CHAPTER 1

Electrical Characteristics of Wire

1.1 INTRODUCTION

It may not be necessary for the worker who installs wiring systems to understand the electrical properties of electrical conductors and fiber optical cables to install a system correctly. However, his or her understanding of these properties will give a better appreciation of the job to be done, the tools that are to be used, and the results of troubleshooting the system.

It is necessary for the staff person responsible for communications and for the wiring system designer to understand how wiring characteristics affect signal information. The purpose of this text is to assist both the cable installer and the wiring system designer.

A **wiring system** is a form of an electrical circuit. An electrical circuit is comprised of an energy source, an energy transfer media, and a load. An energy source could be a battery, a generator, an amplifier, a digital computer, or any of the other devices that output energy in the form of a voltage, current, or light. **Energy transfer media** are any of the materials used to transport energy from one place to another. Transfer media include copper wires (conductors), fiber-optic cables, and air (in the case of radiated energy). A **load** in a circuit can be any of many components or devices that receive the energy transferred, such as resistors, lightbulbs, speakers, motors, computer terminals, printers, or personal computers (PCs). To understand better the concept of energy transfer, circuits, sources, and loads, we must introduce the concepts of voltage, current, resistance, power, and energy transfer.

1.2 VOLTAGE IN AN ELECTRIC CIRCUIT

An **electromotive force** (EMF) is a force that tends to move electrical energy. Electromotive force or voltage is conveniently regarded as an attractive or repulsive force on charges. Voltage can be compared to water pressure that causes water flow in a pipe, which is measured in pounds

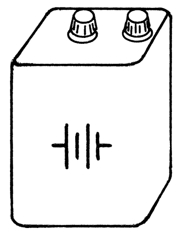


Figure 1-1 A 9-V battery.

per square inch (psi). A voltage is a difference of potential or EMF that attracts and repels electrons. Another way of thinking of voltage (V) or (E) is as a force or pressure that forces electrons through a circuit. The movement of electrons transfers energy throughout the circuit.

DC voltage (direct current voltage) is the name given to voltage in a circuit in which the current flows in one direction only. DC voltage is either positive or negative. This usually means that it is a value above ground (positive) or below ground (negative).

Ground potential or **reference** is considered to be 0 V. Ground potential is the potential of the earth (in England the term is *earth*). The term *ground* is also used to mean the metal case or chassis of a piece of electronic equipment. We will discuss this in more detail later in this chapter.

The polarity of a voltage is usually discussed in reference to ground. A value above ground (for example, 10 V) is said to be +10 V, while a voltage of 10 V below ground is said to be –10 V. A battery such as shown in Figure 1-1 has a positive and a negative terminal. The positive terminal is +9 V with respect to the negative terminal side. On the other hand, the negative side is –9 V with respect to the positive side. When a battery or other dc voltage is connected in a circuit, a dc current (electrons) flows from the negative terminal of the battery through the circuit and returns to the positive terminal. This theory of current flow is called **electron flow**. Most engineers subscribe to positive current flow or conventional current flow simply because it is *conventional* (that is, it was the first theory of current flow). Energy is transferred through the circuit to a load; the results are the same regardless of the current theory used to analyze a circuit. The voltage drops have the same value, polarity, and power dissipation. In electrical circuits a battery voltage or supply voltage is denoted as **E** while voltage drops in a circuit are symbolized as **V.** Voltages can be developed from many sources, such as batteries, solar cells, thermocouples, or generators.

AC voltages (alternating current voltage) are those that vary above and below ground with respect to time. An example of an ac voltage is common house, office, and factory voltage, which changes at a rate of 60 cycles per second (Hertz). In many countries, such as Australia, the frequency is 50 Hz. Figure 1-2 illustrates a cycle of voltage from a 60-Hz source. AC voltages change with time and are also called **analog voltages.**

In this book we are interested in both analog and digital voltages. As just stated, analog voltages are those that vary with time, such as voice signals (Figure 1-3a). *Digital signals* are in

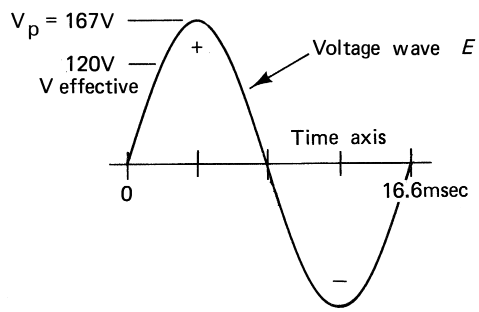


Figure 1-2 A 120-V, 60-Hz sinewave.

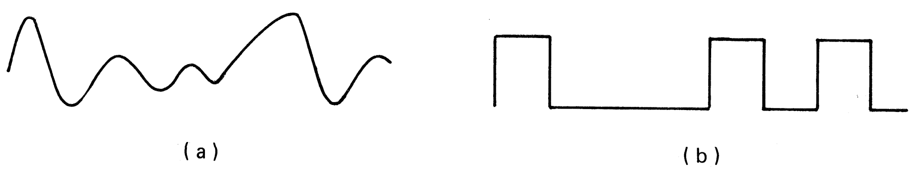


Figure 1-3 Voltages: (a) analog voltages, (b) digital voltages.

the form of pulses, called bits, that change quickly from one level of voltage to another, as shown in Figure 1-3b.

1.3 CURRENT IN AN ELECTRICAL CIRCUIT

As stated earlier, **current** or **current flow** is a movement or flow of electrons through a circuit that is caused by the electromotive force or voltage applied to the circuit. When a voltage is applied to a complete circuit, from a source, electrons move through the conductors of the circuit (energy transfer) to the load at the receiving end of the conductors. The desire is to transport the electrical signals along the conductors (wires) and have them arrive at the destination in the same configuration and with the same voltage level as those at which they left the source. In other words, the system should reproduce the input signals at the receiver and relay the input signals correctly, be they voice signals, other analog signals, dc voltages, or digital pulses.

Fiber-optic cables transport energy via photons of light energy. However, the devices that produce the signals and the devices that receive the signals depend on electrical energy for operation. The signal from the source device must be converted to light energy to be transported by the fiber cable and then converted back to electrical energy to be used by the destination device. Fiber optics will be discussed in some detail in Chapter 4.

