. A good solder joint will be smooth and shiny with the lead outline clearly visible. Before soldering a new joint, clean the soldering iron tip of any residual flux or excess solder but allow a small coating

of solder on the tip to aid in the heat transfer for the next joint. This will also help prevent oxidation from forming on the tip.

After finishing all of the joints, remove excess flux residue from the board using alcohol, acetone, or other organic solvents within 30 minutes and trim the excess leads leaving only a length equal to the radius of the pad. If a poor connection requires rework, it is good practice to remove any solder from the joint prior to resoldering as solder should never be reused. During soldering, some of the base metal dissolves into the solder. Once the solder's capacity for the base metal has been achieved, it will no longer properly bond with the base metal and will usually result in a brittle, cold solder joint with a crystalline appearance.

To remove solder from a connection, use desoldering wick or vacuum desoldering equipment, if available. Desoldering wicks contain plenty of flux that will lift the contamination from the copper trace and any device leads that are present. This will leave a bright, shiny, clean junction to be resoldered.

### **Wiring**

In the event electrical wiring repairs are needed, use flexible stranded wire whenever practical. Solid wire should only be used if it is insulated, and it will be held firmly in place preventing possible equipment failure due to normal in-service vibrations and shock. Wire smaller than 22AWG should be avoided for use unless specific procedures prescribe otherwise.

### **Protection**

Wiring passing through metal partitions or shields less than 1/8 inch (in.) thick should be protected by installing the appropriate-sized grommets in the holes or by punching and rolling the hole. Protect wiring that passes through metal partitions or shields more than 1/8 in. thick by installing grommets in the holes or rounding edge of holes to a minimum radius of 1/16 in. Route conductors and cables as needed to avoid contact with heated or abrasive areas. Unused conductors in a cable or harness should be insulated or capped at both ends. Cables should also be securely tied to cable trays to prevent movement due to shock or vibration.

It is also important to consider the minimum bend requirements of wiring and cables in order to prevent damage to them. The minimum bend radius is the radius below which a cable should not be bent. This is of particular importance in the handling of fiber-optic cables, which are often used in telecommunications. The minimum bending radius will vary with different cable designs, but the guidelines below are a good rule of thumb. For example, to figure out the bend radius of a typical RG6/U coaxial cable (single conductor with shielding) with a diameter of 0.332 in., you would simply multiply 0.332 in. by 12 as shown below. The result (3.984 in.) is the minimum bend radius that the cable should be subjected to. In other words, the cable can be safely bent around a diameter of approximately 8 in. (remember, the radius is half of the diameter).

Single or multiple conductor cables without metallic shielding	8x the overall cable diameter
Single conductor cables with shielding	12x the overall cable diameter
Multiple conductor cables with individually shielded conductor	12x the individual cable diameter or 7x the overall cable diameter—whichever is greater
Fiber-optic cables	10x the overall cable diameter (multimode cables) or 20x the overall diameter (single-mode cables)

### **Marking**

Identify noncoded wire used in the repair and maintenance of electronic equipment by using a wire-stamping machine. It marks the non-color-coded wire either at each end of the wire close to its termination point or at intervals along the full length of the wire with a "letter" color code and the

wire number from the equipment wiring diagram. For example: BK-111 (black wire no. III); BL-121 (blue wire no. 121); R-Y-24 (red wire with yellow tracer no. 24).

The intervals between the identification codes placed on the wire are determined by the length of the wire but are limited to a maximum of 15 in. In addition, stamp wires within 3 in. of each junction (except permanent splices) and at each terminating point. For wires 3 in.-7 in. long, stamp them in the center; wires less than 3 in. long need not be stamped.

### Splicing

Splicing is a method of joining two wires together. Splicing wires is normally accomplished by either crimping or soldering them together.

- If several splices are to be located in an electrical wire bundle, stagger splices along the length of the bundle
- Do not splice aluminum wires. Damaged aluminum wire must be replaced.

### Crimping

Crimping is a method of making an electrical connection by joining two pieces of metal together by deforming one or both of them to hold the other. The bend or deformity is called the *crimp*.

A permanent splice should be performed on broken copper wires sized AWG 22 through 10 by using a preinsulated, permanent copper splice (fig. 1-40). The crimping operation must be done twice, once for each end of splice. After crimping, check that wire ends are still visible through the inspection hole of the splice.

When a permanent splice is not available, the barrel of a terminal lug (fig. 1-41) can be used, provided the barrel is large enough to accommodate both wires.

To use a terminal lug as a splice, first install a piece of insulation sleeving about 1 in. longer than the terminal lug barrel, and of the proper diameter to fit loosely over the insulation, on one piece of the broken wire. Next, cut off the terminal lug tongue and prepare the wires by stripping the insulation. Then, insert the wires from opposite ends of the barrel so that each wire protrudes through the barrel 1/32 in. Crimp the barrel in the center and slide the sleeving down over the connection so that it extends about 1/2 in. past each end of the crimped barrel. Finish by tying it with nylon cord at each end.

Another form of crimping is used during connector repair. The crimping tool shown in figure 1-42 is

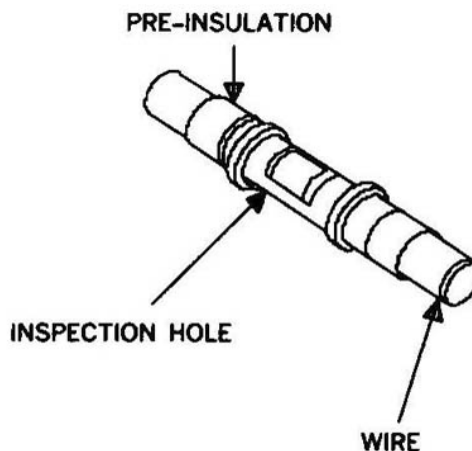


Figure 1-40. Preinsulated permanent copper splice.

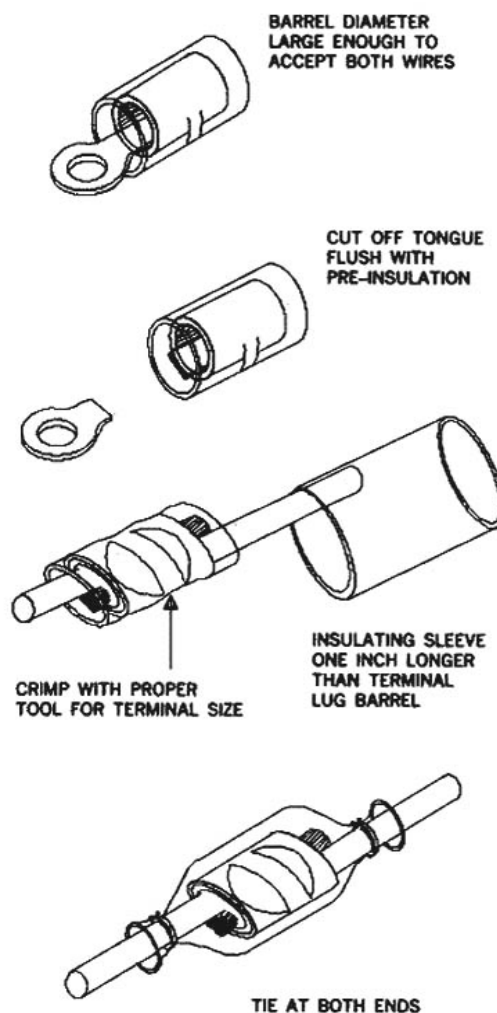


Figure 1-41. Terminal lug barrel splice.

