- Insulators are materials that do not conduct electricity easily.
- Insulators are made from materials that generally contain 7 or 8 valence electrons.
- Semiconductors are materials that contain 4 valence electrons.
- The two most common semiconductor materials are germanium and silicon.
- Silicon is used more often than germanium because it can withstand more heat.
- P-type material is made by combining a material that has 3 valence electrons with a pure semiconductor material.
- A P-type semiconductor material has an excess of holes in its structure.
- N-type material is made by combining a material that has 5 valence electrons with a pure semiconductor material.
- N-type semiconductor material has an excess of electrons in its structure.

KEY TERMS

germanium
lattice structure
N-type material
P-type material
semiconductors
silicon

REVIEW QUESTIONS

1. How many valence electrons are contained in a material used as a conductor?
2. How many valence electrons are contained in a material used as an insulator?
3. What are the two most common materials used to produce semiconductor devices?
4. What is a lattice structure?
5. How is a P-type material made?
6. How is an N-type material made?
7. What type of semiconductor material can withstand the greatest amount of heat?
8. All solid-state components are formed from combinations of P- and N-type materials. What factors determine what kind of components will be formed?

UNIT 50 The PN Junction

OBJECTIVES

After studying this unit the student should be able to:

- Discuss how the PN junction is constructed
- Recognize the schematic symbol for a diode
- Discuss the differences between the conventional current flow theory and the electron flow theory
- Discuss how the diode operates in a circuit
- Identify the anode and cathode leads of a diode
- Properly connect the diode in an electric circuit
- Discuss the differences between a half-wave rectifier and a full-wave rectifier
- Test the diode with an ohmmeter

As stated previously, solid-state devices are made by combining P- and N-type materials together. The device produced is determined by the number of layers of material used, the thickness of the layers of material, and the manner in which the layers are joined together. Hundreds of different electronic devices have been produced since the invention of solid-state components.

It is not within the scope of this text to cover even a small portion of these devices. The devices to be covered by this text have been chosen because of their frequent use in the air conditioning industry as opposed to communications or computers. These devices are presented from a straightforward, practical viewpoint, and mathematical explanation is used only when necessary.

The PN junction is often referred to as the **diode**. The diode is the simplest of all electronic devices.

It is made by joining together a piece of P-type material and a piece of N-type material. Refer to Figure 50–1. The schematic symbol for a diode is shown in Figure 50–2. The diode operates like an electric check valve in that it will permit current to flow through it in only one direction. If the diode is to conduct current, it must be **forward biased**. The diode is forward biased only when a positive voltage is connected to the **anode** and a negative voltage is connected to the **cathode**. If the diode is **reverse biased**, the negative voltage connected to the anode and the positive voltage connected to the cathode, it will act like an open switch and no current will flow through the device.

One thing the service technician should be aware of when working with solid-state circuits is that the explanation of the circuit is often given assuming conventional current flow as opposed to electron flow. *The* ***conventional current flow theory*** *assumes that current flows from positive to negative as opposed to the* ***electron flow theory****, which states that current flows from negative to positive.* Although it has been known for many years that current flows from negative to positive, many of the electronic circuit explanations assume a positive to negative current flow. There are several reasons for this. For one, ground is generally negative and considered to be 0 volts in an electronic circuit. Any voltage above or greater than ground is positive. Most people find it is easier to think of something flowing downhill or from some point above to some point below. Another reason is that all the arrows in an electronic schematic are pointed in the direction of conventional current flow. The diode shown in Figure 50–2 is forward biased only when a positive voltage is applied to the anode and a negative voltage is applied to the cathode. If the conventional current flow theory is used, current will flow in the direction the arrow is pointing. If the electron theory of current flow is used, current must flow against the arrow.

A common example of the use of the conventional current flow theory is the electrical systems of automobiles. Most automobiles use a negative ground system, which means the negative terminal of the battery is grounded. The positive terminal of the battery is considered to be the "HOT" terminal, and it is generally assumed that current flows from the "HOT" to ground. This explanation is offered in an effort to avoid confusion when troubleshooting electronic circuits.

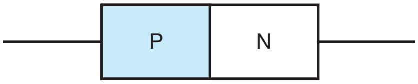

Figure 50–1
PN junction. (Source: Delmar/Cengage Learning)

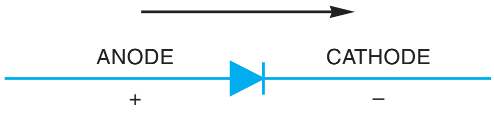

Figure 50–2
Schematic symbol of a diode. (Source: Delmar/Cengage Learning)

TESTING THE DIODE

The diode can be tested with an ohmmeter. When the leads of an ohmmeter are connected to a diode, the diode should show continuity in only one direction. For example, assume that when the leads of an ohmmeter are connected to a diode, it shows continuity. If the leads are reversed, the ohmmeter should indicate an open circuit. If the diode shows continuity in both directions, it is shorted. If the ohmmeter indicates no continuity in either direction, the diode is open. To test the diode, follow this two-step procedure:

1. Connect the ohmmeter leads to the diode. Notice if the meter indicates continuity through the diode or not, Figure 50–3.
2. Reverse the diode connection to the ohmmeter, Figure 50–4. Notice if the meter indicates continuity through the diode or not. The ohmmeter should indicate continuity through the diode in only one direction.

NOTE: ***If continuity is not indicated in either direction, the diode is open. If continuity is indicated in both directions, the diode is shorted.***

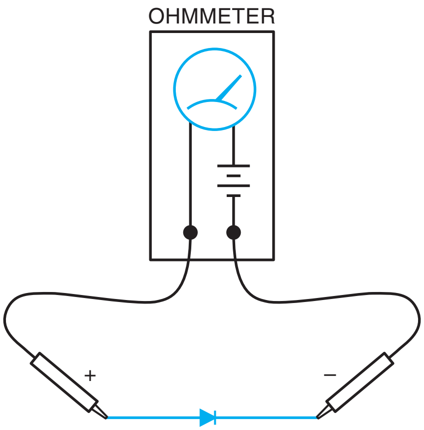

Figure 50–3
Testing a diode. (Source: Delmar/Cengage Learning)

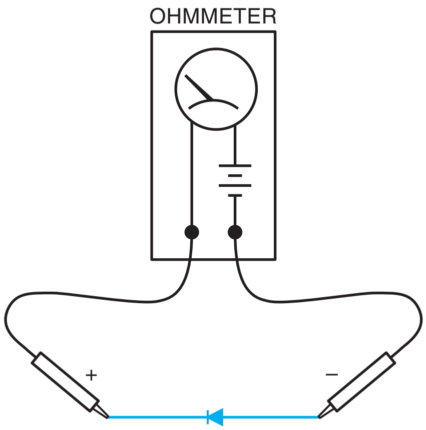

Figure 50–4
A diode connected in the reverse direction. (Source: Delmar/Cengage Learning)

RECTIFIERS

Diodes can be used to perform many jobs, but their most common use in industry is to construct a **rectifier**. A rectifier is a device that changes or converts AC voltage into DC voltage. The simplest type of rectifier is known as the **half-wave rectifier**. Refer to the circuit shown in Figure 50–5. The half-wave rectifier can be constructed with only one diode, and gets its name from the fact that it will rectify only half of the AC waveform applied to it. When the voltage applied to the anode is positive, the diode is forward biased and current can flow through the diode, load resistor, and back to the power supply. When the voltage applied to the anode becomes negative, the diode is reverse biased and no current will flow. Since the diode permits current to flow through the load in only one direction, the current is DC.

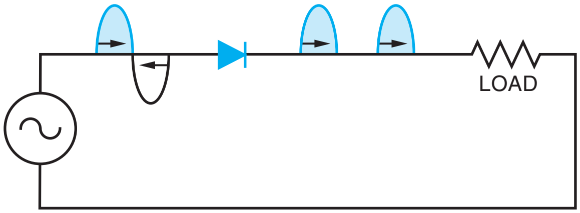

Figure 50–5
Half-wave rectifier. (Source: Delmar/Cengage Learning)

Diodes can be connected to produce full-wave rectification, which means both halves of the AC waveform will be made to flow in the same direction. One type of **full-wave rectifier** is known as the **bridge rectifier** and is shown in Figure 50–6. Notice the bridge rectifier requires 4 diodes for construction.

To understand the operation of the bridge rectifier, assume that point X of the AC source is positive and point Y is negative. Current will flow to point A of the rectifier. At point A, diode D4 is reverse biased and D1 is forward biased. The current will flow through diode D1 to point B of the rectifier. At point B, diode D2 is reverse biased, so the current must flow through the load resistor to ground. The current returns through ground to point D of the rectifier. At point D, both diodes D4 and D3 are forward biased, but current will not flow from positive to positive. Therefore, the current will flow through diode D3 to point C of the bridge, and then to point Y of the AC source, which is negative at this time. Since current flowed through the load resistor during this half cycle, a voltage is developed across the resistor.

Now assume that point Y of the AC source is positive and X is negative. Current will flow from point Y to point C of the rectifier. At point C, diode

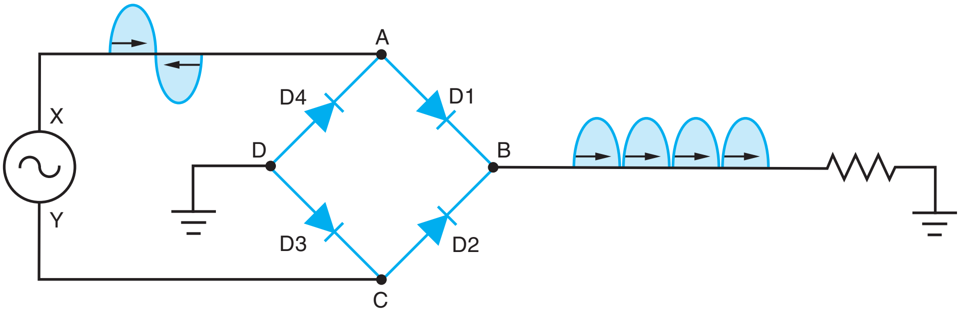

Figure 50–6
Bridge rectifier. (Source: Delmar/Cengage Learning)

D3 is reverse biased and diode D2 is forward biased. The current will flow through diode D2 to point B of the rectifier. At point B, diode D1 is reverse biased, so the current must flow through the load resistor to ground. The current flows from ground to point D of the bridge. At point D, both diodes D3 and D4 are forward biased. As before, current will not flow from positive to positive, so the current will flow through diode D4 to point A of the bridge and then to point X, which is now negative. Since current flowed through the load resistor during this half cycle, a voltage is developed across the load resistor. Notice that the current flow was in the same direction through the resistor during both half cycles.

Most of industry operates on three-phase power instead of single-phase. Six diodes can be connected to form a three-phase bridge rectifier, which will change three-phase AC voltage into DC voltage. Refer to the circuit shown in Figure 50–7.

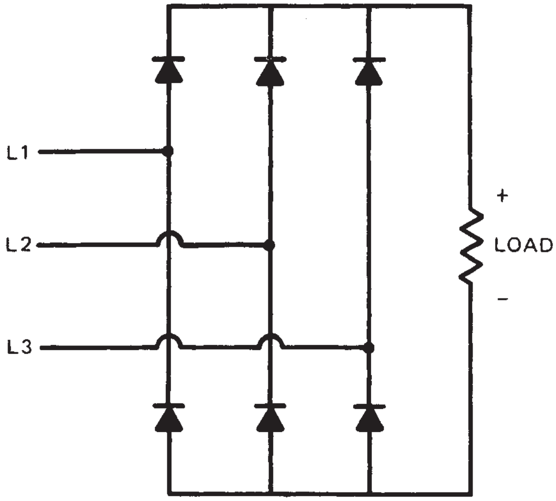

Figure 50–7
Three-phase bridge rectifier. (Source: Delmar/Cengage Learning)

IDENTIFYING DIODE LEADS

When the diode is to be connected in a circuit, there must be some means of identifying the anode and the cathode. Diodes are made in different case styles so there are different methods of identifying the leads. Large stud-mounted diodes often have the diode symbol printed on the case to show proper lead identification. Small plastic case diodes often have a line or band around one end of the case, Figure 50–8. This line or band represents the line in front of the arrow on the schematic symbol of the diode. An ohmmeter can always be used to determine the proper lead identification if the polarity of the ohmmeter leads is known. The positive lead of the ohmmeter must be connected to the anode to make the diode forward biased. A junction diode is shown in Figure 50–9.

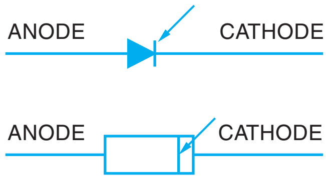

Figure 50–8
Lead identification of a plastic case diode. (Source: Delmar/Cengage Learning)

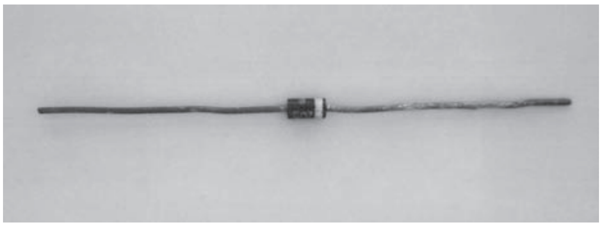

Figure 50–9
Junction diode. (Source: Delmar/Cengage Learning)

SUMMARY

- The PN junction is formed by joining a piece of P-type and a piece of N-typesemiconductor material together.
- The diode operates like an electronic check valve in that it will permit current to flow through it in only one direction.
- The diode can be used to change alternating current into direct current.
- A half-wave rectifier rectifies only one-half of the AC waveform into DC.
- A full-wave rectifier rectifies both halves of the AC waveform into DC.
- The diode can be tested with an ohmmeter by connecting it first one way and then the other. Current should flow through it in only one direction.
- The conventional current flow theory states that current flows from positive to negative.
- The electron flow theory states that current flows from negative to positive.

KEY TERMS

anode
bridge rectifier
cathode
conventional
current flow theory
diode
electron flow theory
forward biased
full-wave rectifier
half-wave rectifier
rectifier
reverse biased

REVIEW QUESTIONS

1. What is the PN junction more commonly known as?
2. On a plastic case diode, how are the leads identified?
3. Explain how a diode operates.
4. Explain the difference between the conventional current flow theory and the electron flow theory.
5. Explain the difference between a half-wave rectifier and a full-wave rectifier.
6. Explain how to test a diode with an ohmmeter.

UNIT 51

Light-Emitting Diodes (LEDs) and Photodiodes

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of a light-emitting diode
- Compute the resistance needed for connecting an LED into a circuit
- Connect an LED in a circuit
- Discuss the differences between light-emitting diodes and photodiodes
- Draw the schematic symbols for LED and photodiodes

Light-emitting diodes (LEDs) are among the most common devices found in the electrical and electronics fields. They are used as indicator lights in many types of equipment. They have an extremely long life when operated within their ratings because there is no filament to burn out. LEDs are constructed by joining special semiconductor materials together that emit photons when power is applied. The color produced is determined by the types of materials used. LED colors are generally IR (infrared), red, green, yellow, orange, and blue. The basic light-emitting diode is formed by joining gallium arsenide (GaAs) or gallium phosphide (GaP) with some other material. These two solutions can be combined to form a solid solution known as gallium arsenide phosphide (GaAsP). Different colors are produced by adding other compounds, called dopants, such as zinc selenide (ZnSe) or silicon carbide (SiC). The

Color	Material	Dopant	Wavelength (nm)
IR	GaAs	Si	900–1020
IR	GaAs	Zn	900
Red	GaP	Zn,O	700
Red	GaAsP	—	650
Orange	GaAsP	N	632
Yellow	GaP	N,N	590
Yellow	GaAsP	N	589
Green	GaP	N	570
Blue	SiC	—	490
Blue	ZnSe	—	490

Figure 51–1
The color of an LED is determined by the material it is made from. (Source: Delmar/Cengage Learning)

chart in Figure 51–1 shows different-colored LEDs, the wavelength of light in nanometers, and the materials used to construct the diode.

LED CHARACTERISTICS

The electrical characteristics of light-emitting diodes vary considerably from those of the common junction or rectifier diode. Junction diodes have a forward voltage drop of about 0.7 volts for silicon and 0.4 volts for germanium. LEDs have a forward voltage drop of about 1.7 volts or greater, depending on the material the diode is made of. Most light-emitting diodes are operated at about 20 mA or less current. A chart showing the typical forward voltage drop of different diodes is shown in Figure 51–2. Junction diodes typically have a PIV rating of 100 volts or greater, but LEDs have a typical PIV rating of about 5 volts. For this reason, when light-emitting diodes are used in applications where they are intended to block any amount of reverse voltage they are connected in series with a junction diode.

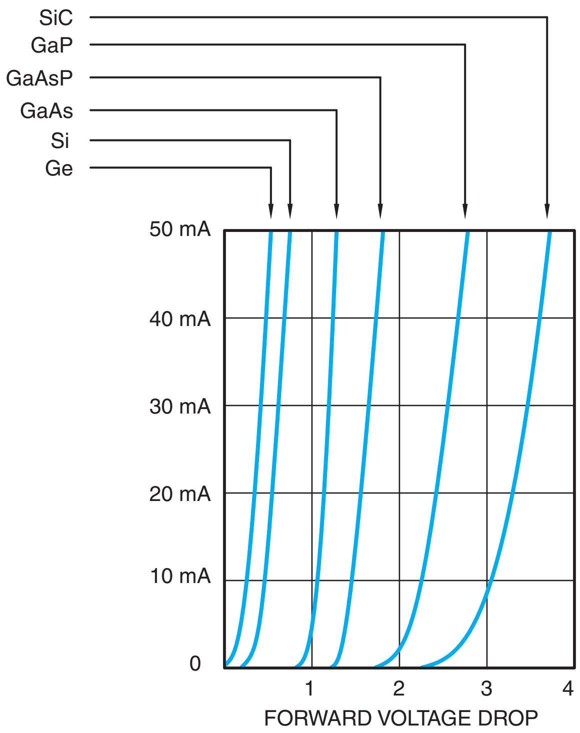

Figure 51–2
Forward voltage and current characteristics of diodes. (Source: Delmar/Cengage Learning)

Testing LEDs

Light-emitting diodes can be tested in a manner similar to that of testing a junction diode. The LED is a rectifier and should permit current to flow through it in one direction only. When testing an LED with an ohmmeter, it must be capable of supplying enough voltage to overcome the forward conduction voltage of about 1.7 volts or higher. The meter, however, must not supply a voltage that is higher than the reverse breakdown voltage. The schematic symbol for a light-emitting diode is shown in Figure 51–3. Some symbols use a straight arrow as shown in Figure 51–3, and others use a lightning arrow as shown in Figure 51–4. The lightning arrow symbol is employed to help prevent the arrow from being confused with a lead attached to the device. The important part of the symbol is that the arrow is pointing away from the diode. This indicates that light is being emitted or given off by the diode.

LED Lead Identification

Light-emitting diodes are housed in many different case styles. Regardless of the case style, however,

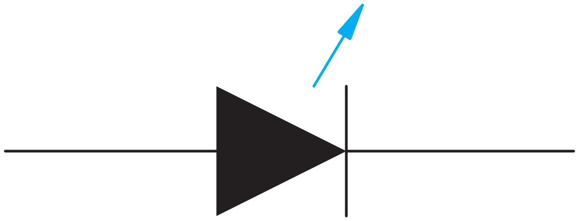

Figure 51–3
Schematic symbol for a light-emitting diode. (Source: Delmar/Cengage Learning)

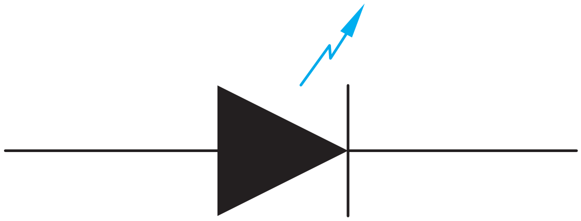

Figure 51–4
LED symbol using lightning arrow. (Source: Delmar/Cengage Learning)

there is generally some method of identifying which lead is the cathode and which is the anode. The case of most LEDs will have a flat side that is located closer to the cathode lead, Figure 51–5. Also, the cathode lead is generally shorter.

Seven-Segment Displays

A very common device that employs the use of light-emitting diodes is the seven segment display, Figure 51–6. The display actually contains eight LEDs, each segment plus the decimal point. Common cathode displays have all the cathodes connected together to form a common point. The display is energized by connecting a more positive voltage to the anode lead of each segment. Common anode displays are energized by connecting the appropriate cathode lead to a more negative voltage (generally ground). The seven-segment display can be used to display any number from 0 to 9.

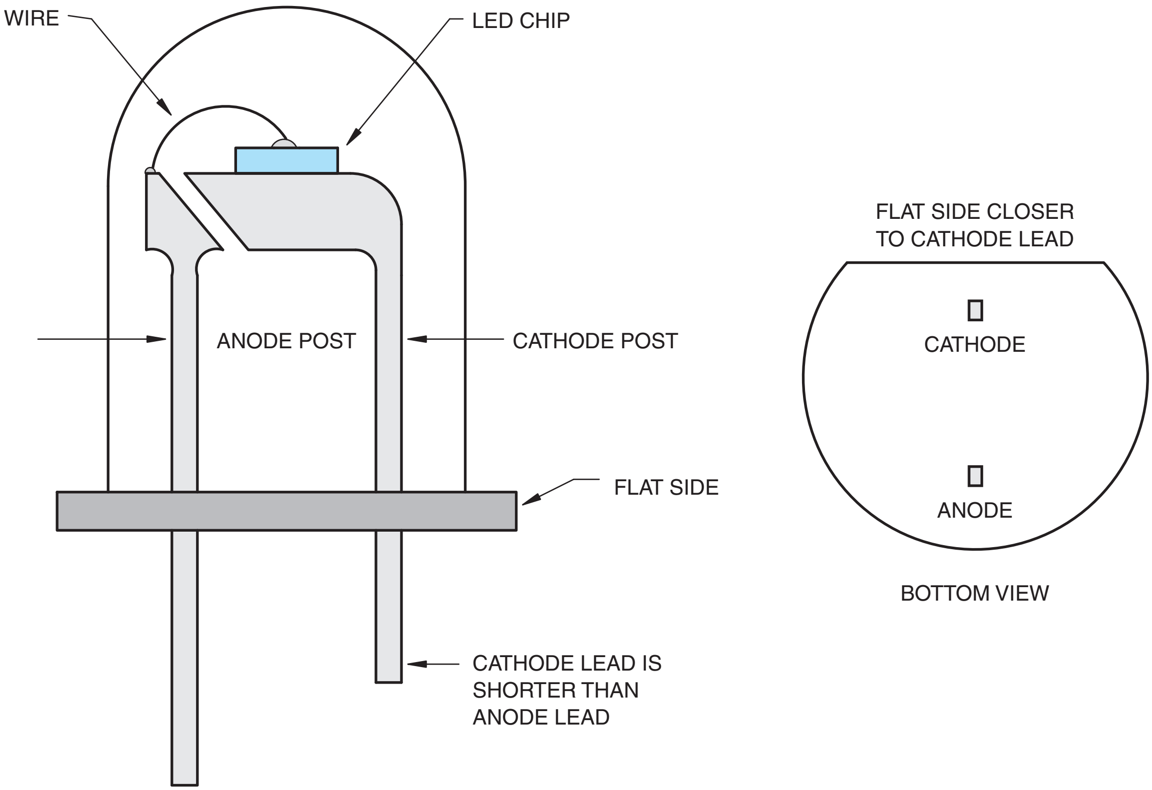

Figure 51–5
Identifying the leads of an LED. (Source: Delmar/Cengage Learning)

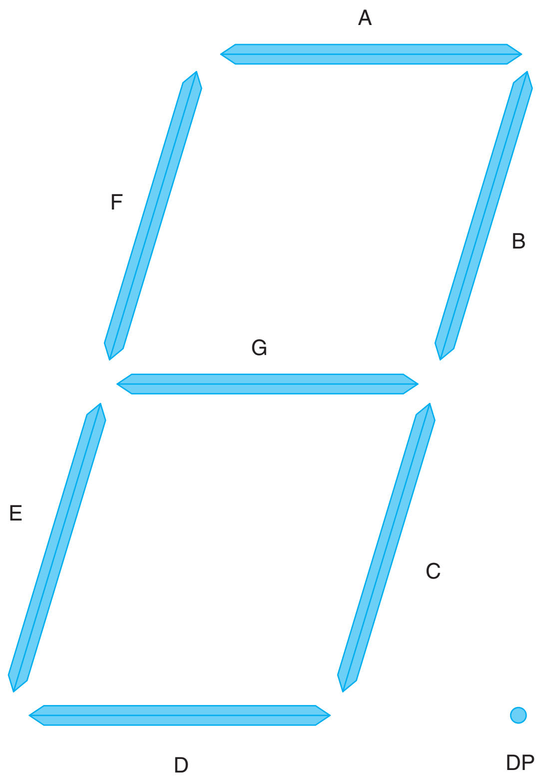

Figure 51–6
Seven-segment display. (Source: Delmar/Cengage Learning)

Connecting the LED in a Circuit

When used in a circuit, the LED generally operates with a current of about 20 mA (0.020 A) or less. Assume that an LED is to be connected in a 12-VDC circuit and is to have a current draw of approximately 20 milliamperes. This LED must have a current-limiting resistor connected in series with it. Ohm's law can be used to determine what size resistor should be connected in the circuit.