1.4 RESISTANCE IN WIRING CIRCUITS

Resistance is the property of an electrical circuit that limits the current. Resistance can be compared to friction in a mechanical device, where the frictional drag on a body limits the speed of

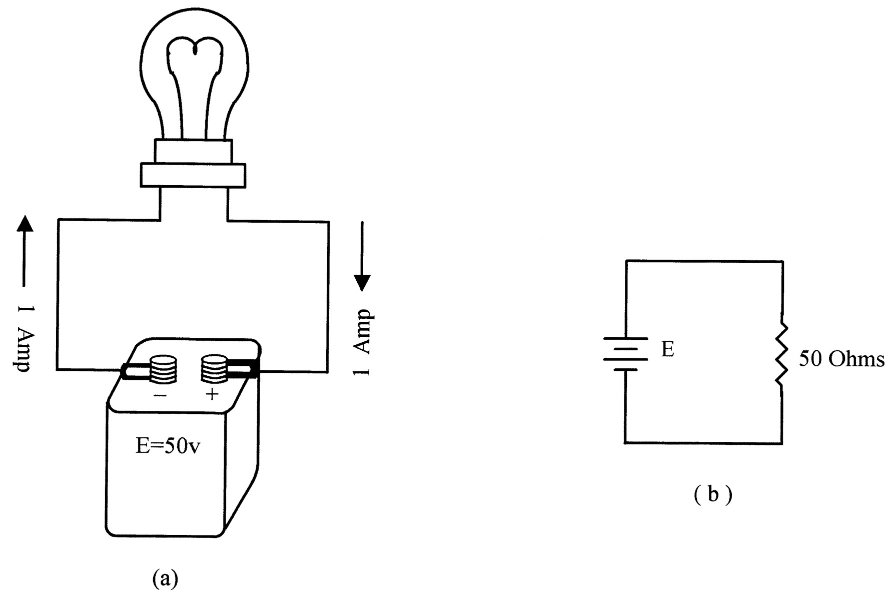


Figure 1-4 A simple electrical circuit: (a) circuit, (b) schematic diagram of the circuit.

the body and produces heat. The resistance of a material limits the number of electrons that flow in the material and the amount of energy that is transferred and causes heat in the circuit. Resistance occurs in all electrical circuits—even the best of conductors have some resistance.

The unit of resistance is the ohm and is symbolized by the Greek capital letter omega, Ω. The relationship among the voltage, current, and resistance in a circuit is called Ohm's law and is formulated as follows:

$$\text{amperes} = \frac{\text{volts}}{\text{resistance}}$$

$$I = \frac{E}{R}$$

Ohm's law states that current is directly proportional to voltage and inversely proportional to resistance. That is, increased voltage causes increased current flow and increased resistance decreases the amount of current.

Figure 1-4 depicts a simple circuit of a battery as a source and a lamp as a load. Figure 1-4a shows a pictorial of the circuit, and Figure 1-4b is a schematic diagram of the circuit. The schematic diagram of the circuit assumes that the wires to and from the 50-Ω load have no resistance.

The current is

$$I = E/R = 10\text{ V}/50\ \Omega = 0.2\text{ A, or }0.2\text{ A}$$

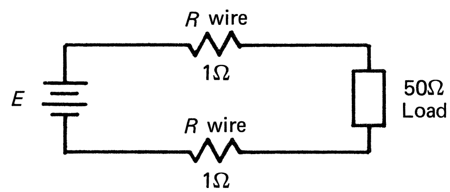


Figure 1-5 An example of an electrical circuit with wiring resistance.

The resistance is determined as follows:

$$R = E/I = 10\text{ V}/2.0\text{ A} = 50\ \Omega$$

We noted earlier that conductors (wires) are not perfect energy transporters but have resistance. In most cable runs wiring resistance can be ignored, but in long runs we might experience situations as depicted in Figure 1-5. The 1-Ω resistors between the source and the load represent the wiring resistance.

The current in this circuit is determined as follows. First find the total resistance:

$$R = R_1 + R_2 + R_{\text{load}} = 1 + 1 + 50 = 52\ \Omega$$

Then the current is

$$I = E/R = 10\text{ V}/52\ \Omega = 0.0192\text{ A}$$

The load voltage is

$$\text{Load} = I \times R_{\text{load}} = 0.192 \times 50 = 9.6\text{ V}$$

There is a loss of 0.4 V along the line.

$$\text{Signal loss} = R_{\text{wire}} \times \text{current}$$

$$\text{SL} = 2\ \Omega \times 0.0192\text{ A} = 0.4\text{ V}$$

This loss of signal voltage can also be related to a loss of signal power, as we will see in Section 1.5. If the length of the wires in the preceding example were doubled, the loss would double. Obviously, very long lines would cause excessive signal loss.

The resistance of wires is determined by both length and cross-sectional area. The smaller the cross-sectional area of the conductor, the greater the resistance for a given length, and the longer the conductor, the greater the resistance for a given cross-sectional area. The properties of wire will be discussed further in Chapter 2.

1.5 POWER AND POWER LOSS

The primary purpose of transmission lines, regardless of type, is to transfer energy (power) from one device to another. **Power** is the time rate of doing work in electrical circuits. Power in watts (W) is formulated as follows:

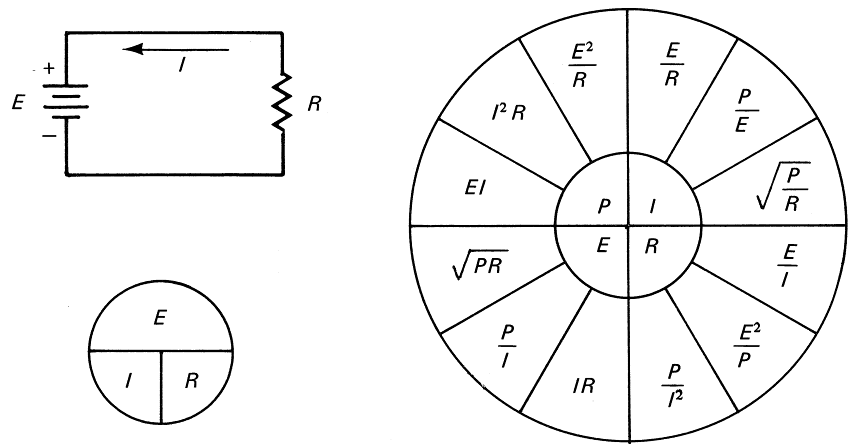


Figure 1-6 A summary of Ohm's laws and power laws for the electrical properties of circuits.

$$\text{Power (watts)} = \text{current in amperes} \times \text{volts}$$
$$\text{or power} = I^2R\ \text{W}$$

Power is the unit that we use most often when relating to the levels of signal in a circuit. We usually refer to the power loss in wires as I^2R losses.

Figure 1-6 presents a summary of the formulas for both Ohm's law and the power laws.

1.6 SIGNAL-TO-NOISE RATIO

Noise is the introduction of any unwanted signal into the system. Noise may be in the background of an audio signal as an audio signal other than the desired signal. In the case of digital signals, noise may appear as analog signals or spikes that can mimic the digital pulses. Figure 1-7 illustrates the introduction of noise spikes into a digital pulse train. These noise spikes can be interpreted by a microprocessor, printer, or routing device as digital pulses and may represent a signal code other than the desired one. Although most systems contain a parity check (bit count), the introduction of two noise spikes would not necessarily be detected. In either an audio or digital system there is a threshold level below which noise can be tolerated without interfer-

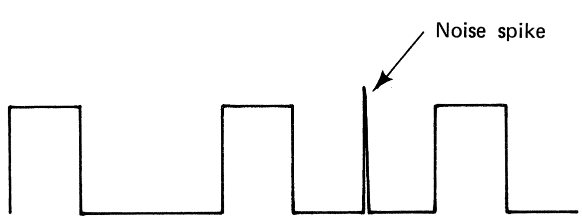


Figure 1-7 An example of noise spikes introduced into a digital pulse stream.

ence or damage to the outcome of the system. The signal-to-noise ratio (SN) in any system is formulated as

$$\text{SN} = \frac{\text{Signal power}}{\text{Noise power}}$$

For example, if an audio system had a signal level of 100 milliwatts (mW) and the noise level was 2 mW, the SN ratio would be 50 : 1.