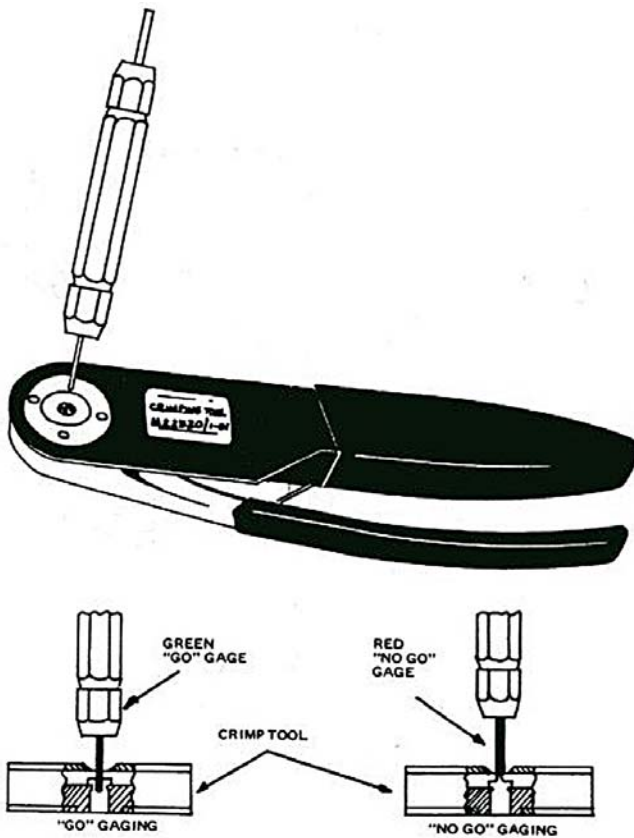


Figure 1-42. Basic crimping tool with inspection gauge.

used to crimp connector pins and sockets to wires by creating a set of impressions with the closure of its four (or more) indenters. The depths of the indenters are adjustable depending on the size of the materials to be crimped. A full-cycle ratcheting mechanism of the tool prevents the indenters from releasing before the crimp cycle has been completed.

Before materials can be crimped together, the crimp tool must be inspected. There are two methods to verify a crimp tool is ready for use. The first method involves checking the proper calibration of the crimping jaws with a gauge to ensure the indenters are working properly. If the indenters are fully closed and the "NO-GO" gauge can still fit through the gap, the tool cannot be used. The second method to verify that the proper operation of the crimp tool involves a pull test is accomplished on a minimum of three prepared sample connections. Here the connections are subjected to a force-gauged pull test to verify the secureness of the connection. If a break does occur

during the pull test, it is preferred that the wire itself breaks (called a "fray break") outside of the contact rather than due to a defect of the contact or crimp. Both inspection methods must be performed for each crimp tool and crimp-contact-conductor combination at the start and the end of each work shift or production run, whichever is shorter.

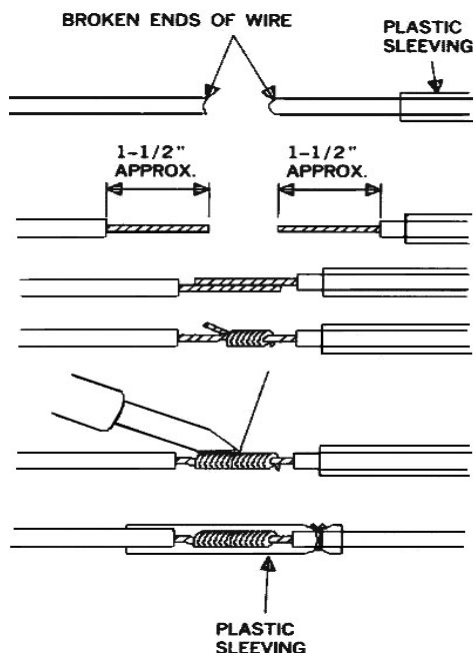


Figure 1-43. Splicing broken wire by soldering.

### Soldered splices

When neither a permanent splice nor a terminal lug is available, you can repair a broken wire by soldering it together (fig. 1-43).

To splice a wire by soldering, first install a piece of plastic sleeving of the proper diameter and about 3 in. long to fit loosely over the insulation on one piece of the broken wire. Next, strip the wire approximately 1 1/2 in. on each side of the break. Lay the stripped ends side by side and twist one wire around the other with approximately four turns. Twist the free end of the second wire around the first wire with approximately four turns. Solder the wire turns together, using 60/40 tin-lead rosin-core solder. Once the solder is cool, clean the connection with a solvent, draw the sleeve over the soldered wires, and tie at both ends. Tying of both ends is not required whenever heat-shrinkable tubing is used because the heated tubing will shrink and form to the diameter of the wire. In either case, the minimum sleeve or heat-shrink overlap is 0.2 in. on either side.



### ***Cable shielding and termination***

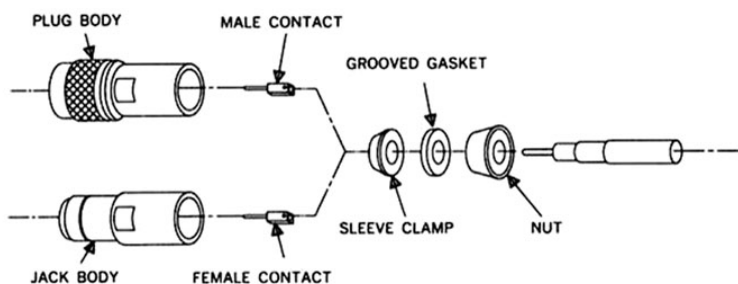
A shielded cable is an electrical cable of one or more insulated conductors enclosed by a common conductive layer. One of the most common types of shielded cable is the coaxial cable, as mentioned in a previous lesson. The shield may be composed of braided strands of copper (or other metal), a nonbraided spiral winding of copper tape, or a layer of conducting polymer. Usually, this shield is covered with a jacket. The shield acts as a Faraday cage in order to reduce electrical noise from affecting the signals and to reduce electromagnetic radiation that may interfere with other devices. The shield also minimizes capacitively coupled noise from other electrical sources; therefore, there are special considerations that must be taken in order to reduce the effects of noise on the cable.