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

$$R = \frac{12}{.020}$$

$$R = 600\ \Omega$$

The nearest standard size resistor without going below 600 Ω is 620 Ω. A 620 Ω resistor would be connected in series with the LED, Figure 51–7. The minimum power rating for the resistor can also be determined using Ohm's law. The LED will have a voltage drop of approximately 1.7 volts. Because the resistor is connected in series with the LED, it will have a voltage drop of 10.3 volts. The power dissipation of the resistor can now be determined.

$$P = E^2/R$$

$$P = \frac{10.3^2}{620}$$

$$P = \frac{106.09}{620}$$

$$P = 0.171 \text{ watt}$$

A ¼ watt resistor can be employed in this circuit. A light-emitting diode is shown in Figure 51–8.

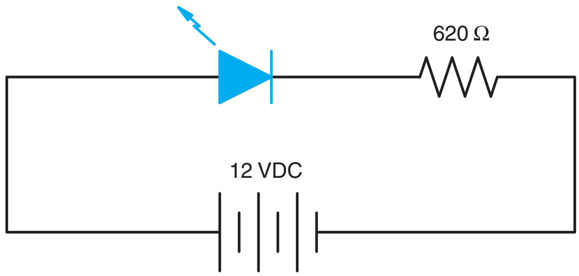

Figure 51–7
Current is limited by a resistor connected in series with the LED. (Source: Delmar/Cengage Learning)

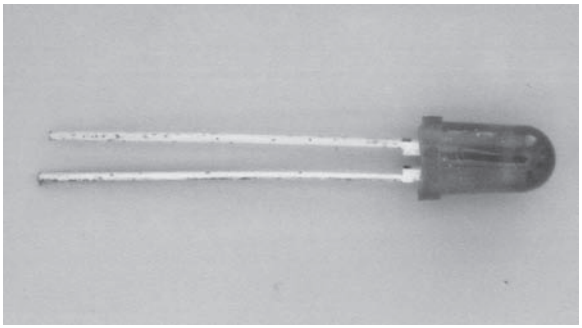

Figure 51–8
Light-emitting diode. (Source: Delmar/Cengage Learning)

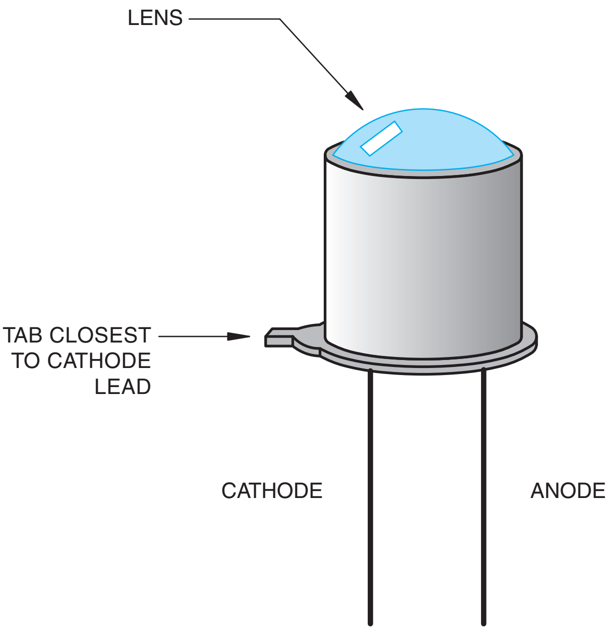

Figure 51–9
Photodiode. (Source: Delmar/Cengage Learning)

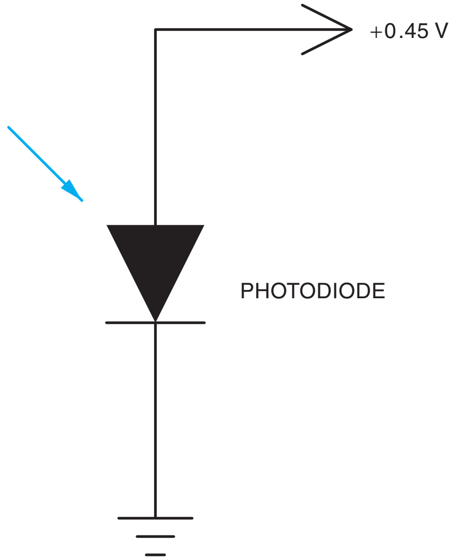

Figure 51–10
Photodiode used as a photovoltaic device. (Source: Delmar/Cengage Learning)

PHOTODIODES

The **photodiode** is so named because of its response to a light source. Photodiodes are housed in a case that has a window that permits light to strike the semiconductor material, Figure 51–9. Photodiodes can be used in two basic ways.

Photovoltaic

Photodiodes can be used as **photovoltaic** devices. When in the presence of light, they will produce a voltage in a manner similar to that of solar cells. The output voltage is approximately 0.45 volts. The current capacity is small and use is generally limited to applications such as operating light-metering devices. The basic schematic for a photodiode used as a photovoltaic device is shown in Figure 51–10.

Note the symbol used to represent a photo diode. The arrow pointing toward the diode indicates that it must receive light to operate.

Photoconductive

Photodiodes can also be used as **photoconductive** devices. When used in this manner they are connected reverse biased, Figure 51–11. In the presence of darkness, the amount of reverse current flow is extremely small, similar to that of a junction diode connected reverse biased. This current is referred to as the *dark current* (I_D) and is generally in the range of a few nanoamperes. For most practical purposes dark current is generally considered to be zero.

When exposed to light, photons enter the depletion region and create electron-hole pairs,

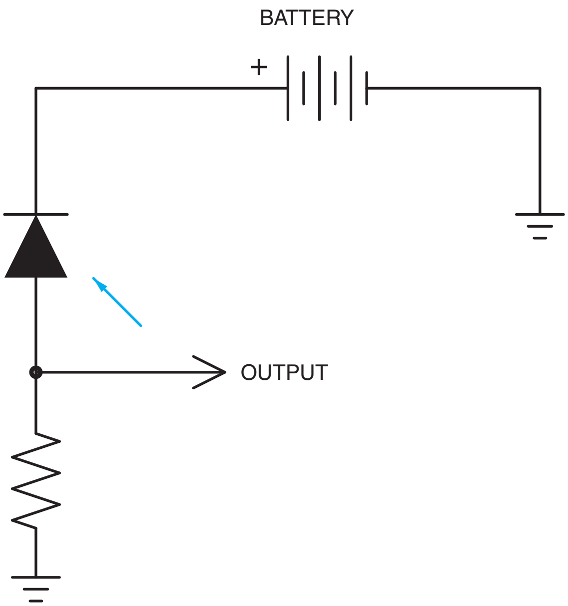

Figure 51–11
Photodiode used as a photoconductive device. (Source: Delmar/Cengage Learning)

increasing conductivity in the reverse direction. The increased conduction may permit several milliamperes of current to flow. This is known as *light current* (I_L). The great advantage of the photodiode over other photoconductive devices, such as the cad cell, is speed of operation. Photodiodes can operate at very high frequencies.

SUMMARY

- The light-emitting diode produces a light when current flows through it.
- The schematic symbol of an LED is a standard diode symbol with an arrow pointing away from the symbol. The arrow indicates that light is being emitted by the device.
- The schematic symbol for a photodiode is a standard diode symbol with an arrow pointing toward the symbol. The arrow indicates that light is received by the device.
- The forward voltage drop of an LED is approximately 1.7 volts.
- Photodiodes are commonly used as photovoltaic devices and as photoconductive devices.
- The greatest advantage of photodiodes over other photoconductive devices is speed of operation.

KEY TERMS

light-emitting diode (LED)
photoconductive
photodiode
photovoltaic

REVIEW QUESTIONS

1. Will the LED rectify an AC voltage into DC voltage?
2. What is the average voltage drop on an LED?
3. How can the anode and cathode leads of an LED be identified?
4. What is the average amount of current permitted to flow through an LED?
5. Can LEDs be tested with most ohmmeters?
6. When used as a photovoltaic device, how much voltage is generally produced by a photodiode?
7. Explain the difference between the schematic symbol used to indicate an LED and the symbol used to indicate a photodiode.
8. What is the greatest advantage of a photodiode used as a photoconductive device as compared with other photoconductive devices such as a cad cell?

UNIT 52

The Transistor

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the differences between PNP and NPN transistors
- Test transistors with an ohmmeter
- Identify the leads of standard case-style transistors
- Discuss the operation of a transistor
- Connect a transistor in a circuit

Transistors are made by joining three pieces of semiconductor material together. There are two basic types of transistors, the **NPN** and the **PNP**, Figure 52–1. The schematic symbols for these transistors are shown in Figure 52–2. The difference in these transistors is the manner in which they are connected in a circuit. The NPN transistor must have positive connected to the **collector** and negative connected to the **emitter**. The PNP must have positive connected to the emitter and negative connected to the collector. Notice that the **base** must be connected to the same polarity as the collector to forward bias the transistor. Also notice that the arrows on the emitters point in the direction of conventional current flow.

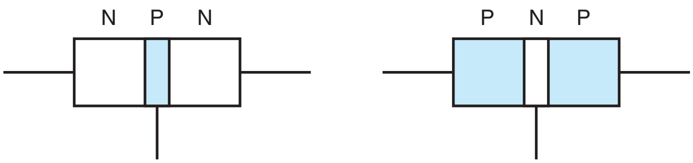

Figure 52–1
Two basic types of transistors. (Source: Delmar/Cengage Learning)

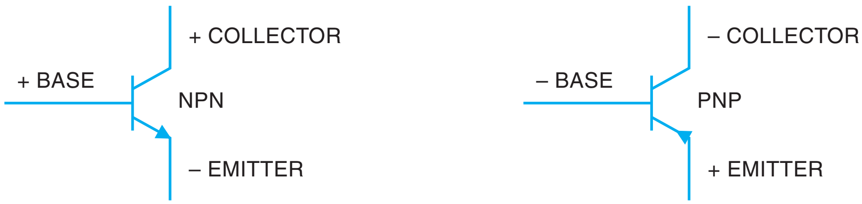

Figure 52–2
Schematic symbols of transistors. (Source: Delmar/Cengage Learning)

TESTING THE TRANSISTOR

The transistor can be tested with an ohmmeter. If the polarity of the output of the ohmmeter leads is known, the transistor can be identified as either NPN or PNP. A transistor will appear to an ohmmeter to be two diodes joined together, Figure 52–3. An NPN transistor will appear to an ohmmeter to be two diodes with their anodes connected together. If the positive lead of the ohmmeter is connected to the base of the transistor, a diode junction should be seen between the base-collector and the base-emitter. If the negative lead of the ohmmeter is connected to the base of an NPN transistor, there should be no continuity between the base-collector and the base-emitter junction.

A PNP transistor will appear to be two diodes with their cathodes connected together. If the negative lead of the ohmmeter is connected to the base of the transistor, a diode junction should be seen between the base-collector and the base-emitter. If the positive ohmmeter lead is connected to the base, there should be no continuity between the base-collector or the base-emitter.

The following step-by-step procedure can be used to test a transistor.

1. Using a diode, determine which ohmmeter lead is positive and which is negative. The ohmmeter will indicate continuity through the diode only when the positive lead is connected to the anode and the negative lead is connected to the cathode, Figure 52–4.
2. If the transistor is an NPN, connect the positive ohmmeter lead to the base and the negative lead to the collector. The ohmmeter should indicate continuity. The reading should be about the same as the reading obtained when the diode was tested, Figure 52–5.
3. With the positive ohmmeter lead still connected to the base of the transistor, connect the negative lead to the emitter. The ohmmeter should again indicate a forward diode junction, Figure 52–6.

NOTE: ***If the ohmmeter does not indicate continuity between the base-collector or the base-emitter, the transistor is open.***

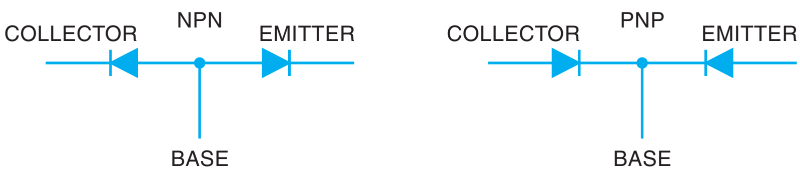

Figure 52–3
Ohmmeter test for transistors.
(Source: Delmar/Cengage Learning)

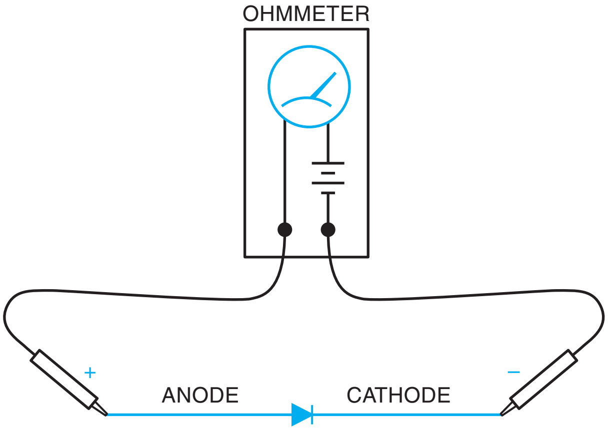

Figure 52–4
Determining ohmmeter polarity. (Source: Delmar/Cengage Learning)

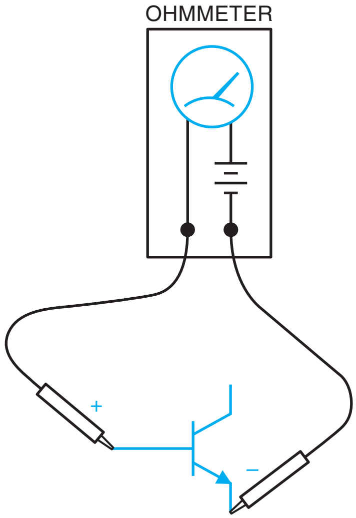

Figure 52–6
Testing the base-emitter junction. (Source: Delmar/Cengage Learning)

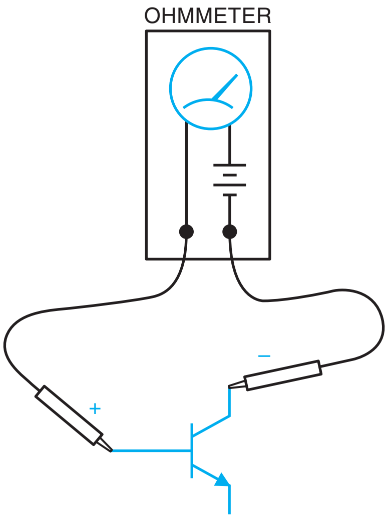

Figure 52–5
Testing the base-emitter junction. (Source: Delmar/Cengage Learning)

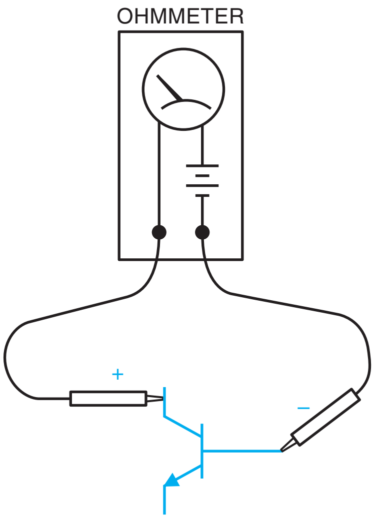

Figure 52–7
Reversing the connection of the base-collector junction. (Source: Delmar/Cengage Learning)

4. Connect the negative ohmmeter lead to the base and the positive lead to the collector. The ohmmeter should indicate infinity or no continuity, Figure 52–7.
5. With the negative ohmmeter lead connected to the base, reconnect the positive lead to the emitter. There should, again, be no indication of continuity, Figure 52–8.

NOTE: *If a very high resistance is indicated by the ohmmeter, the transistor is "leaky" but it may still operate in the circuit. If a very low resistance is seen, the transistor is shorted.*

6. To test a PNP transistor, reverse the polarity of the ohmmeter leads and repeat the test. When the negative ohmmeter lead is

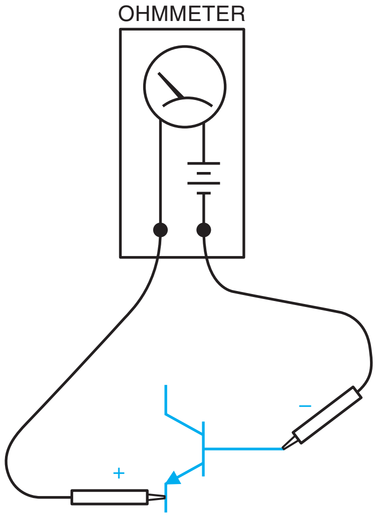

Figure 52–8
Reversing the connection of the base-emitter junction. (Source: Delmar/Cengage Learning)

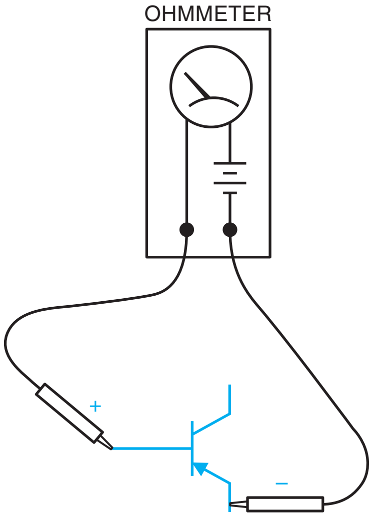

Figure 52–10
Reversing the connection of a PNP transistor. (Source: Delmar/Cengage Learning)

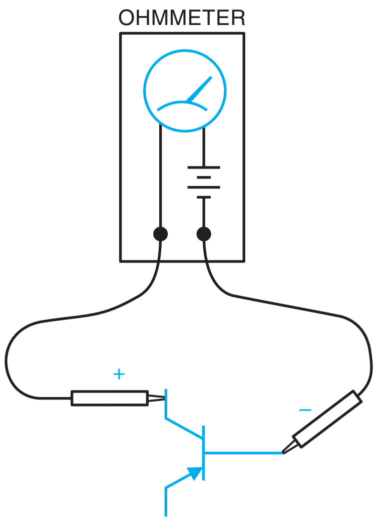

Figure 52–9
Testing the base-collector junction of a PNP transistor. (Source: Delmar/Cengage Learning)

connected to the base, a forward diode junction should be indicated when the positive lead is connected to the collector or emitter, Figure 52–9.

7. If the positive ohmmeter lead is connected to the base of a PNP transistor, no continuity should be indicated when the negative lead is connected to the collector or the emitter, Figure 52–10.

TRANSISTOR OPERATION

The simplest way to describe the operation of a transistor is to say it operates like an electric valve. Current will not flow through the collector-emitter until current flows through the base-emitter. The amount of base-emitter current, however, is small when compared to the collector-emitter current, Figure 52–11. For example, assume that when one milliamp (mA) of current flows through the base-emitter junction, 100 mA of current flows through the collector-emitter junction. If this transistor is a linear device, an increase or decrease of base current will cause a similar increase or decrease of collector current. For instance, if the base current is increased to 2 mA, the collector current would increase to 200 mA. If the base current is decreased to .5 mA, the collector current would decrease to 50 mA. Notice that a small change in the amount of base current can cause a large change in the amount of collector current. This permits a small amount of signal current to operate a larger device, such as the coil of a control relay.

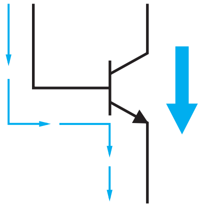

Figure 52–11
A small base current controls a large collector current. (Source: Delmar/Cengage Learning)

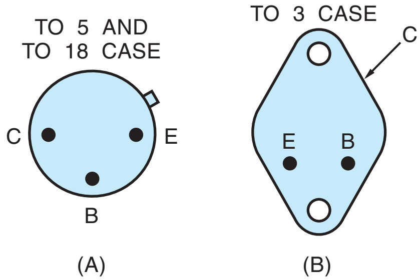

Figure 52–12
Lead identification of transistors. (Source: Delmar/Cengage Learning)

One of the most common applications of the transistor is that of a switch. When used in this manner, the transistor operates like a digital device instead of an analog device. The term **digital** refers to a device that has only two states such as on or off. An **analog** device can be adjusted to different states. An example of this control can be seen in a simple switch connection. A common wall switch is a digital device. It can be used to either turn a light on or off. If the simple toggle switch is replaced with a dimmer control, the light can be turned on, off, or adjusted to any position between. The dimmer is an example of analog control.

If no current flows through the base of the transistor, the transistor acts like an open switch and no current will flow through the collector-emitter junction. If enough base current is applied to the transistor to turn it completely on, it acts like a closed switch and permits current to flow through the collector-emitter junction. This is the same action produced by the closing contacts of a relay or motor starter, but a relay or motor starter cannot turn on and off several thousand times a second and a transistor can.

IDENTIFYING TRANSISTOR LEADS

Some **case** styles of transistors permit the leads to be quickly identified. The TO 5 and TO 18 cases, and the TO 3 case are in this category. The leads of the TO 5 or TO 18 case transistors can be identified by holding the case of the transistor with the leads facing you as shown in Figure 52–12A. The metal tab on the case of the transistor is closest to the emitter lead. The base and collector leads are positioned as shown in Figure 52–12A.

The leads of a TO 3 case transistor can be identified as shown in Figure 52–12B. With the transistor held with the leads facing you and down, the emitter is the left lead and the base is the right lead. The case of the transistor is the collector. Several case styles for the transistor are shown in Figure 52–13.

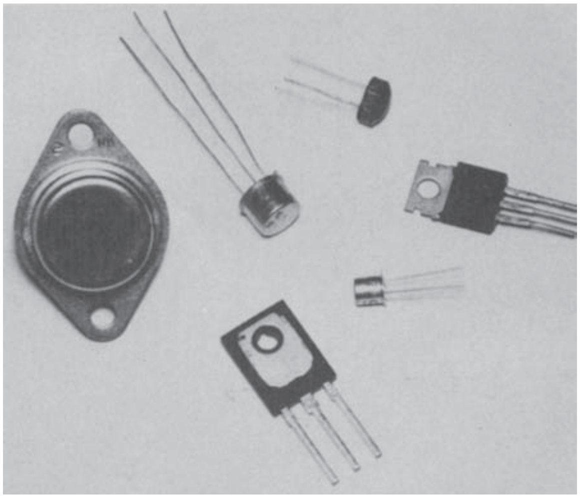

Figure 52–13
Transistors shown in different case styles. (Source: Delmar/Cengage Learning)

SUMMARY

- Transistors are made by joining three layers of semiconductor material together.
- The two basic types of transistors are NPN and PNP.
- The three terminal leads of a transistor are the collector, base, and emitter.
- A PNP transistor must have a more positive voltage connected to the emitter than the collector.
- An NPN transistor must have a more negative voltage connected to the emitter than the collector.
- The current flow through the base-emitter of the transistor controls the amount of current flow through collector-emitter.