1.7 INDUCTANCE AND INDUCTIVE REACTANCE IN WIRING CIRCUITS

Inductance (*L*) is the property of a circuit that causes an opposition to any change of current within the circuit. As electrons (current) move through a conductor, a magnetic field is produced. This magnetic field induces a voltage in the inductor, called a **counterelectromotive force** (CEMF), that opposes the current flow in the circuit. When a current tries to decrease in an inductor, CEMF is produced that tries to keep the current flowing in the circuit. CEMF can be thought of as inertia that tries to prevent change. In other words, the inductor reacts in response to a current change. Therefore, we call this phenomenon **reactance** (*X*).

Reactance caused by the change produces a voltage that opposes the source voltage that is producing the change. This induced voltage is formulated as

$$V_{\text{induced}} = L(di/dt)\ \text{V}$$

This formula states that the induced voltage is equal to the inductance of the coil in henries times the change in current (*di*) over the change in time (*dt*). The unit of inductance is the **henry** (H). If a current change of one ampere in 1 second produces an induced voltage of 1 volt, an inductor has an inductance of 1 henry.

Let us now put the inductive effect in context as to its effects on a digital circuit. When the source voltage (say the output of a PC) increases, the inductive reactance causes a countervoltage that slows down the voltage change at the load terminals (say a printer). Conversely, inductive reactance would slow down a decreasing voltage. The property of inductance can cause severe distortion in digital signals, where the bits must change from zero to maximum voltage and from maximum voltage to zero voltage in less than a millionth of a second. The inductive reactance of an inductor is opposition that an inductor offers to an alternating current and is formulated as

$$X_L = 2\Pi f L$$

where *f* represents frequency. Inspection of the formula reveals that higher frequencies result in greater values of reactance, and therefore high-frequency circuits experience more signal loss than low-frequency circuits. Wire has a small amount of inductance per meter of length; however, inductance increases as the wire length increases, much like wiring resistance. The symbol for inductance is shown in Figure 1-8.

Cross talk, the introduction of signals between conductors in close proximity to each other, is the result of the electromagnetic flux lines that are caused by the signal currents flowing

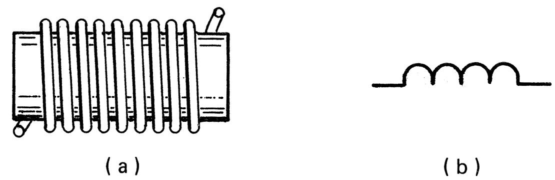


Figure 1-8 (a) Inductor, and (b) circuit symbol for an inductor.

in a conductor. Flux lines are invisible magnetic lines of force that are produced by the current (electron flow) in a circuit. The noise introduced from these flux lines, called cross talk, can cause error signals to be introduced in a data line and unwanted conversation noise in audio lines. We will discuss the methods utilized to reduce cross talk later in this chapter and in the chapters on cabling.

1.8 CAPACITANCE IN WIRING CIRCUITS

When two metals are separated by an insulator, a capacitor is formed. The symbol for a capacitor is shown in Figure 1-9. Capacitors have the ability to store energy in the form of an electrostatic charge. When one plate of the capacitor has more electrons (negative charge) than the other plate, a difference of potential exists between the plates through the insulation. The charge is the results of the force from the electron on one plate acting on the electrons on the other plate. The insulator between the plates is called a **dielectric**. The charge that is stored between the plates tends to oppose any change in circuit voltage. This opposition to a change in voltage is called **capacitive reactance**. Since a capacitor is formed by any two conductors separated by an insulator, there is capacitance between a pair of conductors in a cable, a conductor and a ground, or a conductor and a shield. The reactance of a fixed capacitor or wiring capacitance is formulated as

$$X_C = ½\pi f C$$

where $\pi = 3.14$, f = frequency of the signal, and C = capacitance of the capacitor. A capacitor has a capacitance of 1 **farad** (f) when a current of 1 A causes a voltage change, across the capacitor, of 1 volt in one second.

All wires have resistance, capacitance, and inductance in varying amounts. Any or all of these factors can cause attenuation and deterioration of a pulse or an analog signal. Different

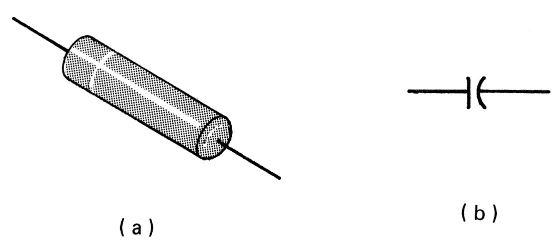


Figure 1-9 Capacitor and symbol for a capacitor.

types of copper transmission lines have different amounts of these three factors. However, it is the resistance and capacitance that result in most of the losses in transmission lines and the inductance that results in the pick-up of noise. The longer the lines, the greater the amounts of resistance, inductance, and capacitance. Increased amounts of these three factors result in increased deterioration of digital signals and increased analog signal loss.

The values of both resistance and capacitance can vary greatly based on the type of cable, wire size, shielding, and insulation. For example, cabling may vary in capacitance from a low of 8 pF per foot (25 pF per meter) to a high of 70 pF per foot (250 pF per meter). The resistance increases as the diameter of the wire decreases. The design engineer must consider these factors against economy when selecting cabling for a network.

1.9 IMPEDANCE IN WIRING CIRCUITS

The current and voltage in a resistor are always in phase with each other. That is, a maximum voltage results in a maximum current and a minimum voltage follows a minimum current. On the other hand, the current and voltage in an inductor and a capacitor are 90 degrees out of phase with each other. The current in a capacitor *leads the voltage by 90 degrees* and the current in an inductor *lags the voltage by 90 degrees*. An example of this phenomenon is depicted in Figure 1-10.

Figure 1-11 depicts a circuit with resistance, inductance, and capacitance. The voltage drops around a circuit with resistance, capacitance, and inductance are written

$$E = V + jV - jVC$$

The $+j$ and $-j$ mean +90 degrees and –90 degrees, respectively.