- Shielded cable (unprotected by outer insulation) used inside electronic equipment should be routed and secured in such a manner as to preclude the possibility of contact with exposed wires and terminals.
- The shield shall be bonded to the chassis, unless connected to an “above ground” equipment or assembly. For “floating shield” terminations, shield strands/braid is allowed to be folded back over the outer insulating jacket.
- Shielded cables, used externally to electronic equipment, shall be bonded to the metal shell of each connector and shall connect to a ground lead in the cable, providing conffliction with a detailed design specification does not result.
- Do not use thermal strippers to remove the insulation on shielded or coaxial cables because damage to the outer jacket, shield, inner dielectric, and center conductor will occur if excessive heat or pressure is applied.
- Nicked, scraped, broken, or otherwise damaged shields are not acceptable.

### ***Shielded cable connector termination***

Shielded and coaxial cables can be terminated in a variety of types of connectors. “N-series” connectors represent a typical connector termination for coaxial cable.

To attach an improved N-series connector to a coaxial cable (fig. 1-44), first comb out the shield and strip the dielectric to 1/8 in. from the end of the jacket, exposing 5/32 in. of the center conductor. Next, disassemble the nut, gasket, and sleeve clamp from the plug or jack body. Taper the shield toward the center conductor,



**Figure 1-44. Attaching improved N connectors to coaxial cable.**

and slide the nut and gasket, in that order, over the tapered shield onto the jack. Make sure the grooved side of the gasket faces away from the nut. Then slide the sleeve clamp over the tapered shield until the clamp inside the shoulder butts flush against the cut end of the jacket. Fold the shield strands back over the sleeve-clamp taper without overlaps and trim the shield with scissors so that the strands end at the end of the clamp taper. Check that the exposed dielectric is 0.045 in. beyond the shield. It is important to check that the correct contact is being used; a male contact always goes into a plug body, and a female contact always goes into a jack body (fig. 1-45). Slip the contact over the center conductor so that the contact butts flush against the dielectric and solder using a clean, well-tinned soldering iron. Next, push the cable assembly into the connector body as far as it will go. Slide the gasket into the connector body and check that the knife edge of the sleeve clamp seats into the groove of the gasket. Then, slide the nut into the connector body and tighten. RF connectors should be physically tight on their coaxial cable. Connectors will allow movement that degrades the

electrical connection by improperly fitting RF bending, nicking, and breaking the braided shield wires. This can cause

premature failure or equipment damage if the cable is used in a transmitting system. Degraded signal-carrying capability can occur in a receiving or data transfer system. If any rotational movement is found between the RF connector and cable, the connector should be replaced.

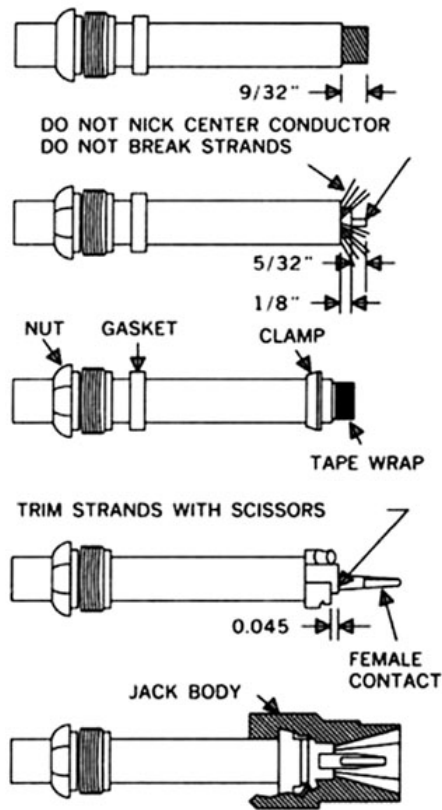


Figure 1-45. Plug body and jack body of an improved N connector.

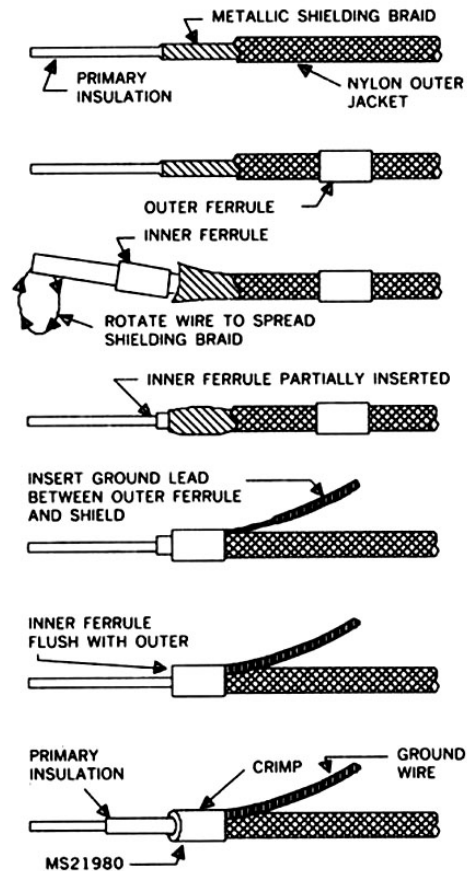


Figure 1-46. Grounding sheath termination for shielded wire.

### Grounding sheath termination

When a shielded or coaxial cable is not used with a connector, the preferred method of terminating the shield is by crimping it, with or as required, between two sleeves (or ferrules) as shown in figure 1-46.

To properly terminate a shielded cable by using ferrules, first strip off the shielding braid and outer jacket, if present. The length to be stripped is determined by the length of unshielded conductor necessary for making connections. Strip the outer jacket (if present) an additional 0.5 to 0.75 in. Measure the outside diameter (OD) of the primary insulation and add 0.005 in. minimum to it. Select an inner sleeve having the nearest larger inside diameter (ID). Note the OD of the inner sleeve selected and add 0.025 in. minimum to it to allow for thickness of the shielding braid. Add an extra 0.030 to 0.040 in. to allow clearance for 20AWG or 18AWG ground wires if required. Select an outer sleeve with the above dimension as the minimum ID. Next, slide the outer sleeve back over the insulation and braid. Rotate the cable with a circular motion to flare out the braid. Slip the inner sleeve under the braid so that about 1/16 in. of sleeve extends beyond the braid. At this point, you should examine the assembly to make sure that shield braid and ground wire come through under the outer sleeve. If it is acceptable, insert the stripped ground wire under the outer sleeve (if required) and

slide both forward over the braid and the inner sleeve until only 1/32 in. to 1/16 in. of inner sleeve and braid protrude. The ground wire may extend from the front or back of the outer sleeve as required, but keep in mind that excessive lengths may result in acting like an antenna for picking up interference. Finally, crimp with a hand tool and the correct die. Remember that every extra connection in a coaxial cable means a loss of efficiency, so repaired coaxial cables shall be replaced at the earliest possible time.