KEY TERMS

analog
base
case
collector
digital
emitter
NPN
PNP

REVIEW QUESTIONS

1. What are the two basic types of transistors?
2. Explain how to test an NPN transistor with an ohmmeter.
3. Explain how to test a PNP transistor with an ohmmeter.
4. What polarity must be connected to the collector, base, and emitter of an NPN to make it forward biased?
5. What polarity must be connected to the collector, base, and emitter of a PNP transistor to make it forward biased?
6. Explain the difference between an analog device and a digital device.

UNIT 53

The Unijunction Transistor

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the differences between junction transistors and unijunction transistors
- Identify the leads of a UJT
- Draw the schematic symbol for a UJT
- Test a UJT with an ohmmeter
- Connect a UJT in a circuit

The **unijunction transistor** is a special transistor that has two bases and one emitter. The unijunction transistor (UJT) is a digital device because it has only two states, on or off, and is generally classified with a group of devices known as **thyristors**. Thyristors are turned completely on or completely off. Thyristors include devices such as the silicon-controlled rectifier (SCR), triac, diac, and the unijunction transistor.

The unijunction transistor is made by combining three layers of semi-conductor material as shown in Figure 53–1. The schematic symbol with polarity connections and the base diagram is shown in Figure 53–2.

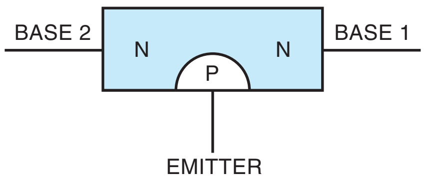

Figure 53–1
Unijunction transistor. (Source: Delmar/Cengage Learning)

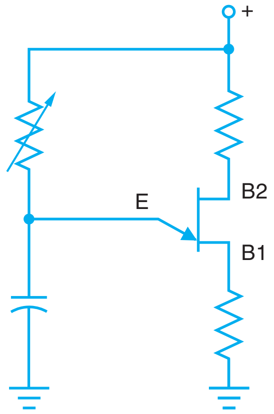

Figure 53–3
Basic UJT connection. (Source: Delmar/Cengage Learning)

UJT CHARACTERISTICS

The UJT has two paths for current flow. One path is from B2 to B1. The other path is through the emitter and base #1. In its normal state, there is no current flow through either path until the voltage applied to the emitter reaches about 10 volts higher than the voltage applied to base #1. When the voltage applied to the emitter reaches about 10 volts more positive than the voltage applied to base #1, the UJT turns on and current flows through the B1–B2 path and from the emitter through base #1. Current will continue to flow through the UJT until the voltage applied to the emitter drops to a point that it is only about 3 volts higher than the voltage applied to B1. When the emitter voltage drops to this point, the UJT will turn off and remain turned off until the voltage applied to the emitter again becomes about 10 volts higher than the voltage applied to B1.

CIRCUIT OPERATION

The unijunction transistor is generally connected into a circuit similar to the circuit shown in Figure 53–3. The variable resistor controls the rate of charge time of the capacitor. When the capacitor has been charged to about 10 volts, the UJT turns on and discharges the capacitor through the emitter and base #1. When the capacitor has been discharged to about 3 volts, the UJT turns off and permits the capacitor to begin charging again. By varying the resistance connected in series with the capacitor, the amount of time needed for charging the capacitor can be changed, thereby controlling the pulse rate of the UJT ($T = RC$).

The UJT can furnish a large output pulse, because the output pulse is produced by the discharging capacitor, Figure 53–4. This large output pulse is generally used for triggering the gate of an SCR.

The pulse rate is determined by the amount of resistance and capacitance connected to the emitter of the UJT. However, the amount of capacitance that can be connected to the UJT is limited. For instance, most UJTs should not have a capacitor larger than 10 µf connected to them. If the capacitor is too large, the UJT will not be able to handle the current spike produced by the capacitor, and the UJT could be damaged.

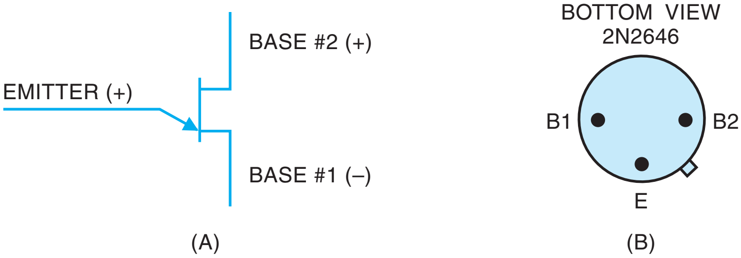

Figure 53–2
The schematic symbol for the unijunction transistor with polarity connections and base diagram. (Source: Delmar/Cengage Learning)

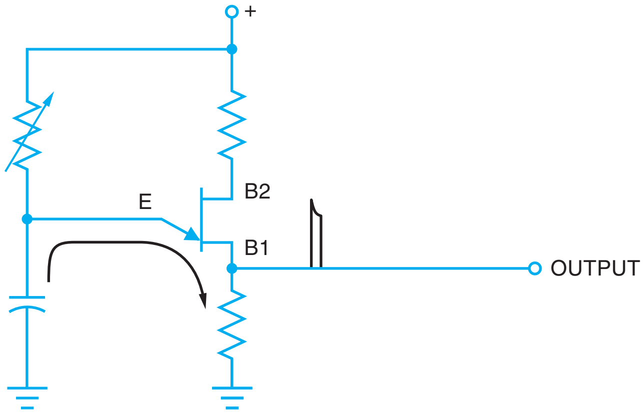

Figure 53–4
A large pulse is produced by the capacitor discharge. (Source: Delmar/Cengage Learning)

TESTING THE UJT

The unijunction transistor can be tested with an ohmmeter in a manner very similar to testing a common junction transistor. The UJT will appear to the ohmmeter to be a connection of two resistors connected to a common junction diode. The common junction point of the two resistors will appear to be at the emitter of the UJT as shown in Figure 53–5. When the positive lead of the ohmmeter is connected to the emitter, a diode junction should be seen from the emitter to base #2 and another diode connection from the emitter to base #1. If the negative lead of the ohmmeter is connected to the emitter of the UJT, no connection should be seen between the emitter and either base.

The following step-by-step procedure can be used to test a unijunction transistor.

1. Using a junction diode, determine which ohmmeter lead is positive and which is negative. The ohmmeter will indicate continuity when the positive lead is connected to the anode and the negative lead is connected to the cathode, Figure 53–6.

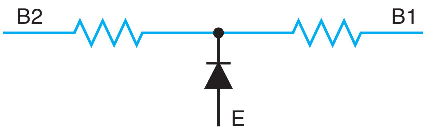

Figure 53–5
The UJT appears as two resistors connected to a diode when tested with an ohmmeter. (Source: Delmar/Cengage Learning)

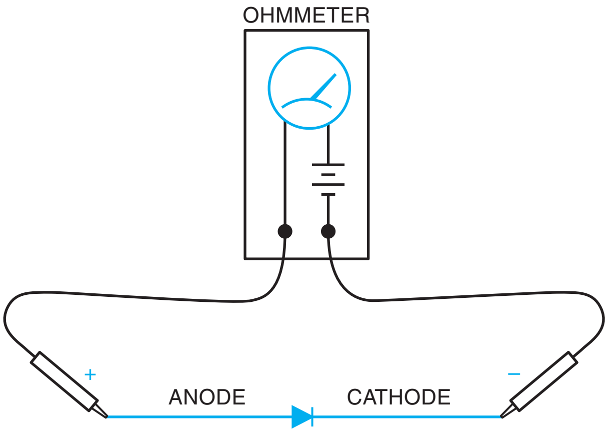

Figure 53–6
Determining ohmmeter polarity. (Source: Delmar/Cengage Learning)

2. Connect the positive ohmmeter lead to the emitter lead and the negative lead to base #1. The ohmmeter should indicate a forward diode junction, Figure 53–7.
3. With the positive ohmmeter lead connected to the emitter, reconnect the negative lead to base #2. The ohmmeter should again indicate a forward diode junction, Figure 53–8.
4. If the negative ohmmeter lead is connected to the emitter, no continuity should be indicated when the positive lead is connected to base #1 or base #2, Figure 53–9.

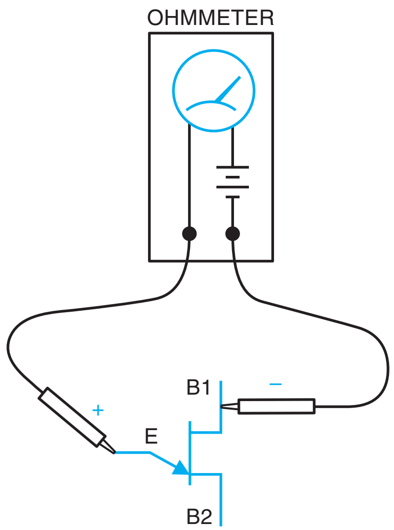

Figure 53–7
Testing a UJT. (Source: Delmar/Cengage Learning)

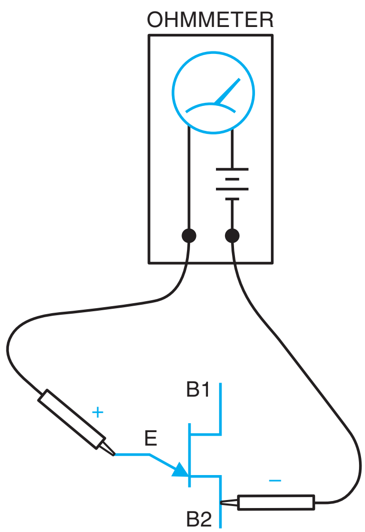

Figure 53–8
Testing the emitter-base 2 junction. (Source: Delmar/Cengage Learning)

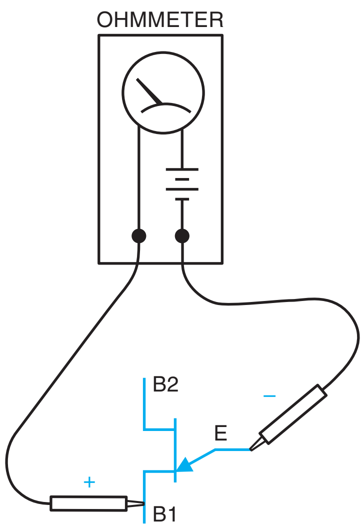

Figure 53–9
Reversing the polarity. (Source: Delmar/Cengage Learning)

SUMMARY

- The unijunction transistor has two bases and one emitter.
- The unijunction transistor is a member of the thyristor family of components.
- Injunction transistors have two states of operation: on or off.
- The unijunction transistor operates like a snap action, voltage sensitive switch.

KEY TERMS

thyristors
unijunction transistor

REVIEW QUESTIONS

1. What do the letters UJT stand for?
2. How many layers of semiconductor material are used to construct a UJT?
3. Briefly explain the operation of the UJT.
4. Draw the schematic symbol for the UJT.
5. Briefly explain how to test a UJT with an ohmmeter.

UNIT 54

The Silicon-Controlled Rectifier

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of a silicon-controlled rectifier (SCR) in a DC circuit and an AC circuit
- Draw the schematic symbol for an SCR
- Discuss phase shifting
- Test an SCR with an ohmmeter
- Connect an SCR in a circuit

The **silicon-controlled rectifier (SCR)** is often referred to as the **PNPN** junction because it is made by joining four layers of semiconductor material together, Figure 54–1. The schematic symbol for the SCR is shown in Figure 54–2. Notice that the symbol for the SCR is the same as the diode except that a gate lead has been added.

SCR CHARACTERISTICS

The SCR is a member of a family of devices known as thyristors. Thyristors are digital devices in that they have only two states, on or off. The SCR is used when it is necessary for an electronic device to control a large amount of power. Assume an SCR has been connected in a circuit as shown in Figure 54–3. When the SCR is turned off, it will drop the full voltage of the circuit and 200 volts will

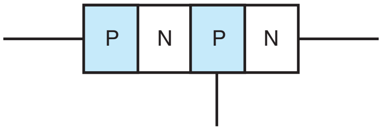

Figure 54–1
PNPN junction. (Source: Delmar/Cengage Learning)

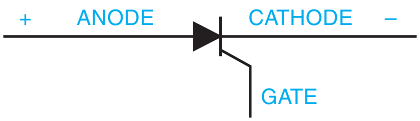

Figure 54–2
Schematic symbol of an SCR. (Source: Delmar/Cengage Learning)

appear across the anode and cathode. Although the SCR has a voltage drop of 200 volts, there is no current flow in the circuit. The SCR does not have to dissipate any power in this condition (200 volts × 0 amps = 0 watts). When the push button is pressed, the SCR will turn on. When the SCR turns on, it will have a voltage drop across its anode and cathode of about 1 volt. The load resistor limits the circuit current to 2 amps (200 volts/100 ohms = 2 amps). Because the SCR now has a voltage drop of 1 volt and 2 amps of current is flowing through it, it must now dissipate 2 watts of heat (1 volt × 2 amps = 2 watts). Notice that the SCR is dissipating only 2 watts of power, but is controlling 200 watts.

THE SCR IN A DC CIRCUIT

When an SCR is connected in a DC circuit as shown in Figure 54–3, the **gate** will turn the SCR on but will not turn the SCR off. The gate must be connected to the same polarity as the anode if it is to turn the anode-cathode section of the SCR on. Once the gate has turned the SCR on, it will remain turned on until the current flowing through the anode-cathode drops to a low enough level to permit the device to turn off. The amount of current required to keep the SCR turned on is called the **holding current**, Figure 54–4. Assume resistor R1 has been adjusted for its highest value and resistor R2 has been adjusted to its lowest or 0 value. When switch S1 is closed, no current will flow through the anode-cathode section of the SCR because resistor R1 prevents enough current flowing through the gate-cathode section of the SCR to trigger the device. If resistor R1 is slowly decreased in value, current flow through the gate-cathode will slowly increase. When the gate current reaches a certain level, assume 5 mA for this SCR, the SCR will fire or turn on. When the SCR fires, current will flow through the anode-cathode section and the voltage drop across the device becomes about 1 volt. Once the SCR has turned on, the gate has no more control over the device and could be disconnected from the anode without having any effect on the circuit. When the SCR fires, the anode-cathode becomes a short circuit for all practical purposes and current flow is limited by resistor R3. Now assume that resistor R2 is slowly increased in value. When the resistance of R2 is slowly increased, the current flow through the anode-cathode will slowly decrease. Assume that when the current flow through the anode-cathode drops to 100 mA, the device suddenly turns off and the current flow drops to 0. This SCR requires 5 mA of gate current to turn it on, and has a holding current value of 100 mA.

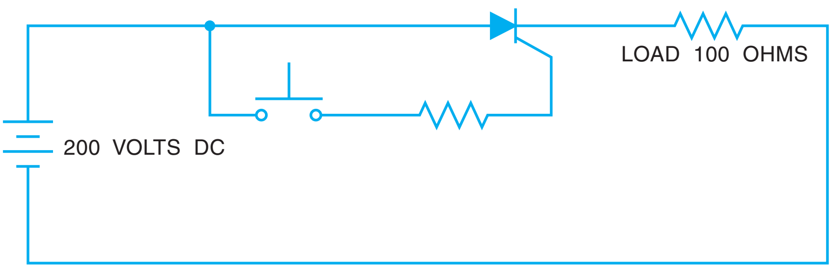

Figure 54–3
Gate turns SCR on. (Source: Delmar/Cengage Learning)

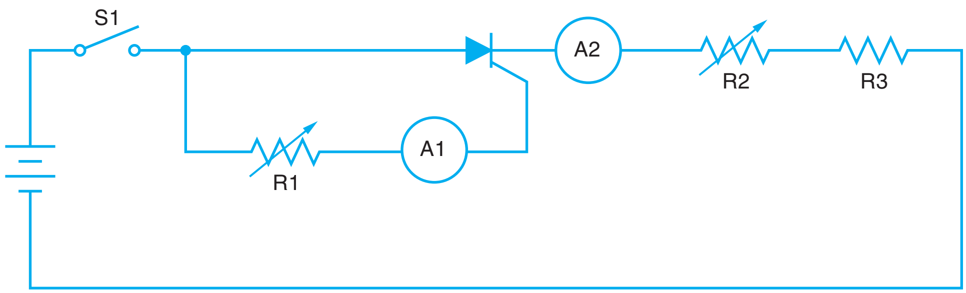

Figure 54–4
Operation of an SCR in a DC circuit. (Source: Delmar/Cengage Learning)

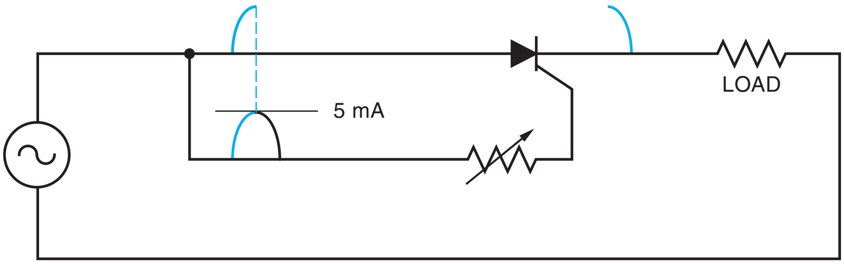

Figure 54–5
SCR fires when the AC waveform reaches peak value. (Source: Delmar/Cengage Learning)

THE SCR IN AN AC CIRCUIT

The SCR is a rectifier. When it is connected in an AC circuit the output will be DC. The SCR operates in the same manner in an AC circuit as it does in a DC circuit. The difference in operation is caused by the AC waveform falling back to 0 at the end of each half cycle. When the AC waveform drops to 0 at the end of each half cycle, it will permit the SCR to turn off. This means the gate must re-trigger the SCR for each cycle it is to conduct. Refer to the circuit shown in Figure 54–5.

Assume that the variable resistor connected to the gate has been adjusted to permit 5 mA of current to flow when the voltage applied to the anode reaches its peak value. When the SCR turns on, current will begin flowing through the load resistor when the AC waveform is at its positive peak. Current will continue to flow through the load until the decreasing voltage of the sine wave causes the current to drop below the holding current level of 100 mA. When the current through the anode-cathode drops below 100 mA, the SCR turns off and all current flow stops. The SCR will remain turned off when the AC waveform goes into the negative half cycle because it is reverse biased and cannot be fired.

If the resistance connected in series with the gate is reduced, a current of 5 mA will be reached before the AC waveform reaches it peak value, Figure 54–6. This causes the SCR to fire sooner in the cycle. Since the SCR fires sooner, current is permitted to flow through the load resistor for a longer period of time, which causes a higher average voltage drop across the load. If the resistance of the gate circuit is reduced again, as shown in Figure 54–7, the 5 mA of gate current needed to fire the SCR will be reached sooner than before. This permits current to begin flowing through the load sooner than before, which permits a higher average voltage to be dropped across the load.

Notice that this circuit will permit the SCR to control only half of the positive waveform. The latest the SCR can be fired in the cycle is when the AC waveform is at 90° or peak. If a lamp were used as the load for this circuit, it would burn at half brightness when the SCR first turned on. This control would permit the lamp to be operated from half brightness to full brightness, but it could not be operated at a level less than half brightness.

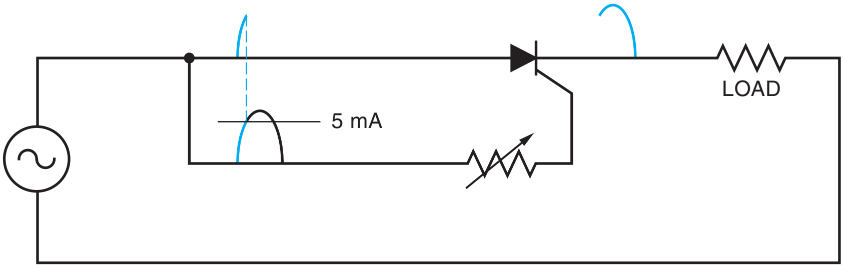

Figure 54–6
SCR fires before the AC waveform reaches peak value.
(Source: Delmar/Cengage Learning)

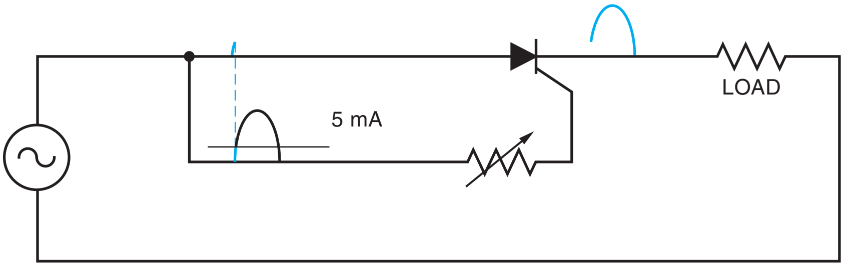

Figure 54–7
SCR fires sooner than before.
(Source: Delmar/Cengage Learning)

PHASE SHIFTING THE SCR

If the SCR is to control all of the positive waveform, it must be **phase shifted**. As the term implies, phase shifting means to shift the phase of one thing in reference to another. In this instance, the voltage applied to the gate must be shifted out of phase with the voltage applied to the anode. There are several methods that can be used for phase shifting an SCR, but it is beyond the scope of this text to cover all of them. The basic principles are the same for all of the methods, however, so only one method will be covered.

If the SCR is to be phase shifted, the gate circuit must be unlocked or separated from the anode circuit. The circuit shown in Figure 54–8 will accomplish this. A 24-volt center-tapped transformer has been used to isolate the gate circuit from the anode circuit. Diodes D1 and D2 are used to form a two-diode type of full wave rectifier to operate the unijunction transistor (UJT) circuit. Resistor R1 is used to determine the pulse rate of the UJT by controlling the charge time of capacitor C1. Resistor R2 is used to limit the current through the emitter of the UJT if resistor R1 is adjusted to 0 ohms. Resistor R3 limits current through the base 1–base 2 section when the UJT turns on. Resistor R4 permits a voltage spike or pulse to be produced across it when the UJT turns on and discharges capacitor C1. The pulse produced by the discharge of capacitor C1 is used to trigger the gate of the SCR.

Because the pulse of the UJT is used to provide a trigger for the gate of the SCR, the SCR can now be fired at any time regardless of the voltage applied to the anode. This means the SCR can now be fired as early or late during the positive half cycle as desired, because the gate pulse is now determined by the charge rate of capacitor C1. The voltage across the load can now be adjusted from 0 to the full applied voltage.

TESTING THE SCR

The SCR can be tested with an ohmmeter. To test the SCR, connect the positive output lead of the ohmmeter to the anode and the negative lead to the cathode. The ohmmeter should indicate no continuity. Touch the gate of the SCR to the anode. The ohmmeter should indicate continuity through the SCR. When the gate lead is removed from the anode, conduction may stop or continue, depending on whether the ohmmeter is supplying enough current to keep the device above its holding current level or not. If the ohmmeter indicates continuity through the SCR before the gate is touched to the anode, the SCR is shorted. If the ohmmeter will not

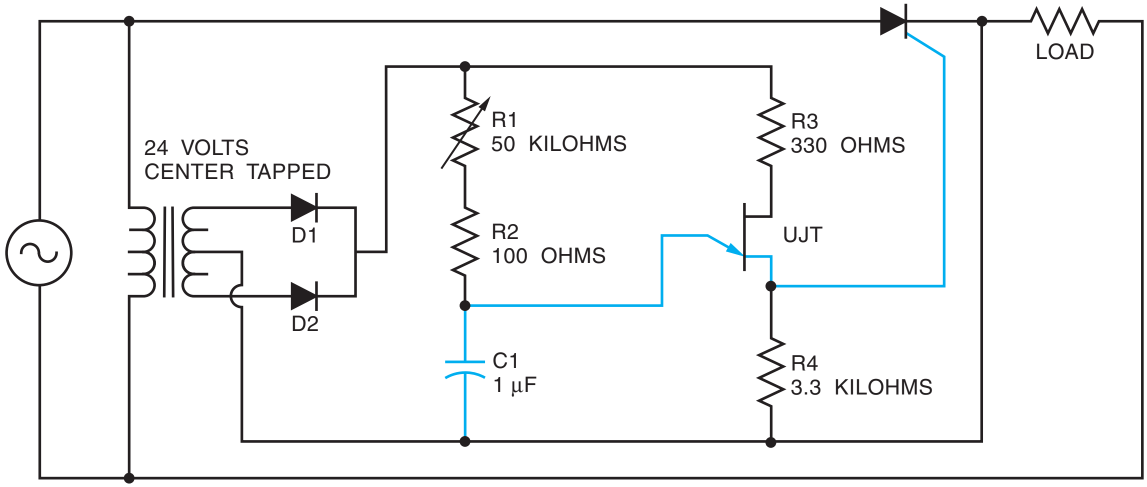

Figure 54–8
UJT phase shift for an SCR. (Source: Delmar/Cengage Learning)

indicate continuity through the SCR after the gate has been touched to the anode, the SCR is open. The following step-by-step procedure can be used for testing an SCR.