Impedance is the name given to the total opposition to the flow of electrical energy in a circuit and is the result of a combination of resistance, inductance, and capacitance. The symbol of impedance is Z and the unit of impedance is the ohm. Impedance is formulated as

$$Z = R + jX_L$$

The jX_L indicates that reactance must be treated different from resistance. Capacitive reactance is denoted as $-jX_C$ and inductive reactance is denoted as $+jX_L$. Again, the $+j$ and the $-j$ can be considered to indicate +90 and –90 degrees, respectively. This means that Z must be calculated as shown in Figure 1-12.

The Pythagorean theorem states that

$$Z = \sqrt{R^2 + (X_L - X_C)}$$
$$Z = \sqrt{100^2 + 100^2} = 141\ \Omega/45°$$

The 45 degrees indicates that the current and the voltage in the circuit are out of phase by 45 degrees. Impedance is rather complex in ac circuits, and it is not within the scope of this text to offer a complete study of the subject. (If you want more information, consult one of the several fine basic electronic fundamental texts available or contact the author on the Internet.) For our

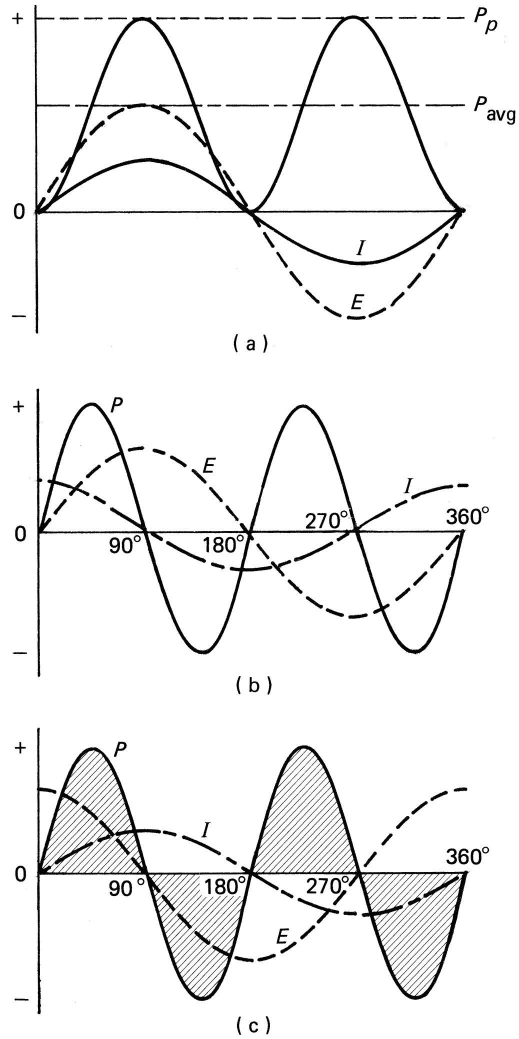


Figure 1-10 Relationship between current and voltage in an AC circuit: (a) in a resistor, (b) in a capacitor, and (c) in an inductor.

purposes we need to understand only that any output device has impedance, that all transmission lines have impedance, and that any communication device that is a load has impedance. Figure 1-13 is a summary of the reactance and impedance formulas for resistive and reactive circuits.

Transmission lines have a characteristic impedance, and loads are rated at an impedance value. We will discuss the importance of matching impedance of the transmission line to the device impedance in a later chapter.

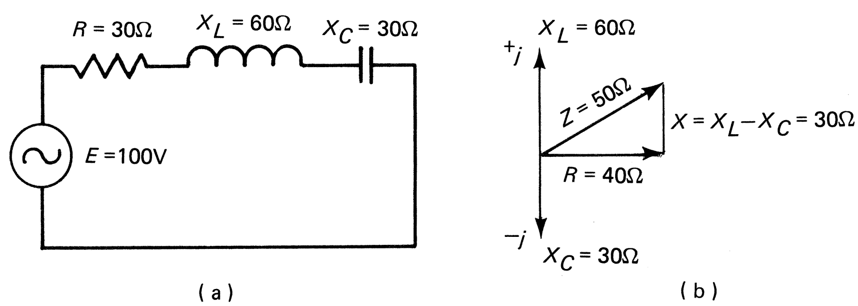


Figure 1-11 Electrical circuit with resistance, inductance, and capacitance; (a) circuit diagram, (b) vector diagram of voltages.

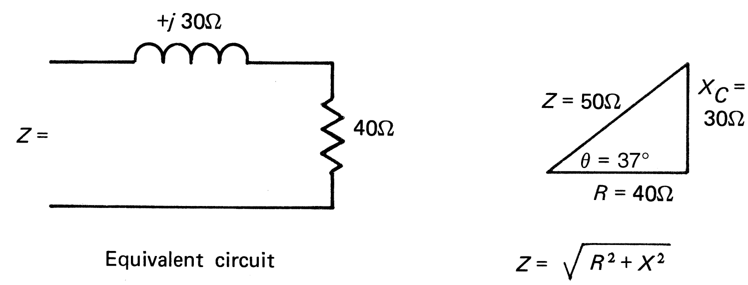


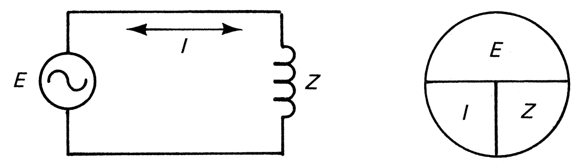
Figure 1-12 The impedance of a circuit must be calculated by using a right triangle and the Pythagorean theorem.

1.10 DIGITAL SIGNALS

Digital signals are discretely variable in the form of pulses. The pulses may represent a digital code that can be interpreted by a computer or other digital device as instructions, information, or data. Examples of instructions are add, save, or fetch. Examples of data are +3 V, –30 degrees, or $100.00. Examples of information are where to save or where to send (as an address) within the computer. Digital pulses are usually coded in a series of voltages and no voltages or ones and zeros, as shown in Figure 1-14. These digital pulses are called bits. A group of eight of these bits is called a **byte**.

The rate at which digital pulses are transmitted is called the **baud rate**, defined as bits per second or pulses per second, and is directly related to frequency. The amplitude of the pulse is the negative or positive peak voltage, as shown in Figure 1-15.

A pulse often appears to rise and fall in zero time when observed on an oscilloscope; however, this is never the case. The capacitive reactance and the inductive reactance within the circuit cause the pulse in Figure 1-14 to appear as shown in Figure 1-16. Each pulse has a rise time and a fall time as shown in Figure 1-17. The **rise time** (Figure 1-17c) is measured between the 10% point and the 90% point, and the **fall time** is measured between the 90% point and the 10%



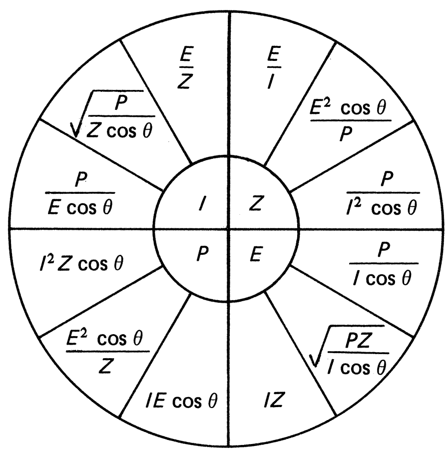


Figure 1-13 Summary of reactance and impedance formulas for reactive and resistive circuits.