### **Binding**

Single conductors should be bound into a cable or harness whenever practical. Cables or harnesses are made by binding wires together by lacing, spot tying, or by using plastic self-clinching cable straps to hold them together.

### **Lacing**

Cable lacing should be performed with 1/8 in. nylon ribbon or equivalent ribbon-type lacing cord instead of round-type cord to minimize the possibility of insulation damage.

To make a cable lace, start by cutting a length of cord  $2\frac{1}{2}$  times the length of the proposed harness. Lay one end of the cord alongside the principal cable, pointing in the direction of the proposed harness. Secure the cord end by winding approximately four turns of cord over it, and wrap until a total of 12 turns is wound about the principal cable (fig. 1-47).

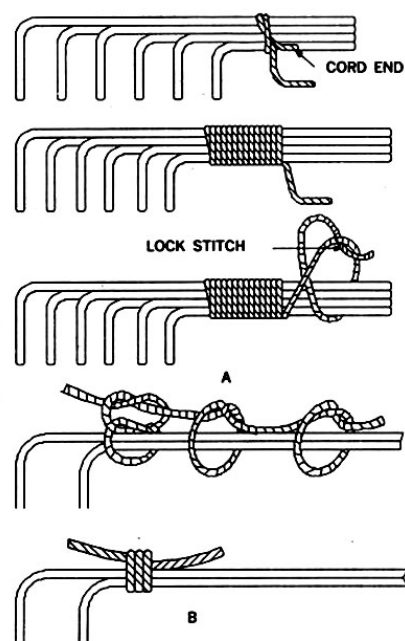


Figure 1-47. Starting a cable lace.

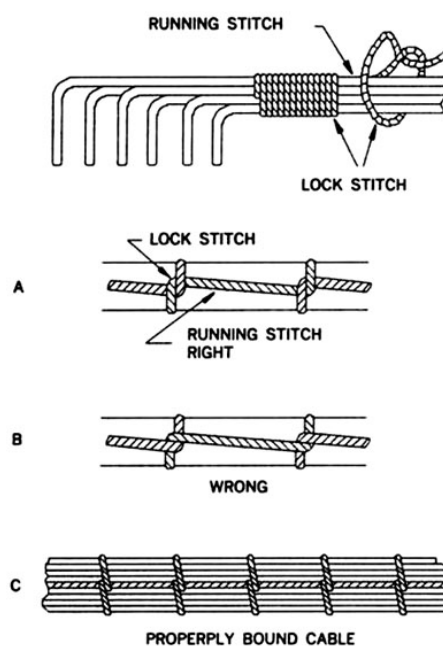


Figure 1-48. Cable stitching.

Secure the wrap with a lock stitch made by forming a loop, passing the cord over the loop, then through the loop, and finally pulling the cord tight as shown.

Lacing may also be started with a square knot, followed by two lock stitches (fig. 1-47). Tighten lacing sufficiently to prevent slippage of conductors, but do not cut or deform the conductor insulation.

Form secure stitches by lacing the cord over the loop, never under, to form the lock stitch (fig. 1-48), which results in the cord being locked under each loop. Lock stitches at approximately 1/2 in. intervals thereafter; secure other loops in the same fashion.

As lacing advances, reform the wires to ensure a neat and firmly bound cable as shown in figure 1-48. Arrange conductors to lie parallel without crossovers except when twisting is required. All lacing should follow the top of the harness. All knots, splices, or other irregularities should be hidden from view when the cable is installed in the equipment.

Terminate lacing by the procedure illustrated in figure 1-49. Wrap four turns of cord adjacent to the last lock stitch. Form a separate piece of cord into a 2 in. loop and lay alongside the cable. Wrap eight turns of lacing about the loop and draw the end of the lacing cord through the loop. Pull both ends of the loop to carefully draw the cord end underneath and out of the wrap. Pull the cord end tight, locking the wrap, and cut the end to approximately 1/8 in. or 1/4 in. Lacing may also be terminated with a lock stitch followed by a square knot.

Branches and sub-branches, including single leads, are usually referred to as "breakouts." A wire breakout should have a spot tie, closing stitch, starting stitch, or plastic wire wrap immediately before and immediately after the breakout. Precede single-lead breakouts with a lock stitch, without variation in the distance between stitches (fig. 1-50). Lace any breakout of two or more wires. When a group of wires is branched from a cable as seen in figure 1-50, wrap a lock stitch six turns firmly about the principal cable adjacent to the new stitch, and then, make another lock stitch adjacent to the new turns. After a branch is secured, continue the running stitches along the main cable.

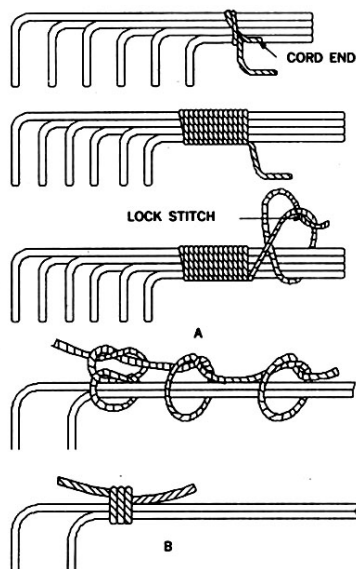


Figure 1-49. Cable lace termination.

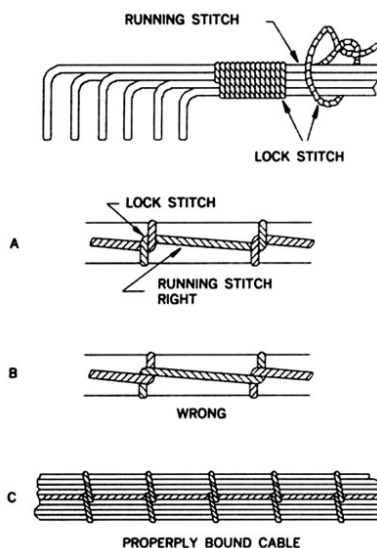


Figure 1-50. Cable branching.

### Spot Tying

Another procedure for lacing, spot tying (fig. 1-51), consists of making a series of individually bound wraps at equidistant points along the cable. Cut the lacing cord 2 in. longer than the length required to make 12 turns about the harness.