1. Using a junction diode, determine which ohmmeter lead is positive and which is negative. The ohmmeter will indicate continuity only when the positive lead is connected to the anode of the diode and the negative lead is connected to the cathode, Figure 54–9.
2. Connect the positive ohmmeter lead to the anode of the SCR and the negative lead to the cathode. The ohmmeter should indicate no continuity, Figure 54–10.
3. Using a jumper lead, connect the gate of the SCR to the anode. The ohmmeter should indicate a forward diode junction when the connection is made, Figure 54–11.

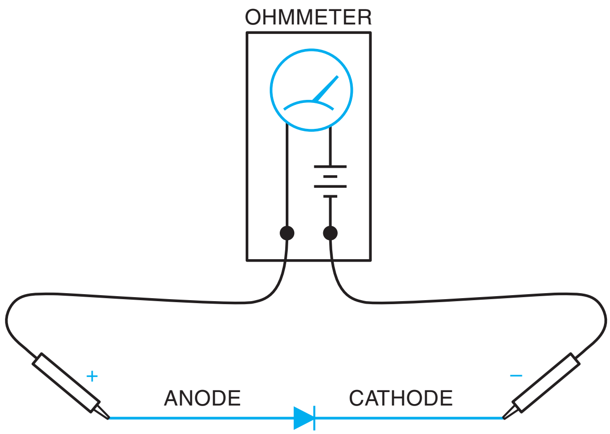

Figure 54–9
Determining ohmmeter polarity. (Source: Delmar/Cengage Learning)

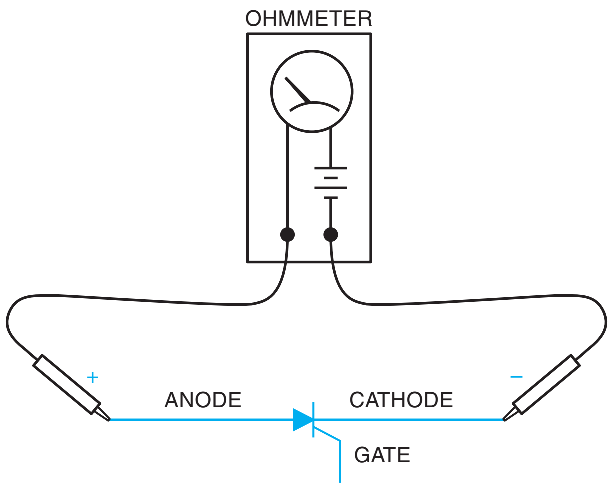

Figure 54–10
There should be no continuity between anode and cathode. (Source: Delmar/Cengage Learning)

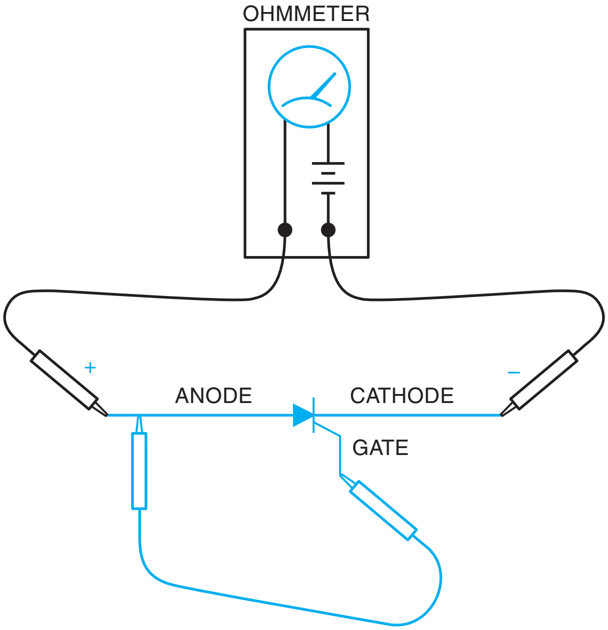

Figure 54–11
Shorting the gate and anode causes the SCR to conduct.
(Source: Delmar/Cengage Learning)

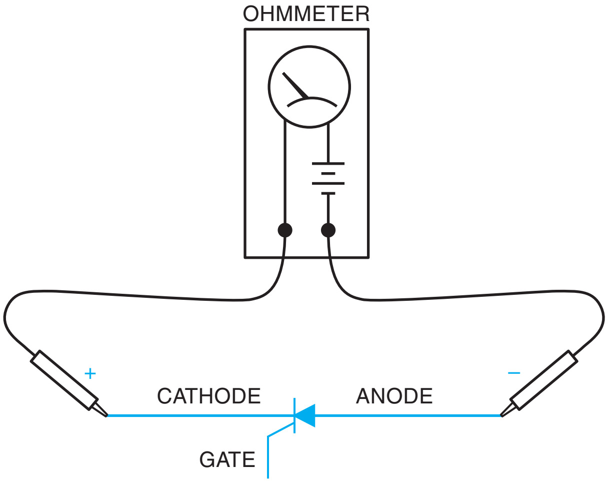

Figure 54–12
Reversing the polarity. (Source: Delmar/Cengage Learning)

***NOTE:** If the jumper is removed, the SCR may continue to conduct or it may turn off. This will be determined by whether or not the ohmmeter can supply enough current to keep the SCR above its holding current level.*

4. Reconnect the SCR so that the cathode is connected to the positive ohmmeter lead and the anode is connected to the negative lead. The ohmmeter should indicate no continuity, Figure 54–12.
5. If a jumper lead is used to connect the gate to the anode, the ohmmeter should indicate no continuity, Figure 54–13. SCRs in different case styles are shown in Figure 54–14.

***NOTE:** SCRs designed to switch large current (50 amperes or more) may indicate some leakage current with this test. This is normal for some devices.*

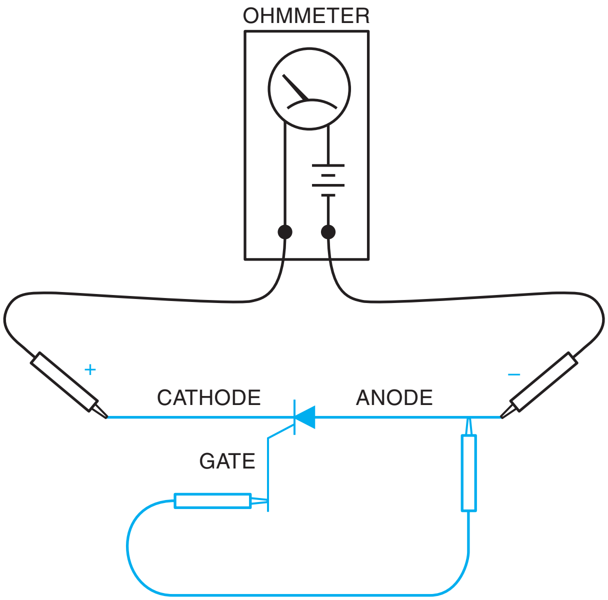

Figure 54–13
The SCR will not conduct when the polarity is reversed.
(Source: Delmar/Cengage Learning)

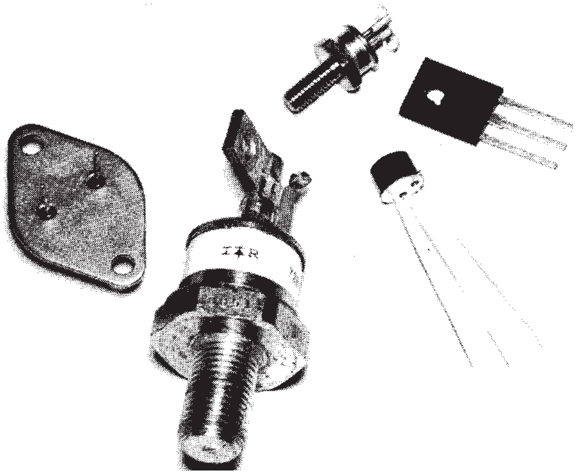

Figure 54–14
SCRs shown in different case styles. (Source: Delmar/Cengage Learning)

SUMMARY

- The silicon-controlled rectifier (SCR) is often referred to as a PNPN junction.
- The SCR is a member of the thyristor family of electronic devices.
- The SCR has two states of operation: on or off.
- When the SCR is connected in a DC circuit, the gate current controls the turn on, but once the SCR is turned on, the gate cannot turn it off.
- Before an SCR can be turned off, the current flow through the anode-cathode section must drop below the holding current level.
- When an SCR is connected in an AC circuit, the voltage returning to zero each half cycle turns the SCR off.
- The SCR is a rectifier; it will change alternating current into direct current.
- In order to gain complete control of the output waveform, the SCR must be phase shifted.
- The unijunction transistor is often used to phase shift an SCR.

KEY TERMS

gate
holding current
phase shifted
PNPN
silicon-controlled rectifier (SCR)

REVIEW QUESTIONS

1. What do the letters SCR stand for?
2. How many layers of semiconductor material are joined to form an SCR?
3. SCRs are a member of what family of devices?
4. If an SCR is connected in an AC circuit, is the output AC or DC?
5. Is gate current used to turn the SCR on or off?
6. The amount of current flow through the anode-cathode section needed to keep an SCR turned on is called what?
7. When an SCR is connected in an AC circuit, what must be done to gain complete control of the output waveform?
8. What electronic component is generally used to phase shift an SCR?

UNIT 55

The Diac

OBJECTIVES

After studying this unit the student should be able to:

- Draw the schematic symbol for a diac
- Discuss the operation of a diac
- Connect a diac in a circuit

The **diac** is a special-purpose **bidirectional** diode. The primary function of the diac is to phase shift a triac. The operation of the diac is very similar to that of a unijunction transistor, except the diac is a "bi" or two-directional device. The diac has the ability to operate in an AC circuit while the UJT is a DC device only.

There are two schematic symbols for the diac, Figure 55–1. Either of these symbols is used in an electronic schematic to illustrate the use of a diac; therefore, you should become familiar with both.

DIAC CHARACTERISTICS

The diac is a voltage-sensitive switch that can operate on either polarity, Figure 55–2. When voltage is applied to the diac, it will remain in the turned-off state until the applied voltage reaches a predetermined

Figure 55–1
Schematic symbols for a diac. (Source: Delmar/Cengage Learning)

Figure 55–2
The diac can operate on either polarity. (Source: Delmar/Cengage Learning)

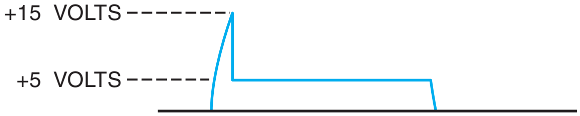

Figure 55–3
The diac operates until the applied voltage falls below its conduction level. (Source: Delmar/Cengage Learning)

level. For this example, assume this to be 15 volts. When the voltage reaches 15 volts, the diac will turn on or fire. When the diac fires, it displays a negative resistance, which means it will conduct at a lower voltage than the voltage that was applied to it, assume 5 volts. The diac will remain turned on until the applied voltage drops below its conduction level, which in this example is 5 volts. Refer to the waveform shown in Figure 55–3. Because the diac is a bidirectional device, it will conduct on either half cycle of the AC applied to it. Refer to the waveform shown in Figure 55–4. Notice that the diac has the same operating characteristic with either half cycle of AC. The simplest way to sum up the operation of the diac is to say it is a voltage-sensitive AC switch.

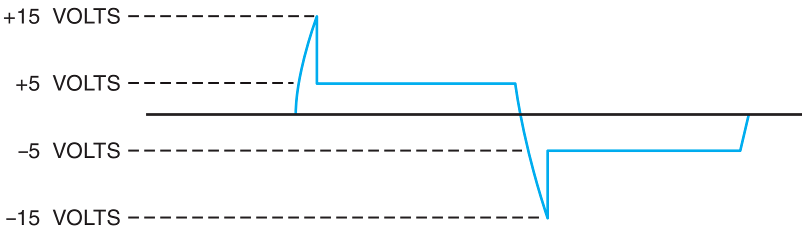

Figure 55–4
The diac will conduct on either half of the alternating current.
(Source: Delmar/Cengage Learning)

SUMMARY

- The diac is a bidirectional diode.
- The primary function of a diac is to phase shift a triac.
- The diac operates on AC.
- The diac operates like a voltage-sensitive AC switch.
- The diac displays a negative resistance characteristic.

KEY TERMS

bidirectional
diac

REVIEW QUESTIONS

1. Briefly explain how a diac operates.
2. Draw the two schematic symbols for the diac.
3. What is the major use of the diac in industry?
4. When a diac first turns on, does the voltage drop, remain at the same level, or increase to a higher level?

UNIT 56

The Triac

OBJECTIVES

After studying this unit the student should be able to:

- Draw the schematic symbol for a triac
- Discuss the similarities and differences between SCRs and triacs
- Discuss the operation of a triac in an AC circuit
- Discuss phase shifting of a triac
- Connect a triac in a circuit
- Test a triac with an ohmmeter

The triac is a PNPN junction connected in parallel with an **NPNP** junction. Figure 56–1 illustrates the semiconductor arrangement of a triac. The triac operates similar to two SCRs in parallel, facing in opposite directions with their gate leads connected together, Figure 56–2. The schematic symbol for the triac is shown in Figure 56–3.

When an SCR is connected in an AC circuit, the output voltage will be DC. When a triac is connected in an AC circuit, the output voltage will be AC. Since the triac operates like two SCRs connected together and facing in opposite directions, it will conduct both the positive and negative half cycles of AC current.

When a triac is connected in an AC circuit as shown in Figure 56–4, the gate must be connected to the same polarity as MT2. When the AC voltage applied to MT2 become positive, the SCR, which

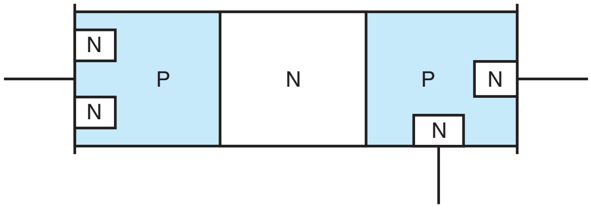

Figure 56–1
Semiconductor arrangement of a triac. (Source: Delmar/Cengage Learning)

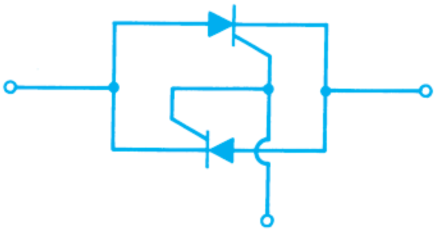

Figure 56–2
The triac operates similar to two SCRs with a common gate. (Source: Delmar/Cengage Learning)

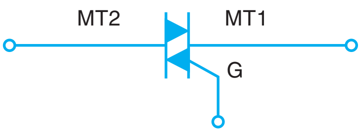

Figure 56–3
Schematic symbol of a triac. (Source: Delmar/Cengage Learning)

is forward biased, will conduct. When the voltage applied to MT2 becomes negative, the other SCR is forward biased and will conduct that half of the waveform. Since one of the SCRs is forward biased for each half cycle, the triac will conduct AC current as long as the gate lead is connected to MT2.

The triac, like the SCR, requires a certain amount of gate current to turn it on. Once the triac has been triggered by the gate, it will continue to conduct until the current flowing through MT2–MT1 drops below the holding current level.

THE TRIAC USED AS AN AC SWITCH

The triac is a member of the thyristor family and has only two states of operation, on or off. When the triac is turned off it will drop the full applied voltage of the circuit at 0 amps of current flow. When the triac is turned on, it has a voltage drop of about 1 volt and circuit current must be limited by the load connected to the circuit. The triac has become very popular in industrial circuits as an AC switch. Because it is a thyristor, it has the ability to control a large amount of voltage and current. There are no contacts to wear out, it is sealed against dirt and moisture, and it can operate thousands of times per second. The triac is used as the output of many solid-state relays that will be covered later.

THE TRIAC USED FOR AC VOLTAGE CONTROL

The triac can be used to control an AC voltage, Figure 56–5. If a variable resistor is connected in series with the gate, the point at which the gate current will reach a high enough level to fire the triac can be adjusted. The resistance can be adjusted to permit the triac to fire when the AC waveform reaches its peak value. This will cause half of the AC voltage to be dropped across the triac and half to be dropped across the load.

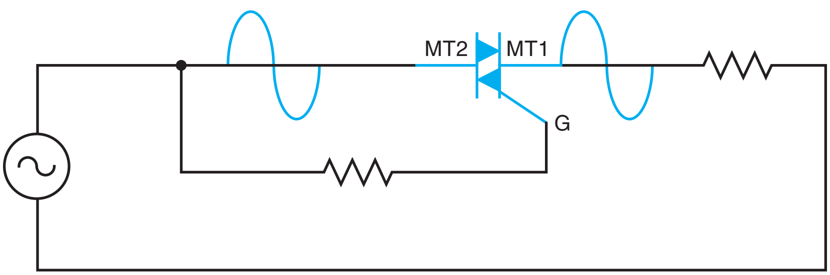

Figure 56–4
The triac will conduct both halves of the AC waveform. (Source: Delmar/Cengage Learning)

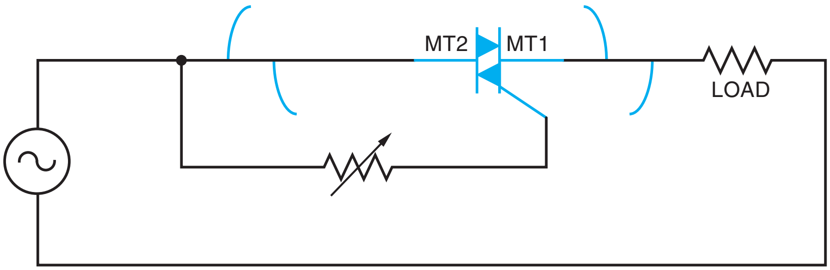

Figure 56–5 The triac controls half of the AC applied voltage. (Source: Delmar/Cengage Learning)

If the gate resistance is reduced, the amount of gate current needed to fire the triac will be obtained before the AC waveform reaches its peak value. This means that less voltage will be dropped across the triac and more voltage will be dropped across the load. This circuit permits the triac to control only one half of the AC waveform applied to it. If a lamp is used as the load, it can be controlled from half brightness to full brightness. If an attempt is made to adjust the lamp to operate at less than half brightness, it will turn off.

PHASE SHIFTING THE TRIAC

The triac, like the SCR, must be phase shifted if complete voltage control is to be obtained. There are several methods that can be used to phase shift a triac, but only one will be covered in this unit. In this example, a diac will be used to phase shift the triac, Figure 56–6. In this circuit, resistors R1 and R2 are connected in series with capacitor C1. Resistor R1 is a variable resistor and is used to control the charge time of capacitor C1. Resistor R2 is used to limit current if resistor R1 should be adjusted to 0 ohms. Assume the diac connected in series with the gate of the triac will turn on when capacitor C1 has been charged to 15 volts. When the diac turns on, capacitor C1 will discharge through the gate of the triac. This permits the triac to fire or turn on.

Once the triac has fired, there will be a voltage drop of about 1 volt across MT2 and MT1. The triac will remain turned on until the AC voltage drops to a low enough value to permit the triac to turn off. Since the phase shift circuit is connected in parallel with the triac, once the triac turns on capacitor C1 cannot begin charging again until the triac turns off at the end of the AC cycle. The diac, being a bidirectional device, will permit a positive or negative pulse to trigger the gate of the triac.

Notice that the pulse applied to the gate is controlled by the charging of capacitor C1 and not the amplitude of voltage. If the correct values are chosen, the triac can be fired at any point in the AC cycle applied to it. The triac can now control the AC voltage from 0 to the full voltage of the circuit.

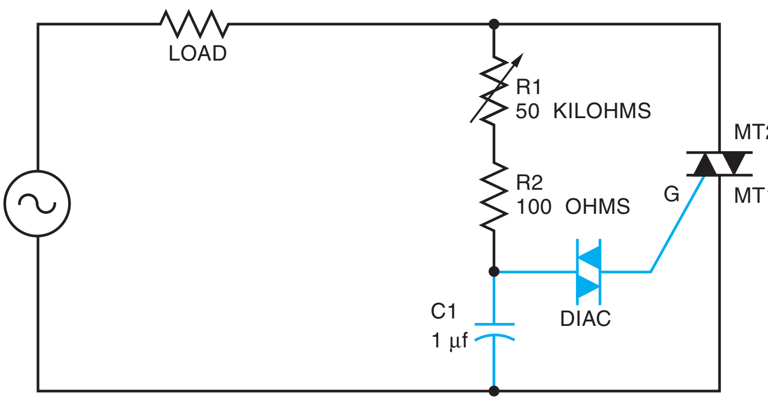

Figure 56–6 Phase-shift circuit for a triac. (Source: Delmar/Cengage Learning)

A common example of this type of triac circuit is the light dimmer control used in many homes.

TESTING THE TRIAC

The triac can be tested with an ohmmeter. To test the triac, connect the ohmmeter leads to MT2 and MT1. The ohmmeter should indicate no continuity. If the gate lead is touched to MT2, the triac should turn on and the ohmmeter will indicate continuity through the triac. When the gate lead is released from MT2, the triac may continue to conduct or turn off depending on whether the ohmmeter supplies enough current to keep the device above its holding current level. This tests one half of the triac. To test the other half of the triac, reverse the connection of the ohmmeter leads. The ohmmeter should again indicate no continuity. If the gate is touched again to MT2, the ohmmeter should indicate continuity through the device. The other half of the triac has been tested. The following step-by-step procedure can be used to test a triac.

1. Using a junction diode, determine which ohmmeter lead is positive and which is negative. The ohmmeter will indicate continuity only when the positive lead is connected to the anode and the negative lead is connected to the cathode, Figure 56–7.
2. Connect the positive ohmmeter lead to MT2 and the negative lead to MT1. The ohmmeter should indicate no continuity through the triac, Figure 56–8.
3. Using a jumper lead, connect the gate of the triac to MT2. The ohmmeter should indicate a forward diode junction, Figure 56–9.