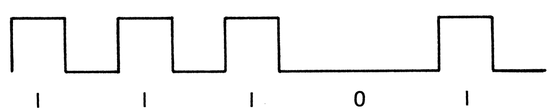


Figure 1-14 A digital pulse train comprised of voltages and no voltages and representing ones and zeros.

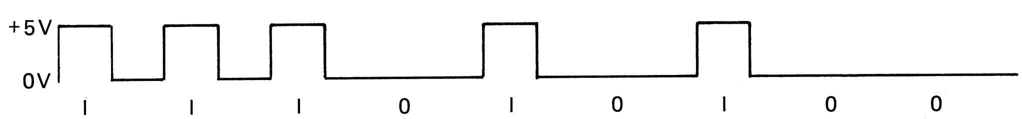


Figure 1-15 A digital pulse with a +5-V amplitude.

point. The zero and 100 percentage points are not used to measure the rise and fall times due to the difficulty of identifying their exact locations.

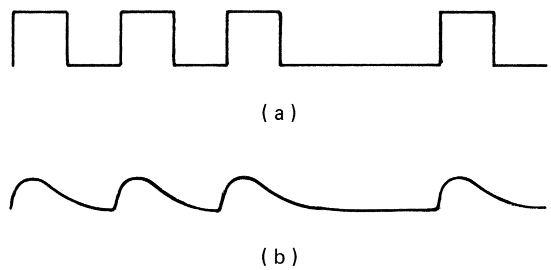


Figure 1-16 Pulse deterioration caused by the capacitance and inductance of the circuit: (a) Pulse into a transmission line, (b) distorted pulse.

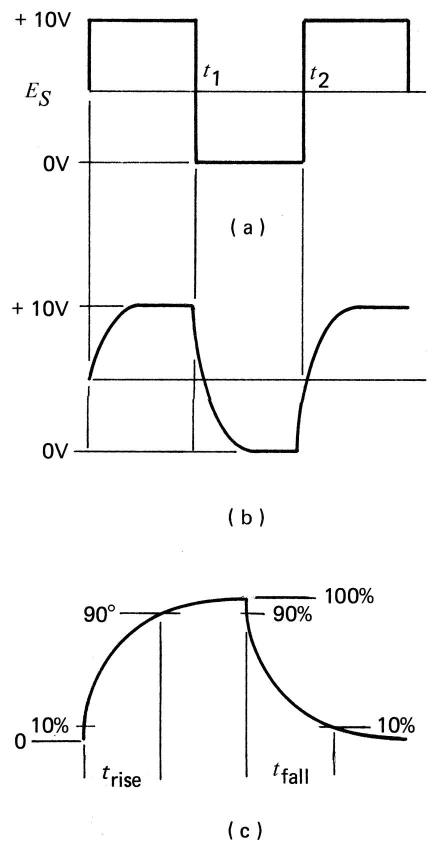


Figure 1-17 Typical digital pulse: (a) theoretical, (b) actual pulse shape, (c) rise time and fall time of a pulse.

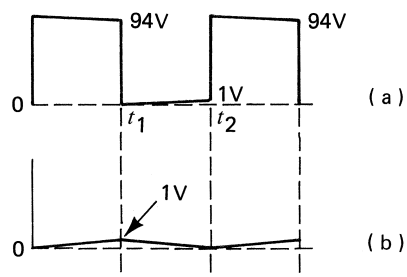


Figure 1-18 Reactance in a circuit can make the pulse unrecognizable to the destination equipment.

With very long transmission lines, where the inductance and capacitance are excessive, a pulse train may become so distorted that it becomes unrecognizable, as shown in Figure 1-18. Special equipment can sometimes reconstruct the signal. Reconstruction of digital signals is much easier than reconstruction of analog signals. For this reason analog signals are often converted to representative digital signals before transmission and reconverted to analog signals at the receiver. Circuits that perform this function are called analog to digital converters (A to D) and digital to analog converters (D to A), respectively.

1.11 ANALOG SIGNAL CONCEPTS

Analog signals are any signals other than pulses. An analog signal has a voltage that is variable with time and is usually continually variable. Some examples of analog signals are shown in Figure 1-19. An analog signal does not have to vary at a constant rate. Examples of analog signals are voice or music (audio), sampling voltages (as from a pressure gauge), or dc voltages. Signals that have a periodic repetition rate (period) have a frequency. This repetition rate or frequency, in cycles per second, is called Hertz or Hz. Frequency is formulated as

$$f = 1/T \text{ Hz}$$

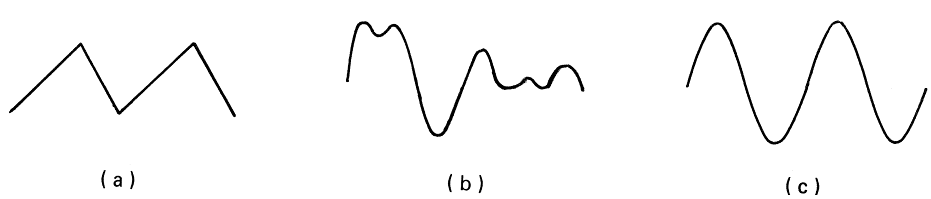


Figure 1-19 Analog signals: (a) A ramp signal, (b) a nonlinear analog signal, (c) a sinusoidal signal.

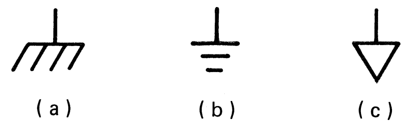


Figure 1-20 The symbols for ground: (a) Chassis, (b) earth, (c) common.

1.12 GROUND AND GROUNDING

Ground, or *earth* as the British say, is usually referred to as the reference level for voltage levels within a system. United States government safety codes specify that all electrical equipment must be electrically connected to ground (grounded) to prevent an electrical potential between the equipment and ground and between pieces of equipment. Equipment grounding is a safety precaution designed to protect both people and equipment. The symbol for ground is shown in Figure 1-20. The chassis of most equipment is grounded, and the return path for current flow is in the chassis. This reduces the need for returned wires from the components. Most voltages in electronic equipment are measured to ground (the chassis).