To spot tie a cable, first form one end of the cord into a 1 in. loop and place it flat on the harness, parallel to the wiring. Wind 12 turns tightly over this loop, and at the last turn, push the cord end through the loop that extends from under the

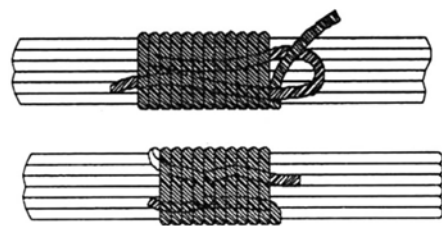


Figure 1-51. Spot tie.

### Self-clinching cable straps

Self-clinching cable straps are adjustable, lightweight, flat plastic straps used for tying and supporting cable assemblies and wire bundles. The strap configuration is shown in figure 1-52.

Straps are not to be used in temperature environments that exceed 185° F (85° C) or on coaxial cables or bundles containing coaxial cable that contain air or air foam dielectric.

To install a cable strap, select a strap size and the appropriate tool for the wire-bundle diameter being secured. Slip the strap tip around the bundle with boss side up as shown in figure 1-53. The distance from the connector or connector accessory to the start of the first tie or plastic wire wrap is based on the harness-bundle diameter.

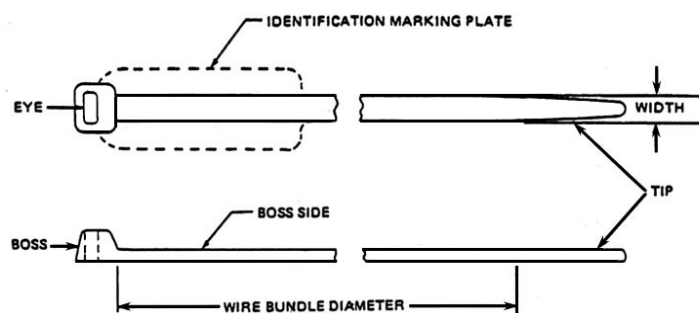


Figure 1-52. Strap configuration.

Thread the tip through the eye, and then hand pull the strap tight against the bundle. Adjust the tool index line to the tension locator value specified for the appropriate sized strap being used. Pass the free end of the cable tie through the slot in the end of the tool, and then push the tool snugly against the boss. While holding the strap firmly against the side of the tool and the tool facing squarely against the boss, pump the handle several times without fully activating the tool's cutting knife. Once the strap has been stretched to its maximum, squeeze the handle slowly and firmly until the strap is cut. The strap must be cut flush with the boss surface in order to eliminate painful cuts and scratches obtained from protruding strap ends. The finished wrap should not slide back and forth on the assembly and should not cause noticeable indentation or distortion of the wire in the harness.

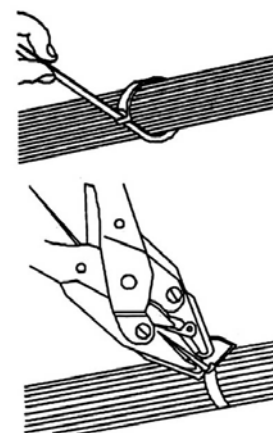


Figure 1-53. Installing self-clinching plastic cable straps.

### Fiber-optic cable

As you may recall from our earlier discussion on wiring, fiber-optic cables are not made out of metal but rather glass or plastic fibers designed to guide light along the fiber length by total internal reflection with a layer of cladding to re-direct light and keep it within the core (fig. 1-54). As such, their design makes them susceptible to signal degradation when their bend radius is exceeded, also called macro-bending. Fibers are terminated in connectors so that the fiber end is held at the end face precisely and securely. A fiber-optic connector is basically a rigid cylindrical barrel surrounded by a sleeve that holds the barrel in its mating socket. It can be push and click, turn and latch, or threaded. A typical connector is installed by preparing the fiber end and inserting it into the rear of the connector body.

Quick-set glue is usually used so the fiber is held securely, and a strain relief is secured to the rear. Once the glue has set, the end is polished to a mirror finish, which ensures the fibers are free of cracks, scratches, and edge chips. Various types of polish profile are used, depending on the type of fiber and the application. For single-mode fiber, the fiber ends are typically polished with a slight curvature, such that when the connectors are mated, the fibers touch

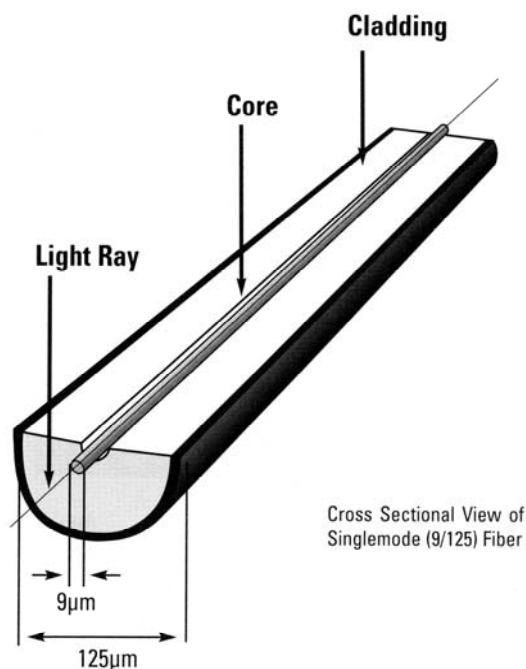


Figure 1-54. Fiber-optic cable. (Reproduced by permission of Fiber Instrument Sales, Inc., Oriskany, NY, <http://www.fiberinstrumentsales.com>.)

only at their cores. This is known as a “physical contact” (PC) polish. The curved surface may be polished at an angle in order to make an angled physical contact (APC) connection. Such connections have higher loss than PC connections, but greatly reduce back reflection because light that reflects from the angled surface leaks out of the fiber core; the resulting loss in signal strength is known as gap loss.

Optical fibers may be connected to each other by connectors or by splicing the two fibers together to form a continuous optical waveguide. The generally accepted splicing method is fusion splicing, which melts the fiber ends together with an electric arc. For quicker fastening jobs, a “mechanical splice” is used.

### ***Fusion splicing***

Fusion splicing is done with a specialized instrument (fig. 1-55) that typically operates by enclosing the two cable ends inside a splice enclosure that protects the splices while the fiber ends are stripped of their protective polymer coating (as well as the sturdier outer jacket, if present). The ends are cut with a precision cleaver to make them perpendicular and are placed into special holders in the splicer. The splice is usually inspected via a magnified viewing screen to check the cleaves before and after the splice. The splicer uses small motors to align the end faces together and emits a small spark between electrodes at the gap to burn off dust and moisture. Then the splicer generates a larger spark that raises the temperature above the melting point of the glass, thus fusing the ends together permanently. The location and energy of the spark is carefully controlled so that the molten core and cladding don’t mix, and this minimizes optical loss, backscatter, and reflection. A splice-loss estimate is measured by the splicer by directing light through the cladding on one side and measuring the light leaking from the cladding on the other side. A splice loss under 0.1 decibel (dB) is typical. The complexity of this process is the major thing that makes fiber splicing more difficult than splicing copper wire.