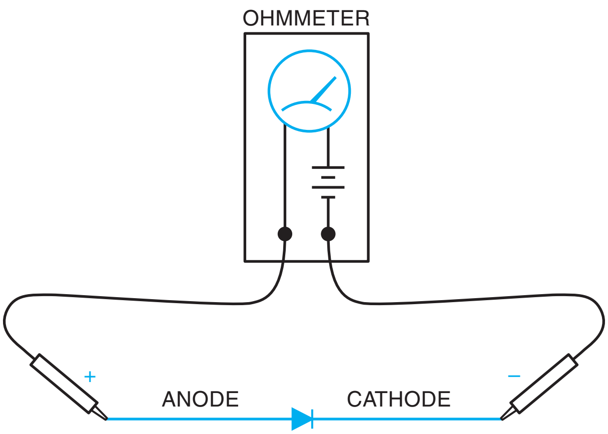

Figure 56–7
Determining ohmmeter polarity. (Source: Delmar/Cengage Learning)

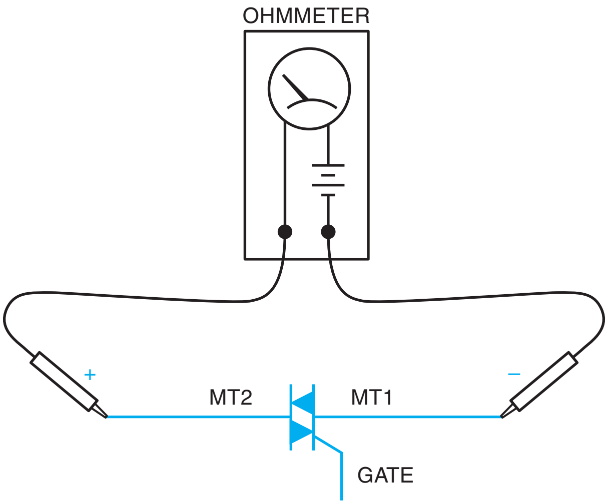

Figure 56–8
No continuity. (Source: Delmar/Cengage Learning)

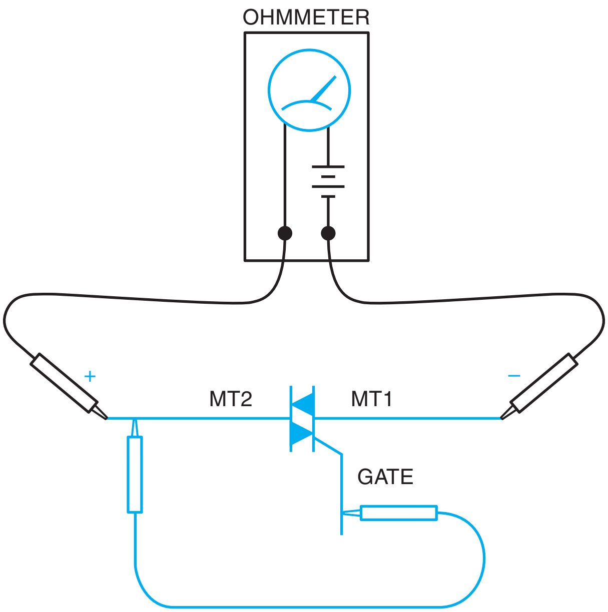

Figure 56–9
The triac will conduct when the gate is connected to MT2. (Source: Delmar/Cengage Learning)

4. Reconnect the triac so that MT1 is connected to the positive ohmmeter lead and MT2 is connected to the negative lead. The ohmmeter should indicate no continuity through the triac, Figure 56–10.
5. Using a jumper lead, again connect the gate to MT2. The ohmmeter should indicate a forward diode junction, Figure 56–11.

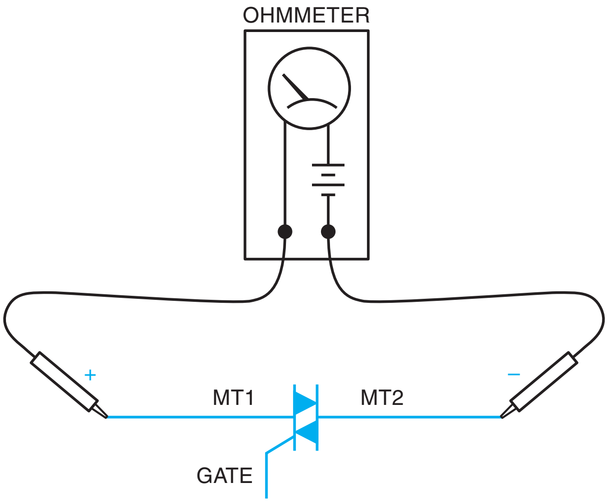

Figure 56–10
Reversing the polarity. (Source: Delmar/Cengage Learning)

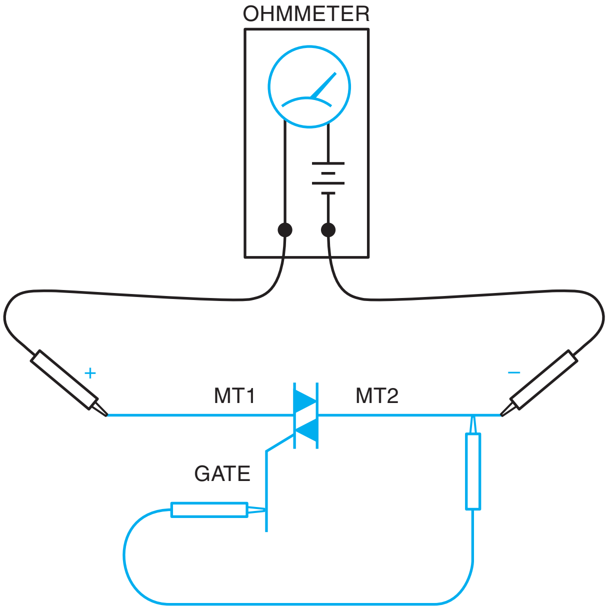

Figure 56–11
The triac will conduct with either polarity. (Source: Delmar/Cengage Learning)

SUMMARY

- The triac operates in a manner similar to two SCRs connected in opposite directions.
- The triac is a bidirectional device, which means that it will operate when connected to AC current.
- Triacs are often used as AC switches.
- A triac must be phase shifted to gain complete control of the AC waveform.
- A diac is often used to phase shift a triac.

KEY TERM

NPNP

REVIEW QUESTIONS

1. Draw the schematic symbol of a triac.
2. When a triac is connected in an AC circuit, is the output AC or DC?
3. The triac is a member of what family of devices?
4. Briefly explain why a triac must be phase shifted.
5. What electronic component is frequently used to phase shift the triac?
6. When the triac is being tested with an ohmmeter, which other terminal should the gate be connected to if the ohmmeter is to indicate continuity?

UNIT 57

The Operational Amplifier

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of the operational amplifier (op amp)
- List the major types of connection for the op amp
- Connect a level detector circuit for an op amp
- Connect an oscillator using an op amp

The **operational amplifier** has become another very common component found in industrial electronic circuits. The operational amplifier, or **op amp** as it is generally referred to, is used in hundreds of different applications. There are different types of op amps used, depending on the type of circuit it is intended to operate in. Some op amps use **bipolar transistors** for the input and others use **field effect transistors**. The advantage of using field effect transistors is their extremely high input impedance, which can be several thousand megohms. The advantage of this extremely high input impedance is that it does not require a large amount of current to operate the amplifier. In fact, op amps, which use FET inputs, are generally considered as requiring no input current.

THE IDEAL AMPLIFIER

Before continuing the discussion of op amps, it should first be decided what an ideal amplifier is. First, the ideal amplifier should have an input impedance of infinity. If the amplifier had an input impedance of infinity, it would require no power drain on the signal source being amplified. Therefore, regardless of how weak the input signal source is, it would not be affected when connected to the amplifier. The ideal amplifier would have 0 output impedance. If the amplifier had 0 output impedance it could be connected to any load resistance desired and not drop any voltage inside the amplifier. If it had no internal voltage drop, the amplifier would utilize 100% of its gain. Third, the amplifier would have unlimited **gain**. This would permit it to amplify any input signal as much as desired.

741 PARAMETERS

There is no such thing as the ideal or perfect amplifier of course, but the op amp can come close. One of the old reliable op amps, which is still used to a large extent, is the 741. The 741 will be used in this description as a typical operational amplifier. Please keep in mind that there are other op amps that have different characteristics of input and output impedance, but the basic theory of operation is the same for all of them.

The 741 op amp uses bipolar transistors for the input. The input impedance is about 2 megohms, and the output impedance is about 75 ohms. Its open loop or maximum gain is about 200,000. Actually, the 741 op amp has such a high gain that it is generally impractical to use and negative feedback, which will be discussed later, is used to reduce the gain. For instance, assume the amplifier has an output voltage of 15 volts. If the input signal voltage is greater than 1/200,000 of the output voltage or 75 microvolts (15/200,00 = .000075), the amplifier would be driven into saturation at which point it would not operate.

741 PIN CONNECTION

The 741 operational amplifier is generally housed in an 8-pin in-line IC package, Figure 57–1, Pins #1 and #5 are connected to the **offset null**. The offset null is used to produce 0 volts at the output. What happens is this: The op amp has two inputs called the **inverting input** and the **noninverting input**. These inputs are connected to a differential amplifier that amplifies the difference between the two voltages. If both of these inputs are connected to the same voltage, say by grounding both inputs, the output should be 0 volts. In actual practice, however, there are generally unbalanced conditions in the op amp that cause a voltage to be produced at the output. Because the op amp has a very high gain, a very slight imbalance of a few microvolts at the input can cause several millivolts at the output. The offset nulls are adjusted after the 741 is connected into a working circuit. Adjustment is made by connecting a 10K ohm potentiometer across pins #1 and #5, and connecting the wiper to the negative voltage, Figure 57–2.

Pin #2 is the inverting input. If a signal is applied to this input, the output will be inverted. For instance, if a positive-going AC voltage is applied

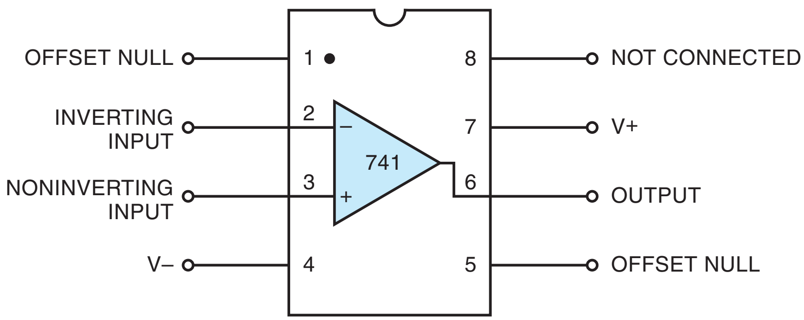

Figure 57–1
741 operational amplifier.
(Source: Delmar/Cengage Learning)

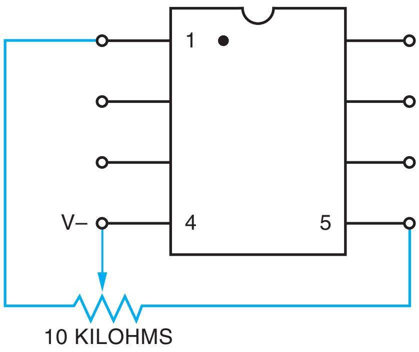

Figure 57–2
Offset null connection. (Source: Delmar/Cengage Learning)

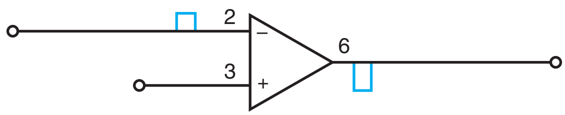

Figure 57–3
Inverted output. (Source: Delmar/Cengage Learning)

to the inverting input, the output will produce a negative-going voltage, Figure 57–3.

Pin #3 is the noninverting input. When a signal voltage is applied to the noninverting input, the output voltage will be the same polarity. If a positive-going AC signal is applied to the noninverting input, the output voltage will be positive also, Figure 57–4.

Pins #4 and #7 are the voltage input pins. Operational amplifiers are generally connected to above- and below-ground power supplies. These power supplies produce both a positive and negative voltage as compared to ground. There are some circuit connections that do not require an above- and below-ground power supply, but these are the

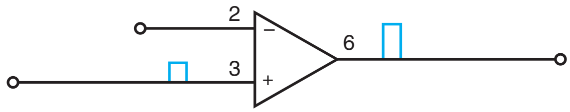

Figure 57–4
Noninverted output. (Source: Delmar/Cengage Learning)

exception instead of the rule. Pin #4 is connected to the negative- or below-ground voltage and pin #7 is connected to the positive- or above-ground voltage. The 741 will operate on voltages that range from about 4 volts to 16 volts. Generally, the operating voltage for the 741 is 12 to 15 volts plus and minus. The 741 has a maximum power output rating of about 500 milliwatts. Pin #6 is the output and pin #8 is not connected.

NEGATIVE FEEDBACK

As stated previously, the open **loop** gain of the 741 operational amplifier is about 200,000. This amount of gain is not practical for most applications, so something must be done to reduce this gain to a reasonable level. One of the great advantages of the op amp is the ease with which the gain can be controlled, Figure 57–5. The amount of gain is controlled by a negative-feedback loop. This is accomplished by feeding a portion of the output voltage back to the inverting input. Since the output voltage is always opposite in polarity to the inverting input voltage, the amount of output voltage fed back to the input tends to reduce the input voltage. Negative feedback has two effects on the operation of the amplifier. One effect is that it reduces the gain. The other is that it makes the amplifier more stable.

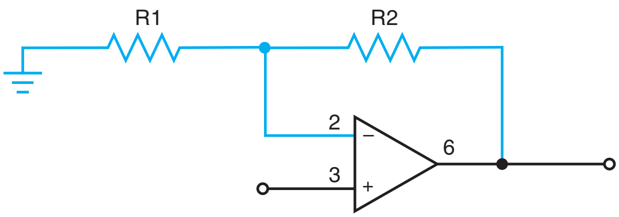

Figure 57–5
Negative feedback connection. (Source: Delmar/Cengage Learning)

The gain of the amplifier is controlled by the ratio of resistors R2 and R1. If a **noninverting amplifier** is used, the gain is found by the formula (R2 + R1)/R1. If resistor R1 is 1K ohms and resistor R2 is 10K ohms, the gain of the amplifier would be 11 (11,000 ÷ 1,000 = 11).

If the op amp is connected as an inverting amplifier, however, the input signal will be out of phase with the feedback voltage of the output. This will cause a reduction of the input voltage applied to the amplifier and a reduction in gain. The formula (R2/R1) is used to compute the gain of an **inverting amplifier**. If resistor R1 is 1K ohms and resistor R2 is 10K ohms, the gain of the inverting amplifier would be 10 (10,000 ÷ 1,000 = 10).

There are some practical limits, however. As a general rule, the 741 operational amplifier is not operated above a gain of about 100. If more gain is desired, it is generally obtained by using more than one amplifier, Figure 57–6.

As shown in Figure 57–6, the output of one amplifier is fed into the input of another amplifier. The reason for not operating the 741 at high gain is that at high gains it tends to become unstable. Another general rule for operating the 741 op amp is the total feedback resistance (R1 + R2) is usually kept more than 1,000 ohms and less than 100,000 ohms. These general rules apply to the 741 operational amplifier and may not apply to other operational amplifiers.

BASIC CIRCUIT CONNECTIONS

Op amps are generally used in three basic ways. This is not to say that op amps are used in only three circuits, but that there are three basic circuits that are used to build other circuits. One of these basic circuits is the **voltage follower**. In this circuit, the output of the op amp is connected directly back to the inverting input, Figure 57–7. Because there is a direct connection between the output of the amplifier and the inverting input, the gain of this circuit is 1. For instance, if a signal voltage of .5 volts is connected to the noninverting input, the output voltage will be .5 volts also. You may wonder why anyone would want an amplifier that does not amplify. Actually, this circuit does amplify something. It amplifies the input impedance by the amount of the open loop gain. If the 741 has an open loop gain of 200,000 and an input impedance of 2 megohms, this circuit would give the amplifier an input impedance of 200K × 2 megohms or 400,000 megohms. This circuit connection is generally used for impedance matching purposes.

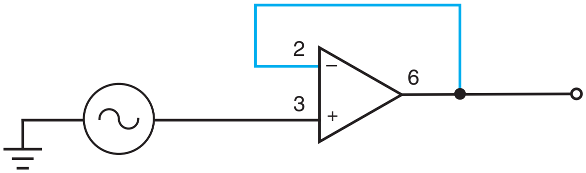

Figure 57–7
Voltage follower connection. (Source: Delmar/Cengage Learning)

The second basic circuit is the noninverting amplifier, Figure 57–8. In this circuit, the output voltage is the same polarity as the input voltage. If the input voltage is a positive-going voltage, the output will be a positive-going voltage at the same time. The amount of gain is set by the ratio of resistors R1 + R2/R1 in the negative feedback loop.

The third basic circuit is the inverting amplifier, Figure 57–9. In this circuit the output voltage will be opposite in polarity to the input voltage. If the

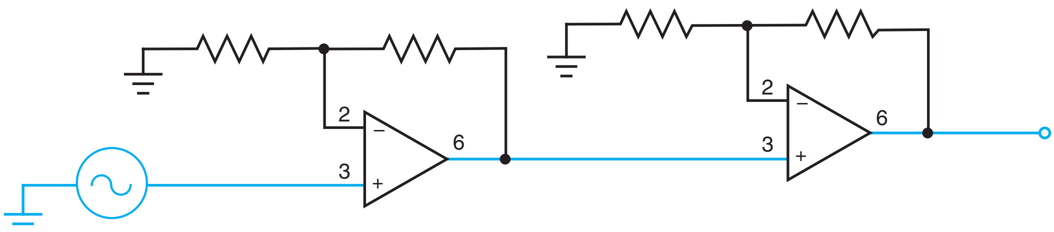

Figure 57–6
Increasing the gain. (Source: Delmar/Cengage Learning)

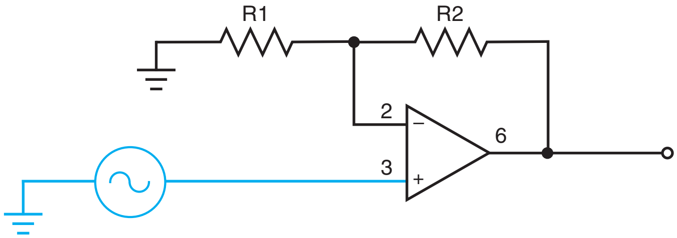

Figure 57–8
Noninverting amplifier connection. (Source: Delmar/Cengage Learning)

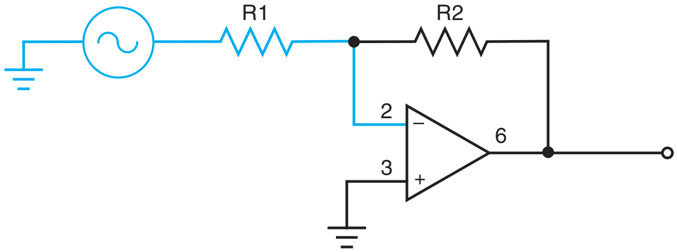

Figure 57–9
Inverting amplifier connection. (Source: Delmar/Cengage Learning)

input signal is a positive-going voltage, the output voltage will be negative-going at the same instant in time. The gain of the circuit is determined by the ratio of resistors R2 and R1.

CIRCUIT APPLICATIONS

The Level Detector

The operational amplifier is often used as a **level detector** or comparator. In this type of circuit, the 741 op amp will be used as an inverted amplifier to detect when one voltage becomes greater than another. Refer to the circuit shown in Figure 57–10. Notice that this circuit does not use an above- and below-ground power supply. Instead it is connected to a power supply with a single positive and negative output. During normal operation, the noninverting input of the amplifier is connected to a zener diode. This zener diode produces a constant positive voltage at the noninverting input of the amplifier, which is used as a reference. As long as the noninverting input is more positive than the inverting input, the output of the amplifier will be high. A light-emitting diode, D1, will be used to detect a change in the polarity of the output. As long as the output of the op amp remains high, the LED will be turned off. When the output of the amplifier is high, the LED has equal voltage applied to both its anode and cathode. Since both the anode

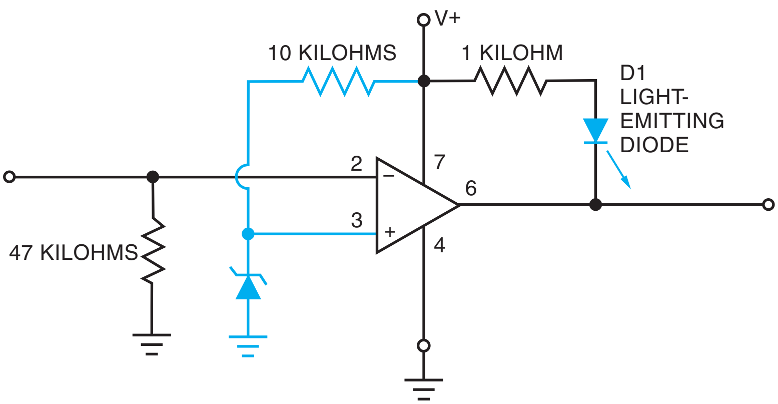

Figure 57–10
Inverting level detector. (Source: Delmar/Cengage Learning)

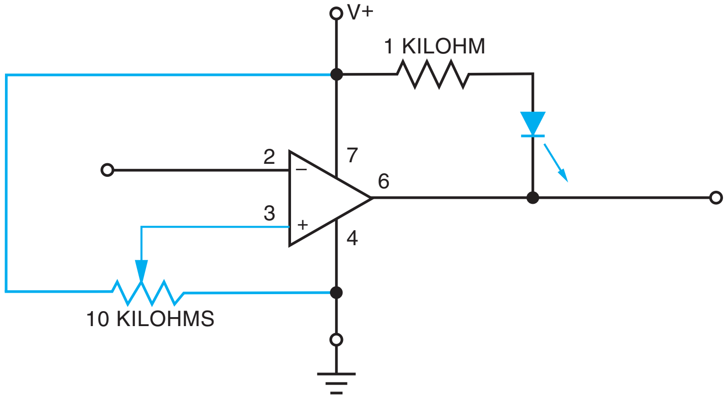

Figure 57–11
Adjustable inverting level detector. (Source: Delmar/Cengage Learning)

and cathode are connected to +12 volts, there is no potential difference and therefore no current flow through the LED.

If the voltage at the inverting input should become more positive than the reference voltage applied to pin #3, the output voltage will go low. The low voltage at the output will be about +2.5 volts. The output voltage of the op amp will not go to 0 or ground in this circuit because the op amp is not connected to a voltage that is below ground. If the output voltage is to be able to go to 0 volts, pin #4 must be connected to a voltage that is below ground. When the output is low there is a potential of about 9.5 volts ($12 - 2.5 = 9.5$) produced across R1 and D1, which causes the LED to turn on and indicate that the state of the op amp's output has changed from high to low.

In this type of circuit, the op amp appears to be a digital device in that the output seems to have only two states, high or low. Actually, the op amp is not a digital device. This circuit only makes it appear digital. Notice there is no negative feedback loop connected between the output and the inverting input. Therefore, the amplifier uses its open loop gain, which is about 200,000 for the 741, to amplify the voltage difference between the inverting input and the noninverting input. If the voltage applied to the inverting input should become 1 millivolt more positive than the reference voltage applied to the noninverting input, the amplifier will try to produce an output that is 200 volts more negative than its high-state voltage ($.001 \times 200{,}000 = 200$). The output voltage of the amplifier cannot be driven 200 volts more negative, of course, because there is only 12 volts applied to the circuit, so the output voltage simply reaches the lowest voltage it can and then goes into saturation. The op amp is not a digital device, but it can be made to act like one.

If the zener diode is replaced with a voltage divider, as shown in Figure 57–11, the reference voltage can be set to any value desired. By adjusting the variable resistor shown in Figure 57–11, the positive voltage applied to the noninverting input can be set for any voltage value desired. For instance, if the voltage at the noninverting input is set for 3 volts, the output of the op amp will go low when the voltage applied to the inverting input becomes greater than +3 volts. If the voltage at the noninverting input is set for 8 volts, the output voltage will go low when the voltage applied to the inverting input becomes greater than +8 volts. Notice that this circuit permits the voltage level at which the output of the op amp will change to be adjusted.

In the two circuits just described, the op amp changed from a high level to a low level when activated. There may be occasions, however, when it is desired that the output be changed from a low level to a high level. This can be accomplished by connecting the inverting input to the reference voltage and connecting the noninverting input to the voltage being sensed, Figure 57–12. In this circuit, the zener diode is used to provide a positive reference voltage to the inverting input. As long as the voltage at the inverting input remains more positive than the voltage at the noninverting input, the output voltage of the op amp will remain low. If the voltage applied to the noninverting input should become more positive than the reference voltage, the output of the op amp will become high.