Grounding of electrical equipment is usually accomplished through the power plug. For 120-V connections the center prong of the three-prong plug is ground (Figure 1-21). The insulation color of the ground wire in a power lead to equipment is usually green or green and yellow. Grounding of the shielding wire in telecommunication cable is important to assure the transmission of electrical signals along a cable without interference from the electromagnetic radiation from other transmission lines and electrical equipment. This interference, called *cross talk*, can originate from adjacent lines, electrical motors, PCs, fluorescent lights, etc. The term cross talk

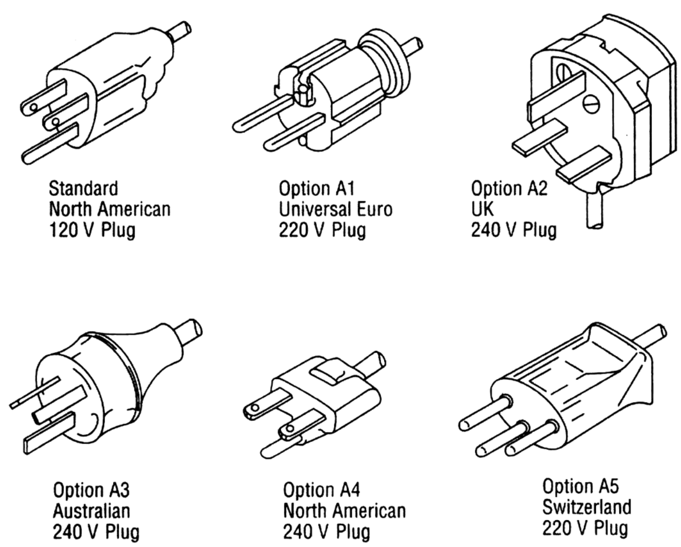


Figure 1-21 Grounded AC power plugs.

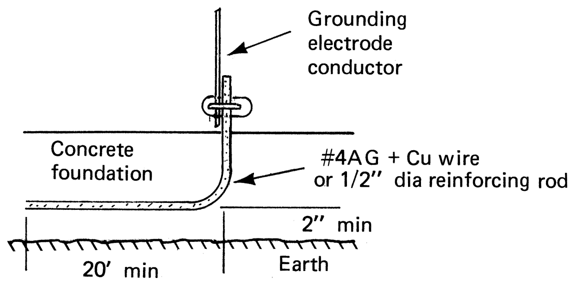


Figure 1-22 A plant grounding system.

originated from the phenomenon of the conversation of an adjacent line being audible on the other.

While equipment grounding is primarily for the protection of people from electrical shock, there are other compelling reasons for grounding. Grounding provides a low-impedance path for electrical energy. In summary, grounding provides the following:

1. Protection of people from electrical shock in the event of an internal short in equipment
2. Protection of semiconductor devices from excessive static voltage buildup
3. A safe path for electrical energy from lightning to protect both equipment and people
4. A low-resistance path around the signal-carrying wires for low-frequency electromagnetic energy from sources such as power lines, lights, and motors
5. A low-resistance path around the signal-carrying wires for electromagnetic radiation from high-frequency electromagnetic waves from computers, other transmission lines, radiated signals (radio, TV), etc.

The grounding system for a facility should maintain all the grounds of all telecommunication equipment, other electronic equipment, all electrical equipment, and all electrical power at the same potential, within the closely prescribed limits of the National Electrical Code (NEC).

The **earth ground system** is the reference for all grounds within a building. The earth ground is established by inserting bronze rods into the earth or bronze or copper wire into the concrete foundation of a building. This part of the ground system is the most difficult to establish to assure long-range effectiveness because of the wide range of soil types and the varying moisture content of soil. The moisture content of soil and the minerals within the soil determine the resistance of the soil, and thereby the effectiveness of the ground in maintaining a low-voltage interface. Figure 1-22 depicts an example of a plant grounding system referenced from the NEC for proper grounding. Whenever possible, the connection to the ground electrode should be less than 1 foot below the surface of the soil, and the grounding electrode should extend at least 10 feet below ground. Ground in soil types other than moist clay requires special installation techniques. For example, grounding in shallow soil requires that grounding cable be laid in trenches and the soil compacted. Grounding systems must be a primary consideration

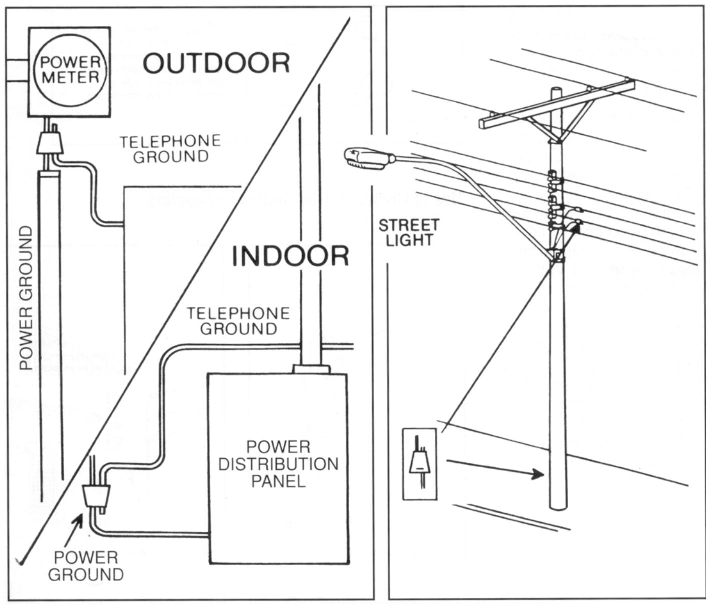


Figure 1-23 Power meter, distribution panel, and street light grounding examples. (*Source:* Courtesy AMP Inc.)

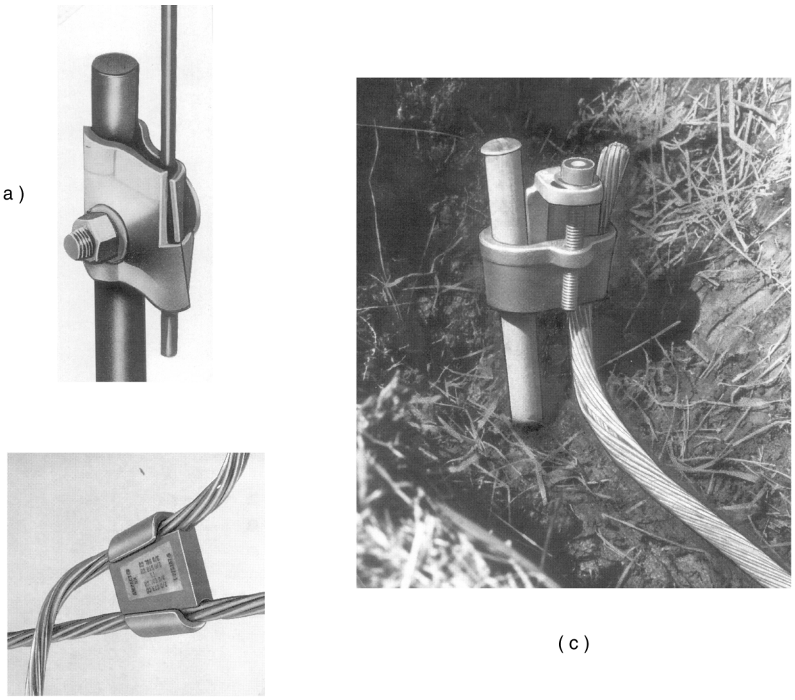
when designing a new facility. Figure 1-23 illustrates examples of telephone grounding, street light grounding, and service entrance grounding. Ground conductors must be electrically connected to prevent any resistance between the conductors. Connectors must withstand physical strains and weather variations without reduction of conductivity. When aluminum and copper conductors are bonded, the connector must keep the two conductors physically isolated to prevent battery action while maintaining high conductivity. When two dissimilar metals, such as copper and aluminum, are bonded a virtual battery is formed, producing corrosion, which causes increased resistance and decreased conductivity between the metals. Figure 1-24 depicts three examples of ground connections.