Figure 1-55. Fiber-optic cable fusion splicer. (Reproduced by permission of Fiber Instrument Sales, Inc., Oriskany, NY, <http://www.fiberinstrumentsales.com>.)

### ***Mechanical splicing***

Mechanical fiber splices are designed to be quicker and easier to install, but there is still the need for stripping, careful cleaning, and precision cleaving. The fiber ends are aligned and held together by a precision-made sleeve, often using a clear gel that enhances the transmission of light across the joint. Such joints typically have higher optical loss and are less robust than fusion splices, especially if the gel is used. All splicing techniques involve the use of an enclosure into which the splice is placed for protection afterward.

## Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

### 207. Electronic test equipment

1. What is the difference between stimuli test equipment and measurement equipment?
2. Match the description in column A with the electronic test equipment in column B. Items in column B may be used once, more than once, or not at all.

#### Column A

- \_\_\_ (1) Generates repeating electronic signals.
- \_\_\_ (2) Used for measuring electrical resistance.
- \_\_\_ (3) Provides electrical energy to an output load.
- \_\_\_ (4) Used for measuring signal frequency.
- \_\_\_ (5) Allows signal voltages to be viewed as a two-dimensional graph.
- \_\_\_ (6) Allows control over the various characteristics of pulses.
- \_\_\_ (7) Used for measuring the potential difference between two points in a circuit.
- \_\_\_ (8) Used for measuring the flow of current in a circuit.
- \_\_\_ (9) Also called a volt-ohm-millimeter (VOM).
- \_\_\_ (10) Used for analyzing and troubleshooting logical states of digital circuits.
- \_\_\_ (11) Locates faults in cables by transmitting a pulse along the conductor.

#### Column B

- a. Counter
- b. Ammeter
- c. Voltmeter
- d. Ohmmeter
- e. Multimeter
- f. Logic Probe
- g. Oscilloscope
- h. Power supply
- i. Pulse generator
- j. Signal generator
- k. Time domain reflectometer

### 208. Diagrams

1. What are the purposes of wiring diagrams?
2. What is the most important key to reading and understanding wiring diagrams?
3. List and briefly explain the three types of wiring diagrams.
4. What are the rules for tracing electrical circuits.
5. List the three rules when extracting circuits.

**209. Electronics troubleshooting**

1. What is the first step when troubleshooting an electrical circuit?
2. What can you use to analyze malfunctions?
3. What must be accomplished after the malfunction has been located?
4. What are the indications of a direct short?
5. What are the symptoms of a cross short?
6. What causes a shorted control?
7. What are some causes of low-power conditions in a circuit?

**210. Electronics preventative maintenance and repair**

1. What is usually the best troubleshooting technique?
2. What is static electricity?
3. Why do nonconductors generate larger amounts of electrostatic voltage than conductors?
4. Why is a latent defect considered the most dangerous?
5. What does an effective electrostatic discharge (ESD) control program consist of?
6. Soldering irons of what wattage rating are commonly used for electrical connections?



7. What is flux used for?
8. What can be done to retain components in place when soldering?
9. What type of wire should be used (when practical) for all electrical repairs?
10. What is the minimum bend radius for fiber-optic cables?
11. What should be done after crimping a preinsulated, permanent copper splice?
12. What two methods are used to verify a crimping tool is ready for use?
13. How much insulation should be stripped when preparing to splice a wire using the soldering method?
14. What is the purpose of a cable's shield?
15. Why should coaxial cables requiring repair be replaced at the earliest possible time?
16. What should a self-clinching plastic strap be checked for once it has been installed?
17. What is the generally accepted method of splicing fiber-optic cables?

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### **Answers to Self-Test Questions**

#### **201**

1. To make extremely large or small numbers easier to work with.
2. The number that is to be multiplied by itself.

3. (1)  $6 \times 10^3$ .  
(2)  $25 \times 10^4$ .  
(3)  $38 \times 10^{-5}$ .  
(4)  $49 \times 10^{-3}$ .
4. (1) 0.00046.  
(2) 1,500,000.
5. The coefficient is always greater than or equal to 1 but less than 10.
6. The exponent is either a zero or a multiple of 3.
7. (1)  $12.45 \times 10^3$ .  
(2)  $68.475 \times 10^3$ .  
(3)  $45.3 \times 10^{-6}$ .  
(4)  $983 \times 10^{-6}$ .
8. (1)  $65.84 \times 10^3$ .  
(2)  $6.4179 \times 10^5$ .  
(3)  $78.03 \times 10^5$ .  
(4)  $30.2 \times 10^5$ .

**202**

1. (1) f.  
(2) l.  
(3) h.  
(4) d.  
(5) e.  
(6) a.  
(7) b.  
(8) g.  
(9) i.  
(10) k.  
(11) j.  
(12) c..

**203**

1. A power source, load device(s), and conductor(s).
2. 4.6K ohms (+/- 10 percent).
3. (1) g.  
(2) l.  
(3) b.  
(4) i.  
(5) j.  
(6) k.  
(7) e.  
(8) m.  
(9) n.  
(10) c.  
(11) d.  
(12) f.  
(13) a.  
(14) h.

4. The American Wire Gauge (AWG) is commonly used as a standard method of denoting cable and wire diameters. Increasing gauge numbers give decreasing wire diameters.
5. Soldering is a method of joining metal parts using a filler material (solder).
6. A switch.
7. Like charges repel each other while unlike charges attract each other.

**204**

1. Analogue, digital, and mixed signal.
2. Analogue circuits are faster than digital circuits but also are much more susceptible to noise.
3. Digital circuits interface well with computers and can achieve lossless data transmission. However, digital circuits tend to require more energy than analogue circuits and are sometimes more expensive and fragile.

**205**

1. Series, parallel, and series-parallel.
2. Because there is only one path for current to flow.
3. Voltage is common among all of the branches.
4. Total resistance is calculated by taking the reciprocal of the sum of the individual reciprocals of each individual component's resistance.
5. It will have the circuit's total current flowing through it.
6. By first figuring out the resistance of the parallel portion of the circuit and then adding that resistance to the total series resistance.

**206**

1. In an electrical circuit, the current is directly proportional to the voltage. Mathematically this can be written several ways such as:  $V=IR$ .
2. 0.003 amps (or 3 milliamps).