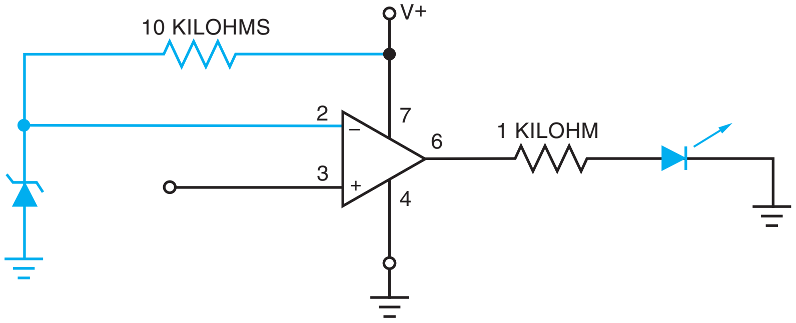

Figure 57–12
Noninverting level detector.
(Source: Delmar/Cengage Learning)

Depending on the application, this circuit could cause a small problem. As stated previously, since this circuit does not use an above- and below-ground power supply, the low output voltage of the op amp will be about +2.5 volts. This positive output voltage could cause any other devices connected to the op amp's output to be turned on even if it should be turned off. For instance, if the LED shown in Figure 57–12 was used, it would glow dimly even when the output is in the low state. This problem can be corrected in a couple of different ways. One way would be to connect the op amp to an above- and below-ground power supply as shown in Figure 57–13.

In this circuit, the output voltage of the op amp will be negative or below ground as long as the voltage applied to the inverting input is more positive than the voltage applied to the noninverting input. As long as the output voltage of the op amp is negative with respect to ground, the LED is reverse biased and cannot operate. When the voltage applied to the noninverting input becomes more positive than the voltage applied to the inverting input, the output of the op amp will become positive and the LED will turn on.

The second method of correcting the output voltage problem is shown in Figure 57–14. In this circuit, the op amp is connected to a power supply that has a single positive and negative output as before. A zener diode, D2, has been connected in series with the output of the op amp and the LED. The voltage value of diode D2 is greater than the output voltage of the op amp in the low state, but less than the output voltage of the op amp in its high state. For example, assume the value of the zener diode D2 is 5.1 volts. If the output voltage of the op amp in its low state is 2.5 volts, diode D2 is turned off and will not conduct. If the output voltage becomes +12 volts when the op amp switches to its high state, the zener diode will turn on and conduct current to the LED. Notice that the zener diode D2 keeps the LED turned completely off until the op amp switches to its high state and provides enough voltage to overcome the reverse voltage drop of the zener diode.

In the preceding circuits, an LED was used to indicate the output state of the amplifier. Keep in mind that the LED is used only as a detector, and

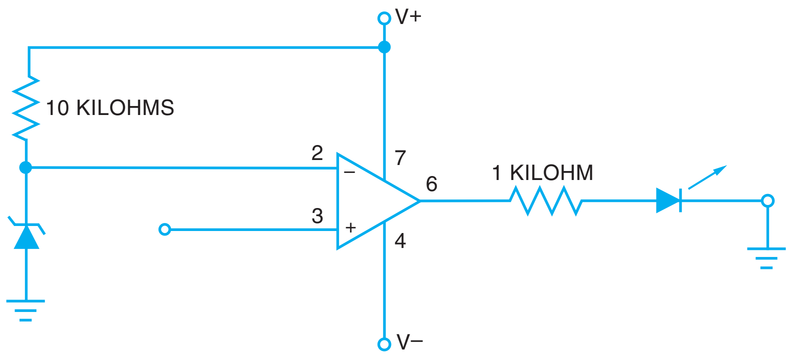

Figure 57–13
Below-ground power connection permits the output voltage to become negative. (Source: Delmar/Cengage Learning)

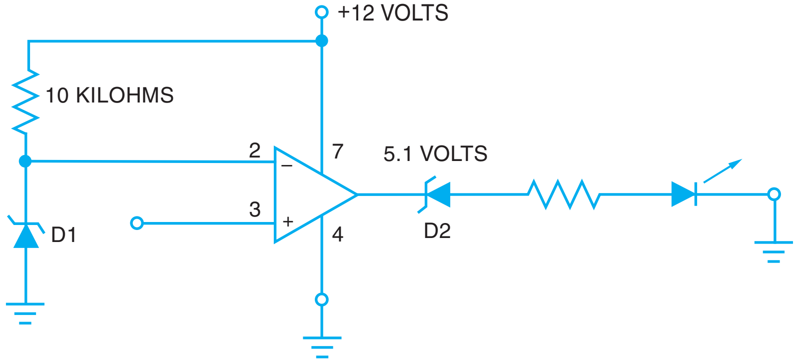

Figure 57–14
A zener diode is used to keep the output turned off. (Source: Delmar/Cengage Learning)

the output of the op amp could be used to control almost anything. For example, the output of the op amp can be connected to the base of a transistor as shown in Figure 57–15. The transistor can then control the coil of a relay, which could be used to control almost anything.

The Oscillator

An operational amplifier can be used as an **oscillator**. The circuit shown in Figure 57–16 is a very simple circuit that will produce a square wave output. This circuit is rather impractical, however. This circuit would depend on a slight imbalance in the op amp or random circuit noise to start the oscillator. A slight voltage difference of a few millivolts between the two inputs is all that is needed to cause the output of the amplifier to go high or low. For example, if the inverting input becomes slightly more positive than the noninverting input, the output will go low or negative. When the output becomes negative, capacitor Ct begins to charge through resistor Rt to the negative value of the output voltage. As soon as the voltage applied to the inverting input becomes slightly more negative than the voltage applied to the noninverting input, the output will change to a high or positive value of voltage. When the output becomes positive, capacitor Ct begins charging through resistor Rt toward the positive output voltage. This circuit will work quite well if the op amp has no imbalance, and if the op amp is shielded from all electrical noise. In practical application, however, there is generally enough imbalance in the amplifier or enough electrical noise to send the op amp into saturation, which stops the operation of the circuit.

The Hysteresis Loop

The problem with this circuit is that a millivolt difference between the two inputs is enough to drive the amplifier's output from one state to the other. This problem can be corrected by the addition of a **hysteresis loop** connected to the noninverting

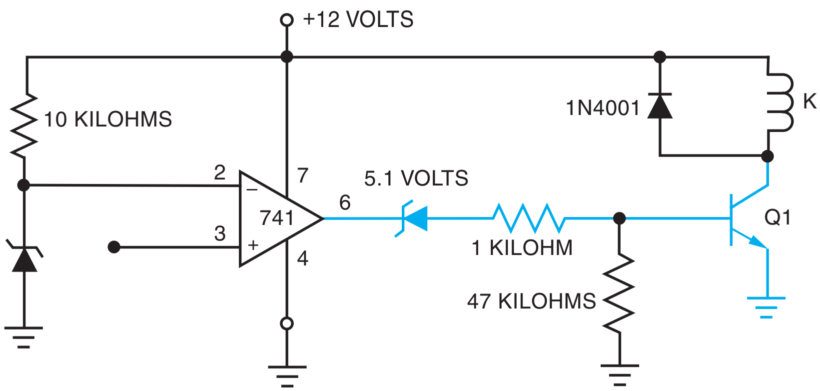

Figure 57–15
Controlling a relay with an op amp. (Source: Delmar/Cengage Learning)

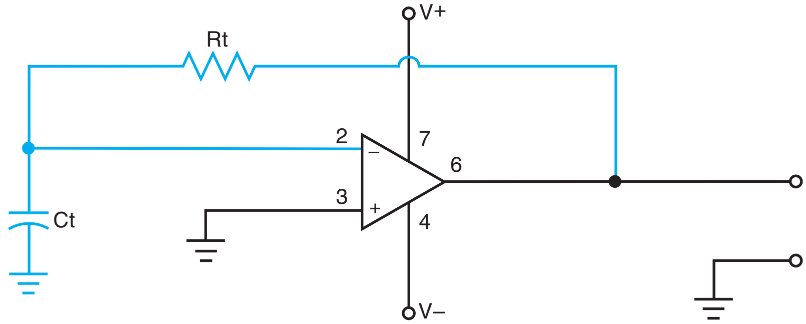

Figure 57–16
Simple square wave oscillator.
(Source: Delmar/Cengage Learning)

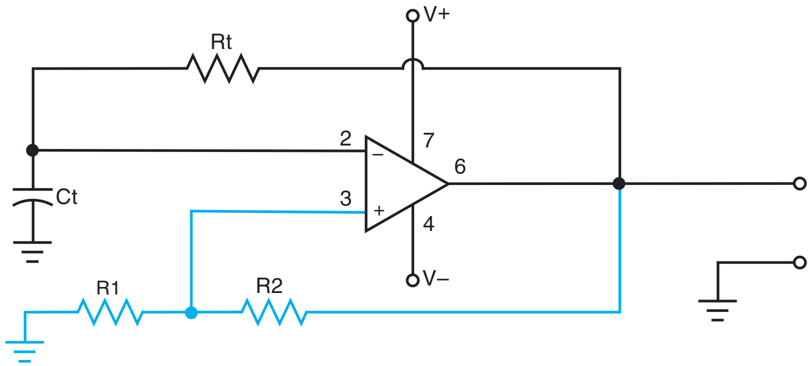

Figure 57–17
Square wave oscillator using a hysteresis loop. (Source: Delmar/Cengage Learning)

input as shown in Figure 57–17. Resistors R1 and R2 form a voltage divider for the noninverting input. These resistors are generally of equal value. To understand the circuit operation, assume that the inverting input is slightly more positive than the noninverting input. This causes the output voltage to go negative. Also assume that the output voltage is now negative 12 volts as compared with ground. If resistors R1 and R2 are of equal value, the noninverting input is driven to –6 volts by the voltage divider. Capacitor Ct begins to charge through resistor Rt to the value of the output voltage. When capacitor Ct has been charged to a value slightly more negative than the −6 volts applied to the noninverting input, the op amp's output goes high or to +12 volts above ground. When the output of the op amp changes from −12 volts to +12 volts, the voltage applied to the noninverting input changes from −6 volts to +6 volts. Capacitor Ct now begins to charge through resistor Rt to the positive voltage of the output. When the voltage applied to the inverting input becomes more positive than the voltage applied to the noninverting input, the output changes to a low value or −12 volts. The voltage applied to the noninverting input is driven from +6 volts to −6 volts, and capacitor Ct again begins to charge toward the negative output voltage of the op amp. Notice that the addition of the hysteresis loop has greatly changed the operation of the circuit. The voltage differential between the two inputs is now volts instead of millivolts. The output frequency of the oscillator is determined by the values of Ct and Rt. The period of one cycle can be computed by using the formula ($T = 2RC$).

The Pulse Generator

The operational amplifier can also be used as a **pulse generator**. The difference between an oscillator and a pulse generator is the period of time the output remains on as compared to the period of time it remains low or off. An oscillator is generally considered to produce a waveform that has positive and negative pulses of equal voltage and time, Figure 57–18. Notice that the positive value of voltage is the same as the negative value. Also notice

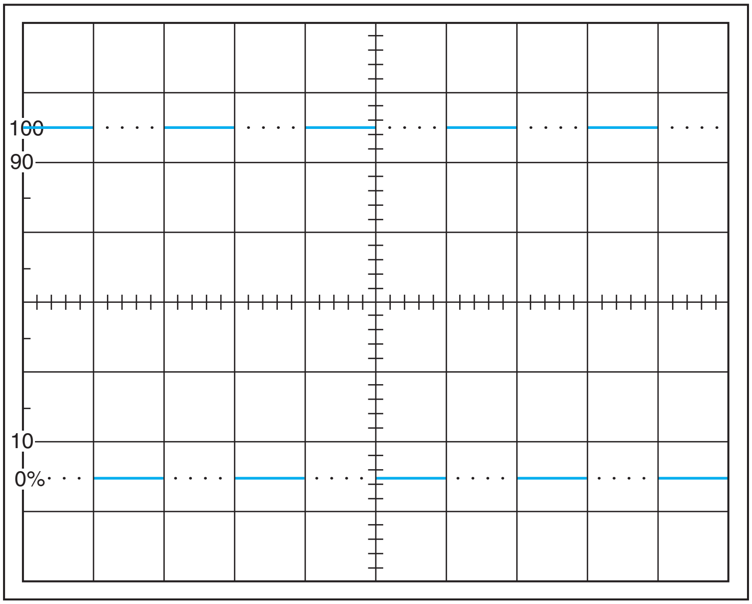

Figure 57–18
Output of an oscillator. (Source: Delmar/Cengage Learning)

that both the positive and negative cycles remain turned on the same amount of time. This waveform is consistent with that which one would expect to see if an oscilloscope is connected to the output of a square wave oscillator.

If the oscilloscope is connected to a pulse generator, however, a waveform similar to the one shown in Figure 57–19 would be seen. Notice that the positive value of voltage is the same as the negative value just as it was in Figure 57–18. However, the positive pulse is of a much shorter duration than the negative pulse. The device producing this waveform is generally considered to be a pulse generator rather than an oscillator.

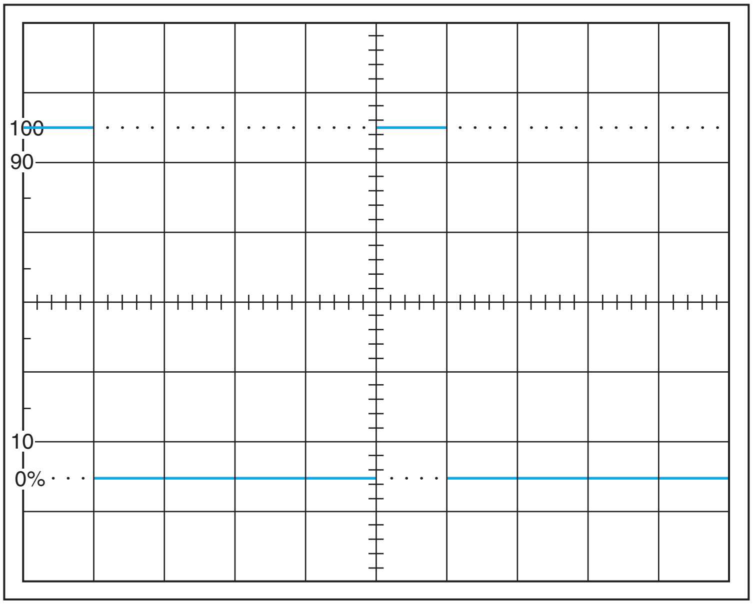

Figure 57–19
Output of a pulse generator.
(Source: Delmar/Cengage Learning)

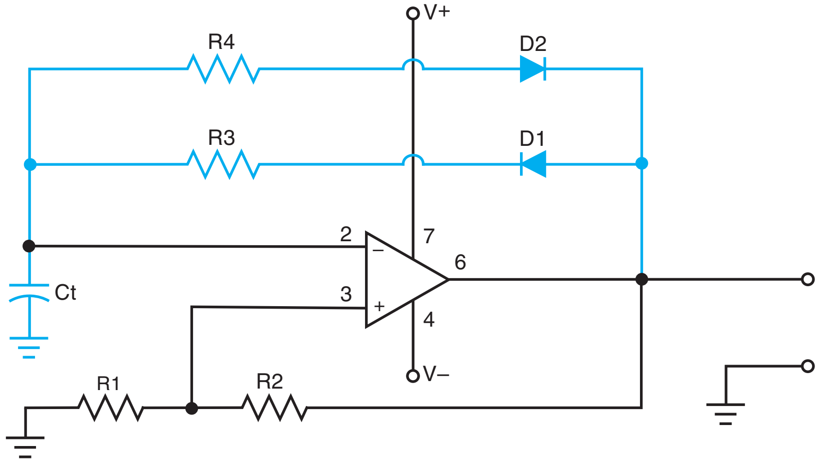

Figure 57–20
Pulse generator circuit. (Source: Delmar/Cengage Learning)

The 741 operational amplifier can easily be changed from a square wave oscillator to a pulse generator. Refer to the circuit shown in Figure 57–20. This is the same basic circuit as the square wave oscillator with the addition of resistor R3 and R4, and diodes D1 and D2. This circuit permits capacitor Ct to charge at a different rate when the output is high or positive than it does when the output is low or negative. For instance, assume that the voltage of the op amp's output is low or –12 volts. If the output voltage is negative, diode D1 is reverse biased and no current can flow through resistor R3. Therefore, capacitor Ct must charge through resistor R4 and diode D2, which is forward biased. When the voltage applied to the inverting input becomes more negative than the voltage applied to the noninverting input, the output voltage of the op amp becomes +12 volts. When the output voltage becomes +12 volts, diode D2 is reverse biased and diode D1 is forward biased. Capacitor Ct, therefore, begins charging toward the +12 volts through resistor R3 and diode D1. Notice that the amount of time the output of the op amp remains low is determined by the value of Ct and R4, and the amount of time the output remains high is determined by the value of Ct and R3. The ratio of time the output voltage is high compared to the amount of time it is low can be determined by the ratio of resistor R3 to resistor R4. A 741 operational amplifier is shown in Figure 57–21.

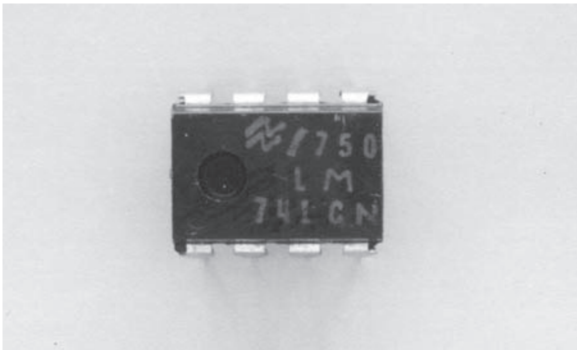

Figure 57–21
741 operational amplifier in an eight-pin in-line case. (Source: Delmar/Cengage Learning)

SUMMARY

- Some op amps use bipolar transistors for the inputs and other use field effect transistors for the inputs.
- The 741 operational amplifier has an input impedance of about 2 megohms.
- The 741 op amp has an output impedance of about 75 ohms.
- The 741 operational amplifier has an open loop, or maximum gain, of about 200,000.
- Op amps have two input connections called the inverting and noninverting inputs.
- If the noninverting input is more positive than the inverting input, the output voltage will be positive with respect to ground.
- If the inverting input is more positive than the noninverting input, the output voltage will be negative with respect to ground.
- Operational amplifiers are generally connected to above- and below-ground power supplies.
- Negative feedback is used to reduce the gain of operational amplifiers.
- The voltage follower connection produces a gain of 1, but increases the input impedance.
- Inverting amplifiers produce an output waveform that is inverted or opposite that of the input.
- Noninverting amplifiers produce an output waveform that is the same as the input.

KEY TERMS

bipolar transistors
field effect transistor
gain
hysteresis loop
inverting amplifier
inverting input
level detector
loop
noninverting amplifier
noninverting input
offset null
operational amplifier (op amp)
oscillator
pulse generator
voltage follower

REVIEW QUESTIONS

1. When the voltage connected to the inverting input is more positive than the voltage connected to the noninverting input, will the output be positive or negative?
2. What is the input impedance of a 741 operational amplifier?
3. What is the average open loop gain of the 741 operational amplifier?
4. What is the average output impedance of the 741?
5. List the three common connections for operational amplifiers.
6. When the operational amplifier is connected as a voltage follower, it has a gain of one. If the input voltage does not get amplified, what does?
7. Name two effects of negative feedback.

8. Refer to Figure 57–8. If resistor R1 is 200 ohms, the resistor R2 is 10K ohms, what is the gain of the amplifier?
9. Refer to Figure 57–9. If resistor R1 is 470 ohms and resistor R2 is 47K ohms, what is the gain of the amplifier?
10. What is the purpose of the hysteresis loop when the op amp is used as an oscillator?

SECTION 9

Solid-State Controls

UNIT 58

Programmable Logic Controllers

OBJECTIVES

After studying this unit the student should be able to:

- List the principal parts of a programmable controller
- Describe the differences between programmable controllers and other types of computers
- Discuss differences between the I/O rack, CPU, and program loader
- Draw a diagram of how the input and output modules work

Programmable logic controllers (PLCs) were first used by the automotive industry in the late 1960s. Each time a change was made in the design of an automobile it was necessary to change the control system operating the machinery. This consisted of physically rewiring the control system to make it perform the new operation. Rewiring the system was, of course, very time consuming and expensive. What the industry needed was a control system that could be changed without the extensive rewiring required to change relay control systems.

DIFFERENCES BETWEEN PLCS AND PCS

One of the first questions generally asked is, "Is a programmable logic controller a computer?" The answer to that question is yes. The PLC is a special type of computer designed to perform a special function. Although the programmable logic controller (PLC) and the personal computer (PC) are both computers, there are some significant differences. Both generally employ the same basic type of computer and memory chips to perform the tasks for which they are intended, but the PLC must operate in an industrial environment. Any computer that is intended for industrial use must be able to withstand extremes of temperature; ignore voltage spikes and drops on the power line; survive in an atmosphere that often contains corrosive vapors, oil, and dirt; and withstand shock and vibration.

Programmable logic controllers are designed to be programmed with schematic or ladder diagrams instead of common computer languages. An electrician who is familiar with ladder logic diagrams can generally learn to program a PLC in a few hours as opposed to the time required to train a person how to write programs for a standard computer.

BASIC COMPONENTS

Programmable logic controllers can be divided into four primary parts:

1. The power supply.
2. The central processing unit (CPU).
3. The programming terminal or program loader.
4. The I/O (pronounced eye-oh) rack.

The Power Supply

The function of the **power supply** is to lower the incoming AC voltage to the desired level, rectify it to direct current, and then filter and regulate it. The internal logic of a PLC generally operates on 5 to 24 volts DC depending on the type of controller. This voltage must be free of voltage spikes and other electrical noise and be regulated to within 5% of the required voltage value. Some manufacturers of PLCs build a separate power supply and others build the power supply into the central processing unit.

The CPU

The **CPU**, or **central processing unit**, is the "brains" of the programmable logic controller. It contains the microprocessor chip and related integrated circuits to perform all the logic functions. The microprocessor chip used in most PLCs is the same as that found in most home and business personal computers.

The central processing unit often has a key located on the front panel, Figure 58–1. This switch must be turned on before the CPU can be programmed. This is done to prevent the circuit from being changed or deleted accidentally. Other manufacturers use a *software switch* to protect the circuit. A software switch is not a physical switch. It is a command that must be entered before the program can be changed or deleted. Whether a physical switch or a software switch is used, they both perform the same function.

Figure 58–1
A central processing unit. (Courtesy of Allen-Bradley, a Rockwell International Company).

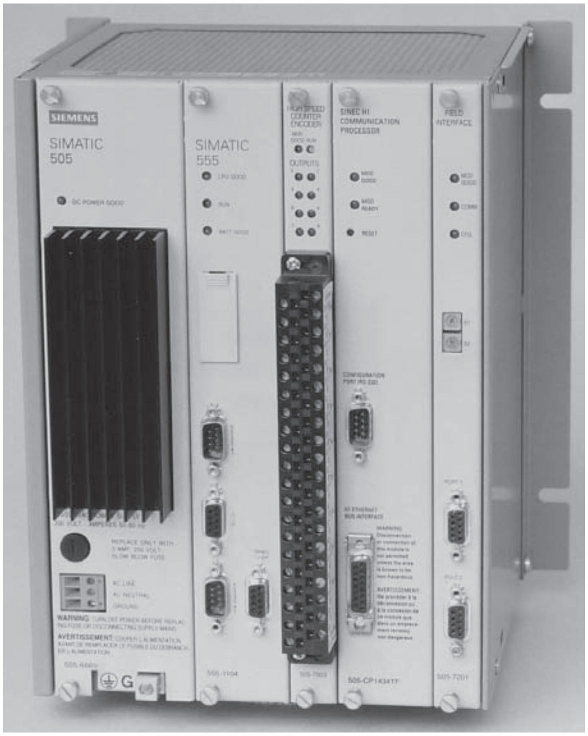

Figure 58–2
Plug connections located on the CPU. (Courtesy of Siemens Energy and Automation, Inc.).