In newer construction, architects often require a grid type of grounding comprised of heavy copper or aluminum conductors or metal rods. Figure 1-25 illustrates methods of bonding subgrounding conductors to the grid.

All grounding installations must be in compliance with the latest edition of the NEC handbook.

1.13 CROSS TALK IN WIRING

Electromagnetic pick-up and radiation can cause serious problems in telecommunication systems, such as signal distortion, noise in conversations, and breach of security from a system. Some types of cables are protected from inductively induced signals (cross talk) from adjacent lines. For example, pairs of wires are usually twisted to reduce inductive effects, and cables can



(a) (b) (c)

Figure 1-24 Grounding connectors: (a) rod to small conductor, (b) conductor to conductor, (c) rod to primary ground cable. (*Source:* Courtesy AMP Inc.)

be shielded from outside electromagnetic lines by surrounding the signal-carrying wires with a braided or solid metal shield. There are also installation procedures that can reduce the effects of magnetic induction noise, such as

1. Shielding the cables
2. Never running data cable in a conduit with power cables
3. Using proper grounding of equipment and cables to protect against lighting and surge voltages and to provide shielding against outside signals

Grounding will be discussed in greater detail in Chapters 2 through 4.

1.14 ATTENUATION OF SIGNAL INFORMATION

As stated earlier, wire has resistance, inductance, and capacitance. All these factors attenuate both digital and analog signals. The attenuation can be measured in either a reduction of voltage or a loss of power. This loss is usually referred to as a decibel loss. The Bel is the logarithm of the power input to the power output of a system (in the case of a cable, the power into the cable

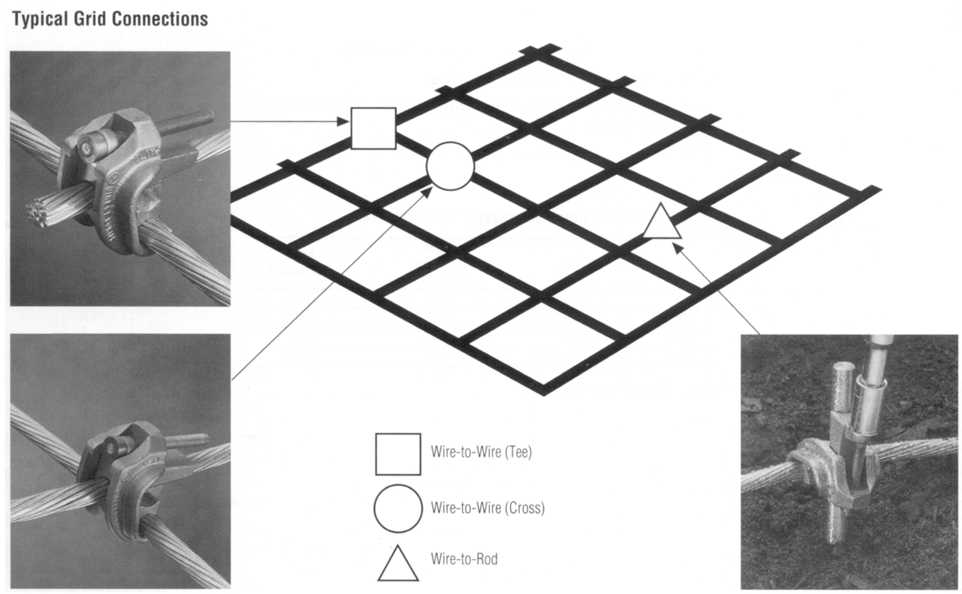


Figure 1-25 Grid-type grounding system (*Source:* Courtesy of AMP Inc.

at the source and power output at the receiver). The Bel unit is such a huge number that the decibel (1/10 Bel) is usually used for calculations.

The formula for the decibel (dB) is

$$\text{dB} = 10\log(P_{\text{out}}/P_{\text{in}})$$

The decibel gain or loss can also be formulated using voltages:

$$\text{dB} = 20\log V_{\text{out}}/V_{\text{in}}$$

For example, if a signal of 1 W was put into a line with a resulting attenuation to 0.5 W at the receiver end, the loss in decibels is

$$\text{dB} = 10\log 0.5/1 = 10\log 0.5 = -3$$

We would say that the signal had a –3-dB loss.

As another example, suppose that a 1-V signal were injected into a transmission line with a reduction of to 0.707 V at the receiver end. The dB gain is

$$\text{dB} = 20\log 0.707/1 = 20\log 0.707 = -3$$

Again we would say that the attenuation within the line was –3 dB. We might note that –3 dB is also a 50% power loss. Figure 1-26 is an example of decibel gains and losses in a circuit.

Communication systems often have to be designed to accommodate a combination of analog and digital signals. The designer and cabling technician are often required to deal with

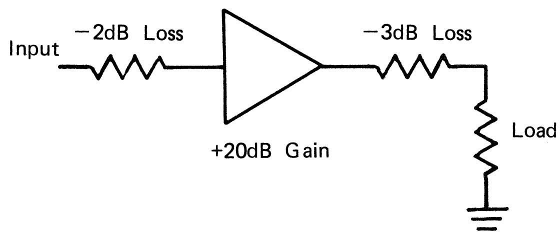


Figure 1-26 dB gains and losses in a circuit.

twisted pairs, coaxial cables, and/or fiber-optic cables. The techniques to perform installation and maintenance of these designs are discussed in later chapters.

1.15 INSULATION OF CONDUCTORS

Insulation is the nonconductive material that encases a wire or cable. Insulation materials are comprised of compounds that have properties that are Underwriters Laboratory (UL) rated and Canadian Standards Association (CSA) approved to prevent certain environment hazards while satisfying special electrical requirements. The electrical requirements might be fire resistance, weather resistance, pressure resistance, etc. The environmental hazards might be that the insulator gives off toxic gases in a fire. Wires are individually insulated for ratings such as minimum breakdown voltage, wiring capacitance, and maximum temperature. The primary purpose of any insulation is to prevent the short circuiting of wires to other wires or ground, which could cause signal loss, damage to equipment, and possibly fire. When more than one conductor is bundled into a cable, the insulating material for the cable is called a jacket. The purpose of the jacket, other than holding the wires together, is to protect the cable.