**207**

1. Stimuli equipment provides operating power, signals, or other inputs to the device under test (DUT) while measurement equipment analyses the various characteristics or responses of the DUT.
2. (1) j.  
(2) d.  
(3) h.  
(4) a.  
(5) g.  
(6) i.  
(7) c.  
(8) b.  
(9) e.  
(10) f.  
(11) k.

**208**

1. To show the system components; to allow you to understand system operation; to aid in the troubleshooting of electrical systems.
2. The ability to read symbols.
3. (1) One-line (block) diagram—gives a general view of the entire system.  
(2) Schematic/elementary diagram—shows all circuit components without regard to physical location or relationship, circuit operations, and where the functions within a circuit occur in an exact sequence.  
(3) Interconnection diagram—shows complete connections between equipment units, unit assemblies, and associated apparatus.

4. (1) Use the appropriate technical reference.  
(2) Identify all circuit components.  
(3) Trace the circuit as you read the circuit operation.
5. (1) Identify and label all circuit components.  
(2) Set all switches, contacts, and relays to desired positions.  
(3) Know how meters are energized and connected to the source of power.

**209**

1. Perform an operational check.
2. Your senses (sight, sound, smell, feel), systems or technical manuals, troubleshooting flowcharts, circuit descriptions, wiring diagrams.
3. A neat, permanent-type repair.
4. The circuit is inoperative, and its protective device has been actuated.
5. Two or more independent circuits operate from one control device. In addition, the protective device may or may not actuate.
6. The contacts of a switch or relay being welded together.
7. Weak batteries, loose connections, dirty switch contacts, or conductors too small to carry the load.

**210**

1. The prevention of trouble.
2. An unbalanced amount of electrons that have built up on a material and have nowhere to go.
3. The generated charge is not distributed over the entire surface of the material as is the case with conductors.
4. Because the failure is not detected until it occurs during the item's operation.
5. The proper handling and storage of electrostatic discharge sensitive (ESDS) components.
6. 25 watts to 100 watts.
7. Flux is used to remove any surface oxidation, to provide a protective cover to prevent surface reoxidation, and to promote wetting action of the molten solder.
8. Component leads can be bent up to 30 degrees in order to help retain the part during soldering, or you may use plastic mounting clips or holders for large devices to reduce mounting stresses.
9. Stranded wire.
10. 10x the overall cable diameter for multimode cables or 20x the overall diameter for single-mode cables.
11. Check that wire ends are still visible through the inspection hole of the splice.
12. The first method involves checking the proper calibration of the crimping jaws with a gauge to ensure the indenters are working properly. The second method involves a pull test of three prepared sample connections.
13. Approximately 1½ inches.
14. The shield acts as a Faraday cage to reduce electrical noise from affecting the signals and to reduce electromagnetic radiation that may interfere with other devices. The shield also minimizes capacitively coupled noise from other electrical sources.
15. Extra connections in a coaxial cable result in a loss of efficiency.
16. The strap must be cut flush with the boss surface, it should not slide back and forth on the assembly, and it should not cause noticeable indentation or distortion of wire in the harness.
17. Arc fusion splicing.

**Do the unit review exercises before going to the next unit.**

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## Unit Review Exercises

**Note to Student:** Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to ECI (AFIADL) Form 34, Field Scoring Answer Sheet.

**Do not return your answer sheet to AFIADL.**

1. (201) Which of the following is true for numbers expressed using scientific notation?
  - a. The coefficient is less than or equal to one.
  - b. The resulting exponent must be a zero or multiple of two.
  - c. The resulting exponent must be a zero or a multiple of three.
  - d. The coefficient is greater than or equal to one but less than ten.
2. (201) Which of the following is true for numbers expressed using engineering notation?
  - a. The coefficient is less than or equal to one.
  - b. The resulting exponent must be a zero or multiple of two.
  - c. The resulting exponent must be a zero or a multiple of three.
  - d. The coefficient is greater than or equal to one but less than ten.
3. (201) What is the metric prefix for 1,000?
  - a. Milli.
  - b. Kilo.
  - c. Mega.
  - d. Giga.
4. (202) What is the term for the movement of free electrons through a conductor?
  - a. Power.
  - b. Current.
  - c. Voltage.
  - d. Inductance.
5. (202) What is the unit of measurement for impedance?
  - a. Ohms.
  - b. Watts.
  - c. Farads.
  - d. Henries.
6. (202) Which of the following electrical components acts like a battery?
  - a. Resistor.
  - b. Inductor.
  - c. Capacitor.
  - d. Transformer.
7. (203) What is not a requirement for a simple circuit?
  - a. Load device.
  - b. Conductors.
  - c. Power source.
  - d. Protective device.
8. (203) What does not provide the motion necessary to be considered a prime mover?
  - a. Waterfall.
  - b. Windmill.
  - c. Generator.
  - d. Steam engine.

9. (203) What does the fourth colored band of a four-banded resistor indicate?
  - a. Tolerance.
  - b. Reliability.
  - c. Multiplier.
  - d. The fourth digit of the resistor's value.
10. (203) What does the fourth color band of a six-banded resistor indicate?
  - a. Tolerance.
  - b. Multiplier.
  - c. Reliability.
  - d. Power rating.
11. (203) What potentiometer's value is adjusted by turning its shaft?
  - a. Wattage.
  - b. Tolerance.
  - c. Reliability.
  - d. Resistance.
12. (203) Where is energy stored in a capacitor?
  - a. In a series of cells.
  - b. In the ferromagnetic core.
  - c. Between conductive plates.
  - d. In the magnetic field of the coil.
13. (203) What type of materials are silicon, germanium, and gallium arsenide considered?
  - a. Insulators.
  - b. Conductors.
  - c. Nonconductors.
  - d. Semiconductors.
14. (203) What device is used to transfer electrical energy from one circuit to another by means of an electromagnetic field?
  - a. Inductor.
  - b. Capacitor.
  - c. Transistor.
  - d. Transformer.
15. (203) What is the purpose of a motor?
  - a. To convert mechanical energy to electrical energy.
  - b. To convert electrical energy to mechanical energy.
  - c. To convert chemical energy to electrical energy.
  - d. To convert electrical energy to chemical energy.
16. (203) What wire characteristic is indicated by an increasing gauge value?
  - a. An increasing diameter.
  - b. A decreasing diameter.
  - c. An increasing cladding size.
  - d. A decreasing cladding size.
17. (203) Which switch would be best suited for a radio AM/FM selector switch?
  - a. Single-pole single-throw (SPST).
  - b. Single-pole double-throw (SPDT).
  - c. Double-pole double-throw (DPDT).
  - d. Double-pole single-throw (DPST).