They prevent a program from being accidentally changed or deleted.

Plug connections on the central processing unit provide connection for the programming terminal and I/O racks, Figure 58–2. CPUs are designed so that once a program has been developed and tested it can be stored on some type of medium such as tape, disk, CD, or other storage device. In this way, if a central processor unit fails and has to be replaced, the program can be downloaded from the storage medium. This eliminates the time-consuming process of having to reprogram the unit by hand.

The Programming Terminal

The **programming terminal** or **loading terminal** is used to program the CPU. The type of terminal used depends on the manufacturer and often the preference of the consumer. Some are small handheld devices that use a liquid crystal display or light-emitting diodes to show the program, Figure 58–3. Some of these small units will display one line of the program at a time and others require the program to be entered in a language called Boolean.

Another type of programming terminal contains a display and keyboard, Figure 58–4. This type of terminal generally displays several lines of the program at a time and can be used to observe the operation of the circuit as it is operating.

Many industries prefer to use a notebook or laptop computer for programming, Figure 58–5. An interface that permits the computer to be connected to the input of the PLC and software program is generally available from the manufacturer of the programmable logic controller.

The terminal is used not only to program the PLC but also to troubleshoot the circuit. When the terminal is connected to the CPU, the circuit can be examined while it is in operation. Figure 58–6 illustrates a circuit typical of those which are seen on the display. Notice that this schematic diagram is different from the typical ladder diagram. All of the line components are shown as normally open or normally closed contacts. There are no NEMA symbols for pushbutton, float switch, limit switches, and so on. The programmable logic controller recognizes only open or closed contacts. It does not know if a contact is connected to a pushbutton, a limit switch, or a float switch. Each contact, however, does have a number. The number is used to distinguish one contact from another.

In this example, coil symbols look like a set of parentheses instead of a circle as shown on most ladder diagrams. Each line ends with a coil and each coil has a number. When a contact symbol has the same number as a coil, it means that the contact is controlled by that coil. The schematic in Figure 58–6 shows a coil numbered 257 and two contacts numbered 257. When coil 257 is energized, the programmable logic controller interprets both contacts 257 to be closed.

A characteristic of interpreting a diagram when viewing it on the screen of most loading terminals is that when a current path exists through a contact or if a coil is energized they will be highlighted on the display. In the example shown in Figure 58–6, coil 257, both 257 contacts, contact 16, and contact

Figure 58–3
Small programmable controller and handheld programming unit. (Source: Delmar/Cengage Learning)

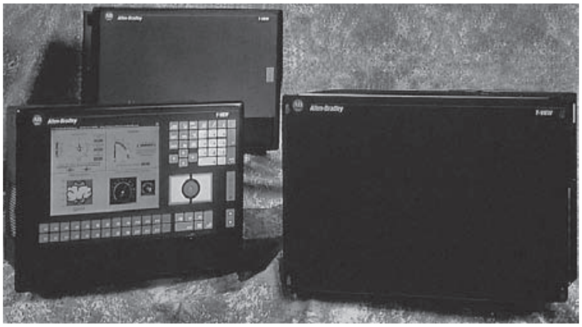

Figure 58–4
Programming terminal. (Courtesy of Allen-Bradley, a Rockwell International Company).

Figure 58–5
A notebook computer is often used as the programming terminal for a PLC. (Courtesy of Dell Computers).

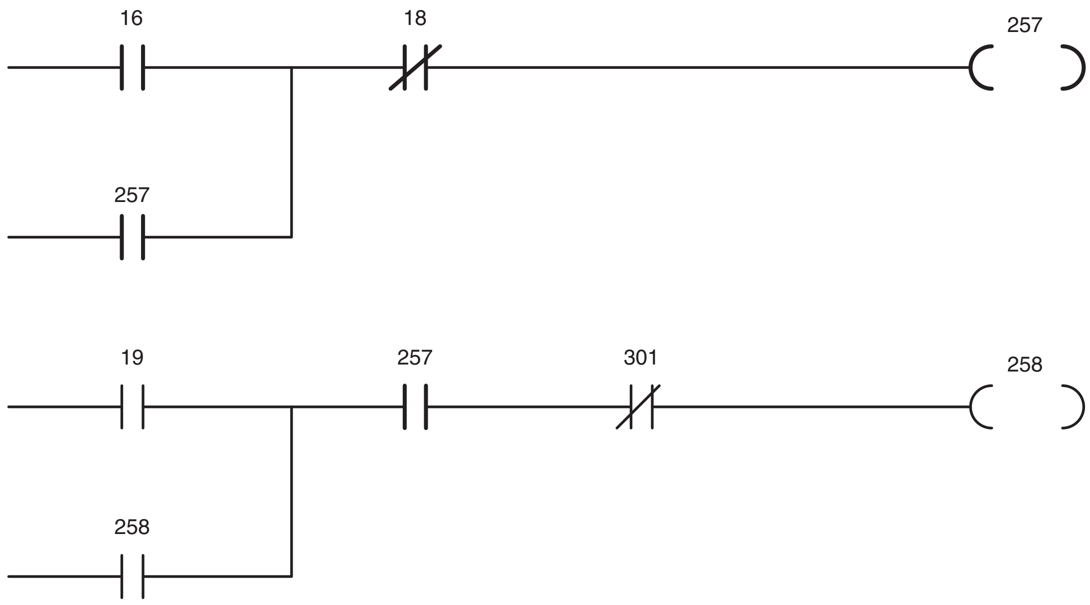

Figure 58–6
Analyzing circuit operation with a terminal. (Source: Delmar/Cengage Learning)

18 are drawn with dark heavy lines, illustrating that they are highlighted or **illuminated** on the display. Highlighting a contact does not means that it has changed from its original state. It means that there is a complete circuit through that contact. Contact 16 is highlighted, indicating that coil 16 has energized and contact 16 is closed and providing a complete circuit. Contact 18, however, is shown as normally closed. Because it is highlighted, coil 18 has not been energized because a current path still exists through contact 18. Coil 257 is shown highlighted, indicating that it is energized. Because coil 257 is energized, both 257 contacts are now closed, providing a current path through them.

When the loading terminal is used to load a program into the PLC, contact and coil symbols on the keyboard are used, Figure 58–7. Other keys permit specific types of relays, such as timers, counters, or retentive relays to be programmed into the logic of the circuit. Some keys permit parallel paths, generally referred to as down rungs, to be started and ended. The method employed to program a PLC is specific to the make and model of the controller. It is generally necessary to consult the manufacturer's literature if you are not familiar with the specific programmable logic controller.

The I/O Rack

The **I/O rack** is used to connect the CPU to the outside world. It contains input modules that carry information from control sensor devices to the CPU and output modules that carry instructions from the CPU to output devices in the field. I/O racks are shown in Figures 58–8A and 58–8B. Input and output modules contain more than one input or output. Any number from 4 to 32 is common, depending on the manufacturer and model of PLC. The modules shown in Figure 58–8A can each handle 16 connections. This means that each input module can handle 16 different input devices such as pushbutton, limit switches, proximity switches, float switches, and so on. The output modules can each handle 16 external devices such as pilot lights, solenoid coils, or relay coils. The operating voltage can be either alternating or direct current, depending on the manufacturer and model of controller, and is generally either 120 or 24 volts.

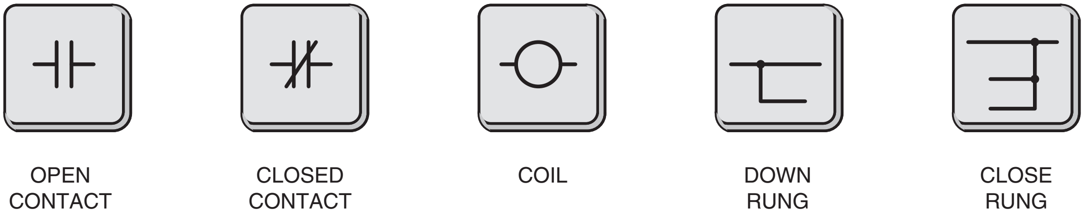

Figure 58–7
Symbols are used to program the PLC. (Source: Delmar/Cengage Learning)

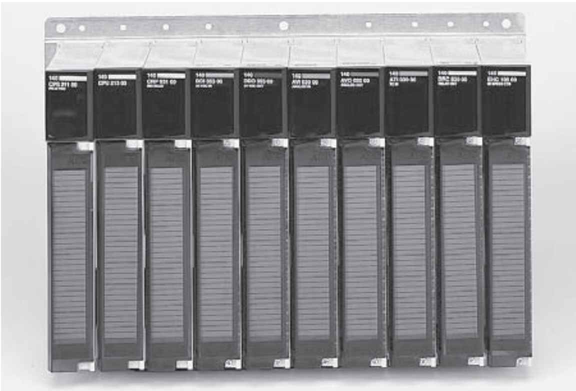

Figure 58–8A
I/O rack with input and output modules. (Courtesy of Schneider Automation).

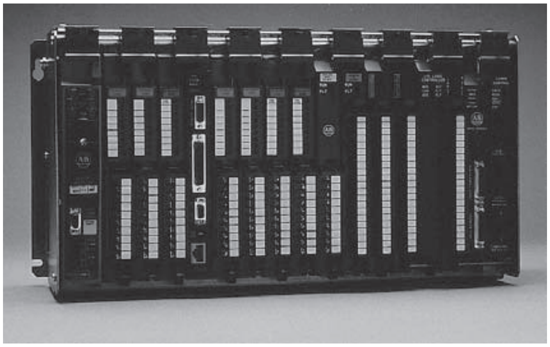

Figure 58–8B
I/O rack with input and output modules. (Courtesy of Allen-Bradley Co., Systems Division).

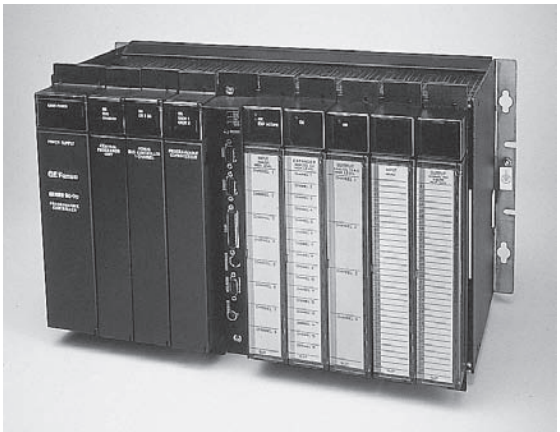

Figure 58–9
Central processor with I/O racks. (Courtesy of General Electric).

The I/O rack shown in Figure 58–8A can handle 10 modules. Because each module can handle 16 input or output devices, the I/O rack is capable of handling 160 input and output devices. Many programmable logic controllers are capable of handling multiple I/O racks.

I/O CAPACITY

One factor that determines the size and cost of a programmable logic controller is its **I/O capacity**. Many small units may be intended to handle as few as 16 input and output devices. Large PLCs can generally handle several hundred. The number of input and output devices the controller must handle also affects the processor speed and amount of memory the CPU must have. A central processing unit with I/O racks is shown in Figure 58–9.

THE INPUT MODULE

The central processing unit of a programmable logic controller is extremely sensitive to voltage spikes and electrical noise. For this reason, the

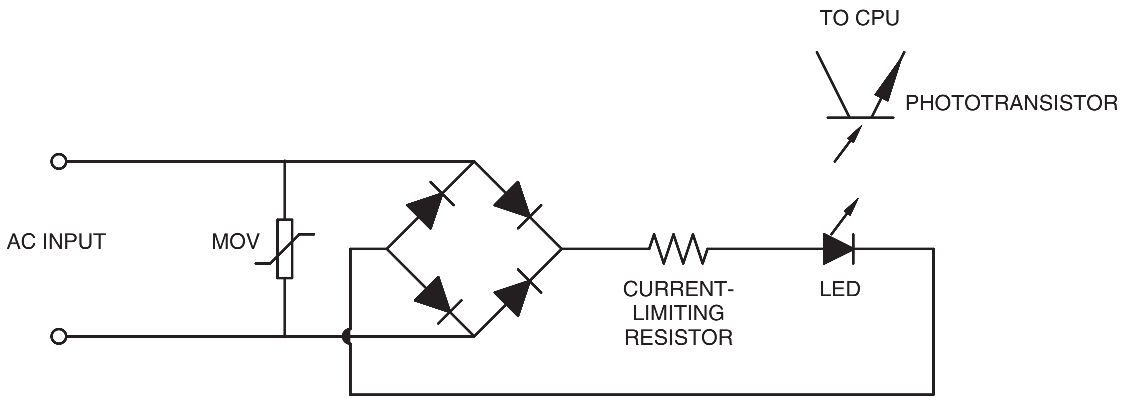

Figure 58–10
Input circuit. (Source: Delmar/Cengage Learning)

input I/O uses opto-isolation to electrically separate the incoming signal from the CPU. Figure 58–10 shows a typical circuit used for the input. A metal-oxide-varistor (MOV) is connected across the AC input to help eliminate any voltage spikes that may occur on the line. The MOV is a voltage-sensitive resistor. As long as the voltage across its terminals remains below a certain level, it exhibits a very high resistance. If the voltage should become too high, the resistance almost instantly changes to a very low value. A bridge rectifier changes the AC voltage into DC. A resistor is used to limit current to a light-emitting diode. When power is applied to the circuit, the LED turns on. The light is detected by a phototransistor that signals the CPU that there is a voltage present at the input terminal.

When the module has more than one input, the bridge rectifiers are connected together on one side to form a common terminal. On the other side, the rectifiers are labeled 1, 2, 3, and 4. Figure 58–11 shows four bridge rectifiers connected together to form a common terminal. Figure 58–12 shows a limit switch connected to input 1, a temperature switch connected to input 2, a float switch connected to input 3, and a normally open pushbutton connected to input 4. Notice that the pilot devices complete a circuit to the bridge rectifiers. If any switch closes, 120 volts AC will be connected to a bridge rectifier, causing the corresponding light-emitting diode to turn on and signal the CPU that the input has voltage applied to it. When voltage is applied to an input, the CPU considers that input to be at a high level.

THE OUTPUT MODULE

The output module is used to connect the central processing unit to the load. Output modules provide line isolation between the CPU and the external circuit. Isolation is generally provided in one of two ways. The most popular is with optical isolation very similar to that used for the input modules. In this case, the CPU controls a light-emitting diode. The LED is used to signal a solid-state device to connect the load to the line. If the load is operated by direct current, a power phototransistor is used to connect the load to the line, Figure 58–13. If the load is an alternating current device, a triac is used to connect the load to the line, Figure 58–14. Notice that the central processing unit is separated from the external circuit by a light beam. No voltage spikes or electrical noise can be transmitted to the CPU.

The second method of controlling the output is with small relays, Figure 58–15. The CPU controls the relay coil. The contacts connect the load to the line. The advantage of this type of output module is that it is not sensitive to whether the voltage is AC or DC and can control 120- or 24-volt circuits. The disadvantage is that it does contain moving parts that can wear. In this instance, the CPU is isolated

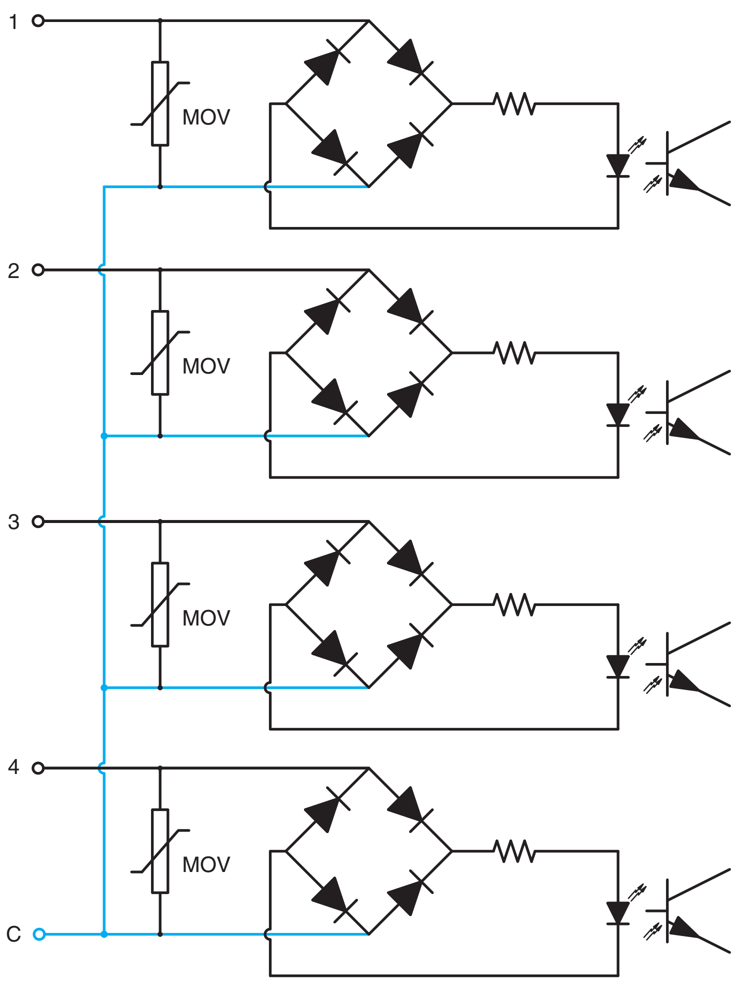

Figure 58–11
Four-input module. (Source: Delmar/Cengage Learning)

from the external circuit by a magnetic field instead of a light beam.

If the module contains more than one output, one terminal of each output device is connected together to form a common terminal similar to a module with multiple inputs, Figure 58–16. Notice that one side of each triac has been connected together to form a common point. The other side of each triac is labeled 1, 2, 3, or 4. If power transistors were used as output devices, the collectors or emitters of each transistor would be connected to form a common terminal. Figure 58–14 shows a relay coil connected to the output of a triac. Notice that the triac is used as a switch to connect the load to the line. The power to operate the load must be provided by an external source. *Output modules do not provide power to operate external loads.*

The amount of current an output can control is limited. The current rating of most outputs can range from .5 to about 3 amperes, depending on the manufacturer and type of output being used. Outputs are intended to control loads that draw a small amount of current such as solenoid coils, pilot lights, and relay coils. Some outputs can control motor starter coils directly and others require an interposing relay. Interposing relays are employed when the current draw of the load is above the current rating of the output.

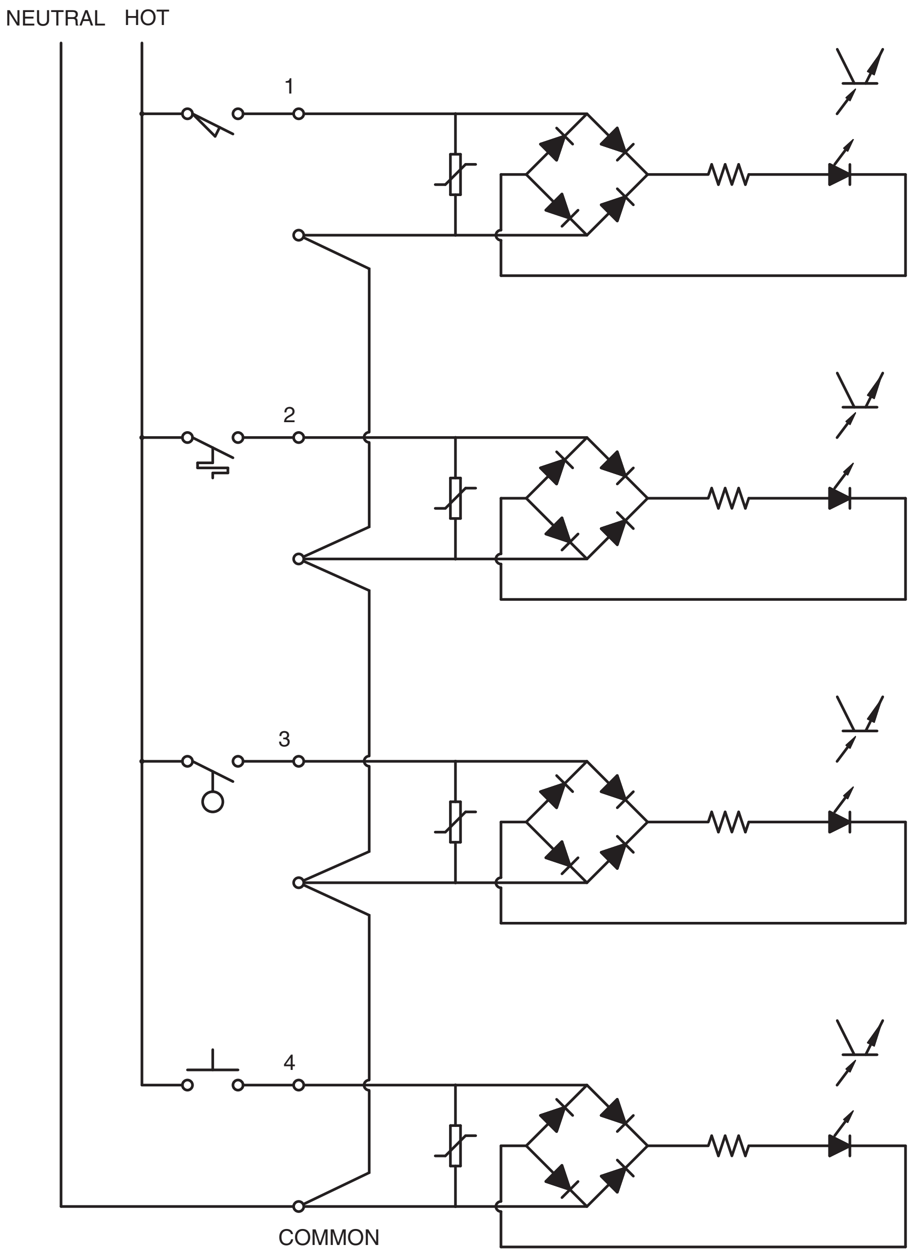

Figure 58–12
Pilot devices connected to input modules. (Source: Delmar/Cengage Learning)

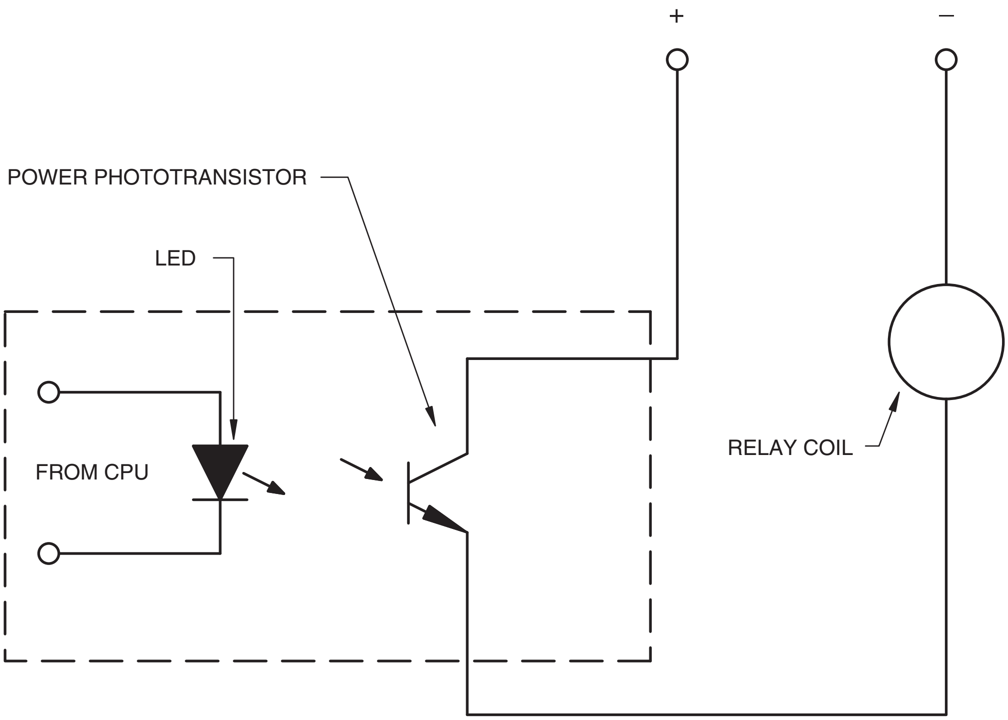

Figure 58–13
A power phototransistor connects a DC load to the line. (Source: Delmar/Cengage Learning)