Wire and cable insulating coverings are made from several insulating materials and compounds. Insulating coverings are rated by the Underwriters Laboratory, a private rating company that is the industry standard for rating of consumer products for properties such as electrical characteristics, heat resistance, chemical characteristics, reliability, and safety. The following are the most common insulating materials used in the insulation of cables and their properties.

- *Vinyl:* Vinyl is sometimes referred to as PVC or polyvinyl chloride. Certain formulas have temperature ratings from –40°C to +105°C. Other common vinyls may have ratings from –20°C to +60°C. There are many formulations for different applications. The formulation affects both the electrical properties and the pliability, which can vary from rock hard to puttylike.
- *Polyethylene:* This material has excellent electrical properties, with a low dielectric value (low capacitance). Flexibility can vary from soft to rock hard. This insulation has excellent moisture resistance and can be formulated to withstand extreme weather conditions.
- *Teflon:* This material has excellent electrical properties, temperature range, and chemical resistance. The material is not suited for high-voltage applications or for an environment

within nuclear radiation. The cost of Teflon insulation is approximately 10 times that for comparable vinyl insulation.

- *Polypropylene:* This insulation is similar to polyethylene in electrical properties but is typically harder than polyethylene. It is suitable for thin-wall insulation. Most UL ratings call for 60°C.
- *Silicone:* This is a very soft insulation with a temperature range of –80°C to +90°C. It has excellent electrical properties along with ozone resistance, low moisture absorption, weather resistance, and radiation resistance. However, it has low mechanical strength and poor scuff resistance and costs from $5.00 to $8.00 per pound compared with $1.00 per pound for other insulation.
- *Neoprene:* The maximum temperature range of this material can vary from 55°C to +90°C. The electrical properties are not as good as other insulating materials, resulting in the need for thicker insulation. Typically this material is used as a coating for separate lead wires or cable jackets.
- *Rubber:* Both natural rubber and synthetic rubber compounds can be used for insulation and cable jackets. The material is formulated for many different applications and many different temperature ranges.

Table 1-1 presents the properties of rubber insulation. Table 1-2 summarizes the properties of plastic insulation. Table 1-3 gives the nominal temperature range of various insulating materials when used as wire insulation or cable jackets.

Table 1-1 Comparative Properties of Rubber Insulation

	Rubber	Neoprene	Hypalon (Chloro-sulfonated Polyethylene)	EPDM (Ethylene Propylene Diene Monomer)	Silicone
Oxidation resistance	F	G	E	G	E
Heat resistance	F	G	E	E	O
Oil resistance	P	G	G	F	FG
Low temperature flexibility	G	F,G	F	G,E	O
Weather, sun resistance	F	G	E	E	O
Ozone resistance	P	G	E	E	O
Abrasion resistance	E	G,E	G	G	P

Table 1-1 Comparative Properties of Rubber Insulation (Continued)

	Rubber	Neoprene	Hypalon (Chloro-sulfonated Polyethylene)	EPDM (Ethylene Propylene Diene Monomer)	Silicone
Electrical properties	E	P	G	E	O
Flame resistance	P	G	G	P	F,G
Nuclear radiation resistance	F	F,G	G	G	E
Water resistance	G	E	G,E	G,E	G,E
Acid resistance	F,G	G	E	G,E	F,G
Alkali resistance	F,G	G	E	G,E	F,G
Gasoline, kerosene, etc. (aliphatic hydrocarbons) resistance	P	G	F	P	P,F
Benzol, Tuluol, etc. (aromatic hydro-carbons) resistance	P	P,F	F	F	P
Degreaser solvents (halogenated hydro-carbons) resistance	P	P	P,F	P	P,G
Alcohol resistance	G	F	G	P	G

P = poor F = fair G = good E = excellent O = outstanding

These ratings are based on average performance of general purpose compounds. Any given property can usually be improved by the use of selective compounding.

Source: Courtesy Belden Corporation.

Table 1-2 Comparative Properties of Plastic Insulation

	PVC	Low-Density Poly-ethylene	Cellular Poly-ethylene	High-Density Polyethylene	Poly-propylene	Poly-urethane	Nylon	Teflon
Oxidation resistance	E	E	E	E	E	E	E	O
Heat resistance	G,E	G	G	G	E	E	E	O
Oil resistance	F	G	G	G,E	F	E	E	O
Low temperature flexibility	P,G	G,E	E	E	P	G	G	O
Weather, sun resistance	G,E	E	E	E	E	G	E	O
Ozone resistance	E	E	E	E	E	E	E	E
Abrasion resistance	F,G	F,G	F	E	F,G	O	E	E
Electrical properties	F,G	E	E	E	E	P	P	E
Flame resistance	E	P	P	P	P	P	P	O
Nuclear radiation resistance	G	G	G	G	F	G	F,G	P
Water resistance	E	E	E	E	E	P,G	P,F	E
Acid resistance	G,E	G,E	G,E	G,E	E	F	P,F	E
Alkali resistance	G,E	G,E	G,E	G,E	E	F	E	E
Gasoline, kerosene, etc. (aliphatic hydrocarbons) resistance	P	P,F	P,F	P,F	P,F	G	G	E
Benzol, Tuluol, etc. (aromatic hydrocarbons) resistance	P,F	P	P	P	P,F	P	G	E
Degreaser solvents (halogenated hydrocarbons) resistance	P,F	P	P	P	P	P	G	E
Alcohol resistance	G,E	E	E	E	E	P	P	E

P = poor F = fair G = good E = excellent O = outstanding

These ratings are based on average performance of general purpose compounds. Any given property can usually be improved by the use of selective compounding.

Source: Courtesy Belden Electronics Division.

Table 1-3 Nominal Temperature Range for Insulating and Jacketing Compounds

Compound	Normal Low	Normal High	Special Low	Special High
Chlorosulfonated polyethylene	–20°C	90°C	–40°C	105°C
EPDM (ethylene propylene rubber)	–55°C	105°C	—	—
Neoprene	–20°C	60°C	–55°C	90°C
Polyethylene	–60°C	80°C	—	—
Polypropylene	–40°C	105°C	—	—
Rubber	–30°C	60°C	–55°C	75°C
Teflon	–70°C	200°C	—	260°C
Vinyl	–20°C	80°C	–55°C	105°C
Silicone	–80°C	150°C	—	200°C
Halar	–70°C	150°C	—	—

Source: Courtesy Belden Electronics Division.

SUMMARY

The proper planning and installation of telecommunication wiring is a complex task and should not to be attempted without the skills and knowledge necessary to complete the task successfully. The material in the following chapters, if studied, will greatly improve your chance of a successful installation.

QUESTIONS

1. What unit is used most often for cable signal loss?
2. What causes cross talk?
3. Why do wires have capacitance?
4. List several factors that would be considered in the selection of wiring insulation.
5. Define the term *analog* and give an example of an analog signal.
6. Define the term *bit*.
7. Define the term *digital signal* and give an example.