18. (203) Which if the following fuses could be used as a substitute for a fuse rated at 150 volts / 2 amps?
- a. 100 volts / 1 amps.
  - b. 100 volts / 3 amps.
  - c. 200 volts / 1 amps.
  - d. 200 volts / 3 amps.
19. (204) What type of circuit is the most common physical representation of Boolean algebra?
- a. Series.
  - b. Digital.
  - c. Parallel.
  - d. Analogue.
20. (205) What is a basic type of circuit configuration?
- a. Digital.
  - b. Analogue.
  - c. Mixed-signal.
  - d. Series-Parallel.
21. (205) What is the name of the physical interface where many devices share the same electric connection?
- a. Electrical Bus.
  - b. Electrical joint.
  - c. Parallel circuit.
  - d. Series-Parallel circuit.
22. (205) What value is common among the branches in a parallel circuit configuration?
- a. Voltage.
  - b. Current.
  - c. Resistance.
  - d. Impedance.
23. (206) What is true concerning Kirchhoff's Laws?
- a. Current is directly proportional to voltage.
  - b. Current is directly proportional to resistance.
  - c. The sum of the voltage drops in a circuit must equal the circuit's total resistance.
  - d. The sum of all currents entering a node is equal to the sum of all currents leaving a node.
24. (207) What is a Galvanometer used for?
- a. Measuring resistance.
  - b. Measuring frequency.
  - c. Measuring current flow.
  - d. Measuring the potential difference between two points in an electric circuit.
25. (207) What axis is used to represent time on an oscilloscope?
- a. W.
  - b. X.
  - c. Y.
  - d. Z.
26. (207) What is not visually indicated by the lights on a logic probe?
- a. Pulses.
  - b. Frequency.
  - c. Voltage states.
  - d. Single occurring events.

27. (208) What is not a purpose of wiring diagrams?
- Showing system components.
  - Identify faults within a system.
  - Allowing an understanding of system operation.
  - Aid in the troubleshooting of electrical systems.
28. (208) What is the most important key to reading and understanding wiring diagrams?
- The ability to read symbols.
  - Being able to trace circuits.
  - Being able to extract circuits.
  - Setting all switches to the desired position.
29. (208) What diagram gives a general view of the entire system?
- Block.
  - Schematic.
  - Elementary.
  - Interconnection.
30. (208) What type of lines is normally used to represent exciter and field circuits on a interconnection diagram?
- Heavy
  - Medium.
  - Light.
  - Dotted/dashed.
31. (208) Which is one of the three rules for tracing electrical circuits?
- Locate all sources of resistance on the schematic first.
  - Identify and label all physical components in the circuit.
  - Set all switches, contacts, and relays to the open position.
  - Use the appropriate technical reference to understand circuit operation.
32. (209) What is the proper sequence of events when troubleshooting?
- Perform an operational check, analyze the malfunction, locate the malfunction, perform corrective action, and perform an operational check.
  - Analyze the malfunction, locate the malfunction, perform an operational check, perform corrective action, and perform an operational check.
  - Locate the malfunction, perform an operational check, analyze the malfunction, perform corrective action, and perform an operational check.
  - Perform an operational check, locate the malfunction, analyze the malfunction, perform corrective action, and perform an operational check.
33. (209) What is a characteristic of an open circuit?
- Circuit cannot be turned off.
  - Indicator lamps are illuminated.
  - Protective device will not activate.
  - Two or more circuits operate from one control device.
34. (209) What is not a type of electrical short?
- Cross.
  - Direct.
  - Coupled.
  - Shorted control.



35. (209) What type of short is characterized by two or more independent circuits making contact with each other?
- a. Cross.
  - b. Direct.
  - c. Coupled.
  - d. Shorted control.
36. (209) What is not a symptom of a low power condition?
- a. Dim lights.
  - b. Sluggish motor.
  - c. Chattering relays.
  - d. Dirty switch contacts.
37. (210) What material is most capable of generating large amounts of electrostatic voltages?
- a. Wood.
  - b. Silicon.
  - c. Plastic.
  - d. Copper.
38. (210) What is the minimum series resistance between electrostatic discharge work surfaces and facility ground?
- a. 0 ohms.
  - b. 100,000 ohms.
  - c. 250,000 ohms.
  - d. 1,000,000 ohms.
39. (210) ESD wrist straps must be able to limit current to how many amperes for personnel safety?
- a. 1 milliamp.
  - b. 5 milliamps.
  - c. 10 milliamps.
  - d. 100 milliamps.
40. (210) What is the ideal relative humidity range when working with electrostatic discharge sensitive items?
- a. 10 – 20%.
  - b. 30 – 50%.
  - c. 40 – 60%.
  - d. 60 – 70%.
41. (210) How far can component leads be bent in order to help retain them to printed wiring boards during soldering?
- a. 10°.
  - b. 30°.
  - c. 45°.
  - d. Component leads cannot be bent at all.
42. (210) Once soldered, to what length should excess component leads be trimmed?
- a. Flush with the circuit board.
  - b. Equal to the radius of the solder pad.
  - c. Less than the radius of the solder pad.
  - d. No more than twice the radius of the solder pad.

43. (210) Which of the following is not true concerning shielded cables?
- a. The shield acts as a Faraday cage.
  - b. The shield reduces electromagnetic radiation.
  - c. The shield shall be removed with mechanical strippers only.
  - d. The shield minimizes inductively coupled noise from other sources.
44. (210) Which of the following should be used when performing cable lacing?
- a. 1/16" nylon ribbon.
  - b. 1/8" nylon ribbon.
  - c. 1/16" nylon cord.
  - d. 1/8" nylon cord.
45. (210) Which is true concerning self-clinching cable straps?
- a. Excess strap must be trimmed to a minimum of 1/16" with the boss surface.
  - b. Straps should not be used in environments where temperatures exceed 85°F.
  - c. Straps should not cause noticeable distortion of the wire insulation on coaxial cables.
  - d. The harness-bundle diameter determines how far the strap is placed from a connector.
46. (210) What types of connections are not used with fiber optic cables?
- a. Crimped.
  - b. Threaded.
  - c. Push and click.
  - d. Turn and latch.
47. (210) What is not true concerning the polishes used on fiber optic cables?
- a. Physical contact polishes ensure that the fibers touch only at their cores.
  - b. Polishes ensure the fibers are free from cracks, scratches, and edge chips.
  - c. Fiber ends are typically polished with a slight curvature on multimode cables.
  - d. Polished physical contact connections that are angled result in higher optical loss than non-angled physical contact polishes.
48. (210) What is an advantage of mechanically splicing a fiber optic cable as compared with fusion splicing a fiber optic cable?
- a. They are easier to install.
  - b. They offer lower optical loss.
  - c. They do not require precision cleaving.
  - d. They are more robust than fusion splices.