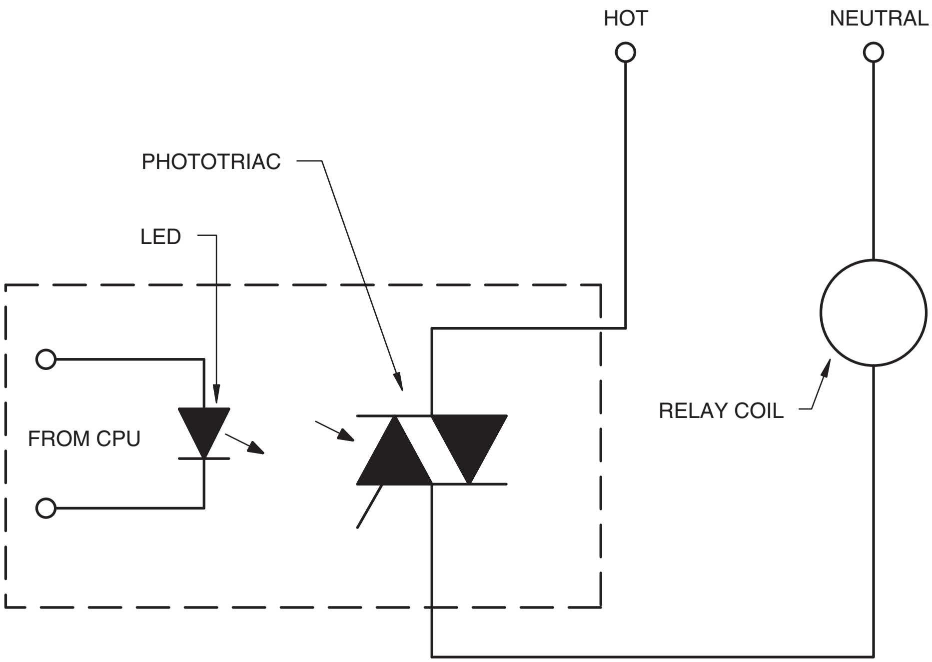

Figure 58–14
A triac connects an AC load to the line. (Source: Delmar/Cengage Learning)

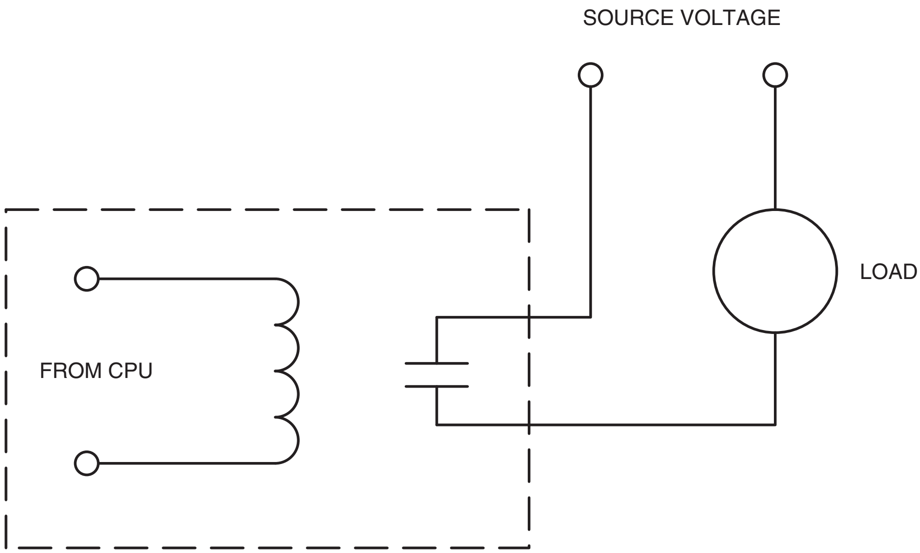

Figure 58–15
A relay connects the load to the line. (Source: Delmar/Cengage Learning)

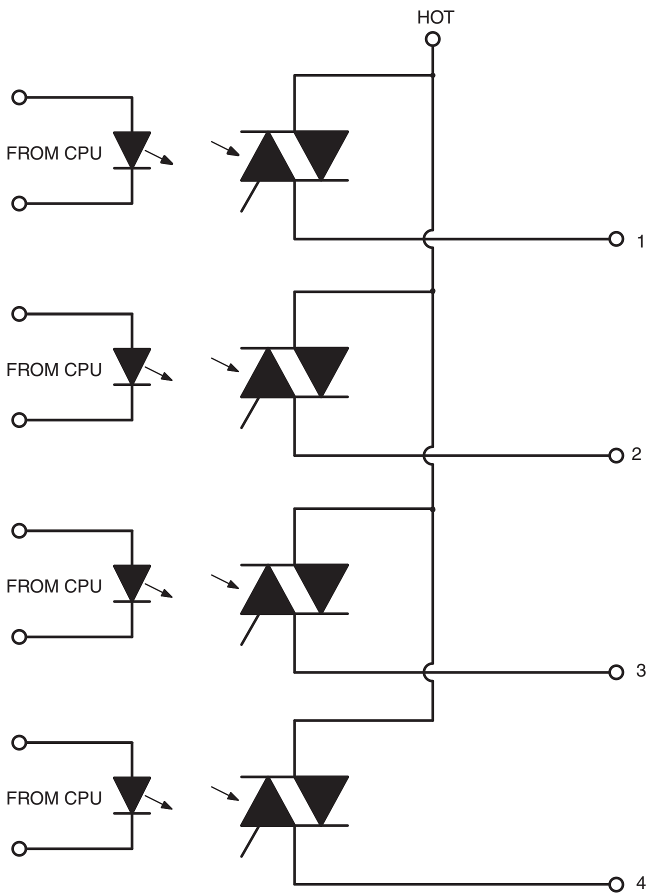

Figure 58–16
Multiple-output module. (Source: Delmar/Cengage Learning)

INTERNAL RELAYS

The actual logic of the control circuit is performed by **internal relays**. An internal relay is an imaginary device that exists only in the logic of the computer. It can have any number of contacts from one to several hundred, and the contacts can be programmed normally open or normally closed. Internal relays are programmed into the logic of the PLC by assigning them a certain number. Manufacturers provide a chart that lists which numbers can be used to program inputs and outputs, internal relay coils, timers, counters, and so on. When a coil is entered at the end of a line of logic and is given a number that corresponds to an internal relay, it will act like a physical relay. Any contacts given the same number as that relay will be controlled by that relay.

TIMERS AND COUNTERS

Timers and counters are internal relays also. There is no physical timer or counter in the PLC. They are programmed into the logic in the same manner as any other internal relay, by assigning them a number that corresponds to a timer or counter. The difference is that the time delay or number of counts must be programmed when they are inserted into the program. The number of counts for a counter are entered using numbers on the keys on the load terminal. Timers are generally programmed in 0.1-second intervals. Some manufacturers provide a decimal key and others do not. If a decimal key is not provided, the time delay is entered as 0.1-second intervals. If a delay of 10 seconds is desired, for example, the number 100 would be entered. One hundred tenths of a second equals 10 seconds.

OFF-DELAY CIRCUIT

Some programmable logic controllers permit a timer to be programmed as on or off delay, but others permit only on-delay timers to be programmed. When a PLC permits only on-delay timers to be programmed, a simple circuit can be used to permit an on-delay timer to perform the function of an off-delay timer, Figure 58–17. To understand the action of the circuit, recall the operation of an off-delay timer. When the timer coil is energized the timed contacts change position immediately. When the coil is deenergized the contacts remain in their energized state for some period of time before returning to their normal state. In the circuit shown in Figure 58–17 it is assumed that contact 400 controls the action of the timer. Coil 400 is an internal relay coil located somewhere in the circuit. Coil 12 is an output and controls some external device. Coil TO-1 is an on-delay timer set for 100 tenths of a second. When coil 400 is energized, both 400 contacts change position. The normally open 400 contact closes and provides a current path to coil 12. The normally closed 400 contact opens and prevents a circuit from being completed to coil TO-1 when coil 12 energizes. Note that coil 12 turned on immediately when contact 400 closed. When coil 400 is deenergized, both 400 contacts return to their normal position. A current path is maintained to coil 12 by the now closed 12 contact in parallel

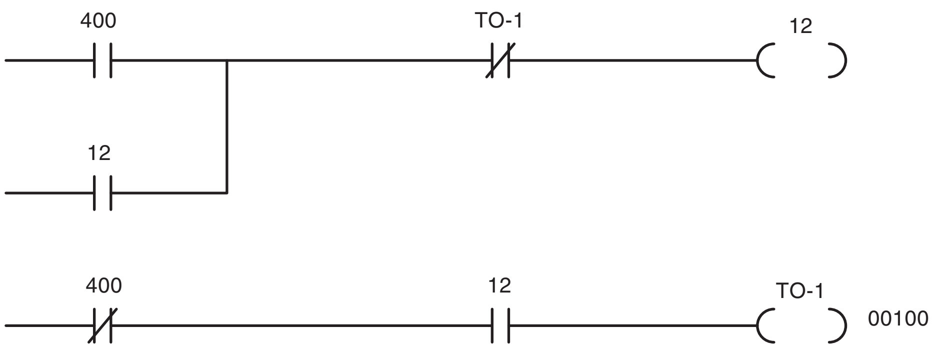

Figure 58–17
Off-delay timer circuit. (Source: Delmar/Cengage Learning)

with the normally open 400 contact. When the normally closed 400 contact returns to its normal position a current path is established to coil TO-1 through the now closed 12 contact. This starts the time sequence of timer TO-1. After a delay of 10 seconds, the normally closed TO-1 contact opens and deenergizes coil 12, returning the two 12 contacts to their normal position. The circuit is now back in the state shown in Figure 58–16. Note the action of the circuit. When coil 400 was energized, output coil 12 turned on immediately. When coil 400 was deenergized, output 12 remained on for 10 seconds before turning off.

The number of internal relays and timers contained in a programmable logic controller is determined by the memory capacity of the computer. As a general rule, PLCs that have a large I/O capacity will have a large amount of memory. The use of programmable logic controllers has steadily increased since their invention in the late 1960s. A PLC can replace hundreds of relays and occupy only a fraction of the space. The circuit logic can be changed easily and quickly without requiring extensive hand rewiring. They have no moving parts or contacts to wear out, and their down time is less than that of an equivalent relay circuit. When replacement is necessary, they can be reprogrammed from a media storage device.

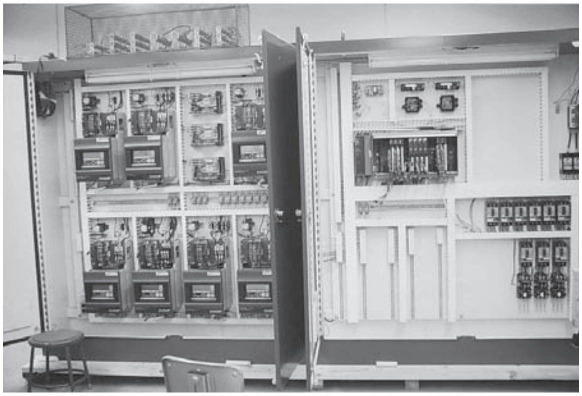

Figure 58–18
DC drive unit controlled by a programmable logic controller. (Courtesy of Reliance Electric).

The programming methods presented in this text are general because it is impossible to include examples of each specific manufacturer. The concepts presented in this chapter, however, are common to all programmable controllers. A programmable logic controller used to control a DC drive is shown in Figure 58–18.

SUMMARY

- Programmable logic controllers were first used by the automotive industry in the early 1960s.
- The major parts of a programmable logic controller are the power supply, central processing unit, programming terminal, and I/O rack.
- The power supply changes AC into DC, and then filters and regulates it to the proper voltage.
- The central processing unit performs all the logic functions loaded into memory.
- The programming terminal is used to load or amend a program in a programmable logic controller.
- Laptop computers are often employed as programming terminals.
- The I/O rack provides inputs and outputs for the programmable logic controller.
- Most programmable logic controllers use opto-isolation in the input and output modules.
- Input modules provide information to the central processing unit from the outside circuit.

- Output modules provide information from the central processing unit to the outside circuit.
- Internal relays are relays that exist only in the logic of the computer.
- Some internal relays can be employed as counters and timers.

KEY TERMS

central processing unit (CPU)
illuminated
internal relay
I/O capacity
I/O rack
loading terminal
power supply
programmable logic controller (PLC)
programming terminal

REVIEW QUESTIONS

1. What industry first started using programmable logic controllers?
2. Name two differences between PLCs and common home or business computers.
3. Name the four basic sections of a programmable logic controller.
4. In what section of the PLC is the actual logic performed?
5. What device is used to program a PLC?
6. What device separates the central processing unit from the outside world?
7. What is opto-isolation?
8. If an output I/O controls a DC voltage, what solid-state device is used to connect the load to the line?
9. If an output I/O controls an AC voltage, what solid-state device is used to connect the load to the line?
10. What is an internal relay?
11. What is the purpose of the key switch located on the front of the CPU in many programmable logic controllers?
12. What is a software switch?

UNIT 59

Programming a PLC

OBJECTIVES

After studying this unit the student should be able to:

- Convert a relay schematic to a schematic used for programming a PLC
- Enter a program into a programmable logic controller

In this unit a **relay schematic** will be converted into a diagram used to program a programmable logic controller. The process to be controlled is shown in Figure 59–1. A tank is used to mix two liquids. The control circuit operates as follows:

1. When the start button is pressed, solenoids A and B energize. This permits the two liquids to begin filling the tank.
2. When the tank is filled, the float switch trips. This deenergizes solenoids A and B and starts the motor used to mix the liquids together.
3. The motor is permitted to run for one minute. After one minute has elapsed, the motor turns off and solenoid C energizes to drain the tank.

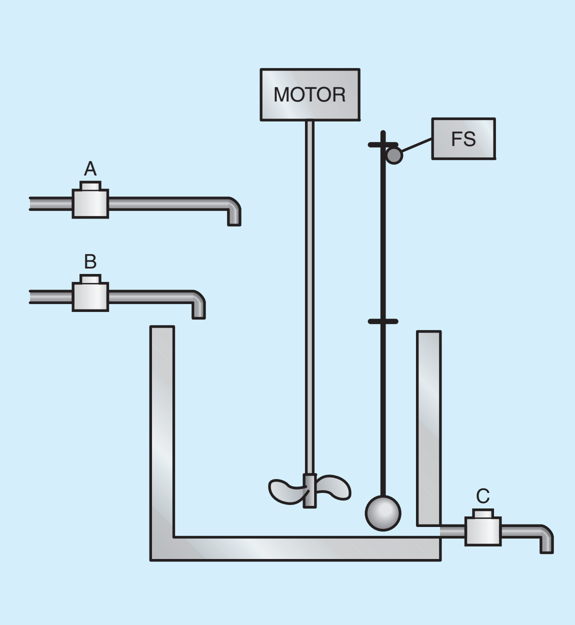

Figure 59–1
Tank used to mix two liquids. (Source: Delmar/Cengage Learning)

4. When the tank is empty, the float switch deenergizes solenoid C.
5. A stop button can be used to stop the process at any point.
6. If the motor becomes overloaded, the action of the entire circuit will stop.
7. Once the circuit has been energized it will continue to operate until it is manually stopped.

CIRCUIT OPERATION

A relay schematic that will perform the logic of this circuit is shown in Figure 59–2. The logic of this circuit is as follows:

1. When the start button is pushed, relay coil CR is energized. This causes all CR contacts to close. Contact CR-1 is a holding contact used to maintain the circuit to coil CR when the start button is released.
2. When contact CR-2 closes, a circuit is completed to solenoid coils A and B. This permits the two liquids that are to be mixed together to begin filling the tank.
3. As the tank fills, the float rises until the float switch is tripped. This causes the normally closed float switch contact to open and the normally open contact to close.
4. When the normally closed float switch opens, solenoid coils A and B deenergize and stop the flow of the two liquids into the tank.
5. When the normally open contact closes, a circuit is completed to the coil of a motor starter and the coil of an on-delay timer. The motor is used to mix the two liquids together.
6. At the end of the one minute time period, all of the TR contacts change position. The normally closed TR-2 contact connected in series with the motor starter coil opens and stops the operation of the motor. The normally open TR-3 contact closes and energizes solenoid coil C which permits liquid to begin draining from the tank. The normally closed TR-1 contact is used to assure that valves A and B cannot be reenergized until solenoid C deenergizes.
7. As liquid drains from the tank, the float drops. When the float drops far enough, the float switch trips and its contacts return to their normal positions. When the normally open float switch contact reopens and de-energizes coil TR, all TR contacts return to their normal positions.
8. When the normally open TR-3 contact reopens, solenoid C deenergizes and closes the drain valve. Contact TR-2 recloses, but the motor cannot restart because of the normally open float switch contact. When contact TR-1 recloses, a circuit is completed to solenoids A and B. This permits the tank to begin refilling, and the process starts over again.
9. If the stop button or overload contact opens, coil CR deenergizes and all CR contacts open. This deenergizes the entire circuit.

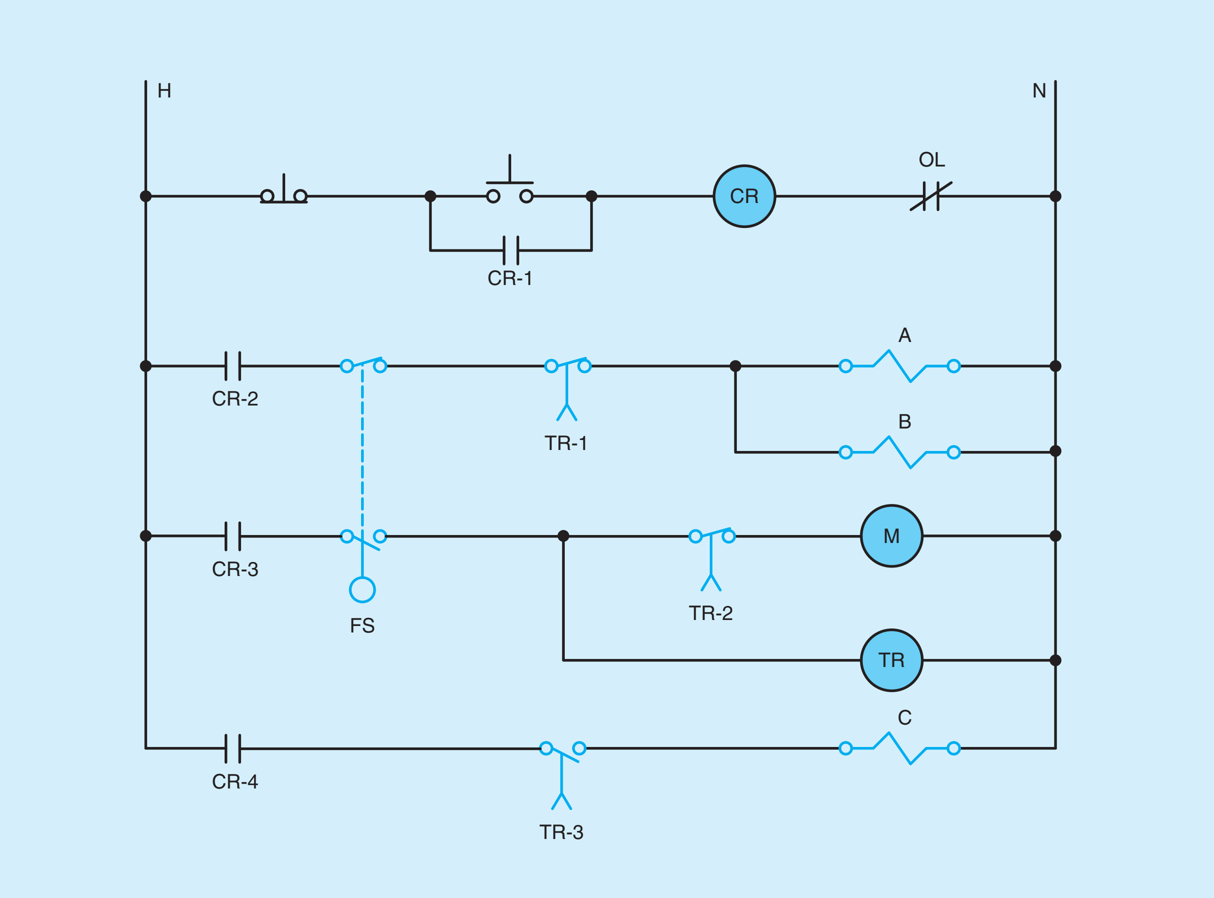

Figure 59–2
Relay schematic. (Source: Delmar/Cengage Learning)

DEVELOPING A PROGRAM

This circuit will now be developed into a program that can be loaded into the programmable controller. Figure 59–3 shows a program being developed on a computer. Assume that the controller has an I/O capacity of 32, that I/O terminals 1 through 16 are used as inputs, and that terminals 17 through 32 are used as outputs.

Before a program can be developed for input into a programmable logic controller, it is necessary to assign which devices connect to the **input** and **output** terminals. This circuit contains four input devices and four output devices. It is also assumed that the motor starter for this circuit contains an overload relay that contains two contacts instead of one. One contact is normally closed and will be connected in series with the coil of the motor starter. The other contact is normally open and is used to supply an input to a programmable logic controller. If the motor should become overloaded, the normally closed contacts will open and disconnect the motor from the line. The normally open contacts will close and provide a signal to the programmable logic controller that the motor has tripped on overload. The input devices are as follows:

1. Normally closed stop pushbutton.
2. Normally open start pushbutton.
3. Normally open overload contact.

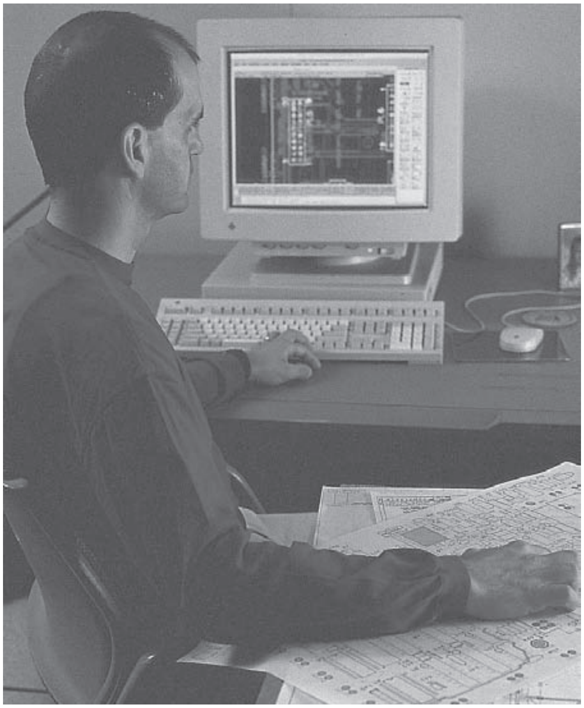

Figure 59–3
A program being developed on a programming terminal. (Courtesy of GE Manuc)

4. A float switch that contains both a normally open and normally closed contact.

The four output devices are:

1. Solenoid valve A.
2. Solenoid valve B.
3. Motor starter coil M.
4. Solenoid valve C.

The connection of devices to the inputs and outputs is shown in Figure 59–4. The normally closed stop button is connected to input 1, the normally open start button is connected to input 2, the normally open overload contact is connected to input 3, and the float switch is connected to input 4.

The outputs for this PLC are 17 through 32. Output 17 is connected to solenoid A, output 18 is connected to solenoid B, output 19 is connected to the coil of the motor starter, and output 20 is connected to solenoid C. Note that the outputs *do not* supply the power to operate the output devices. The outputs simply complete a circuit. One side of each output device is connected to the grounded or neutral side of a 120-VAC power line. The ungrounded or hot conductor is connected to the common terminal of

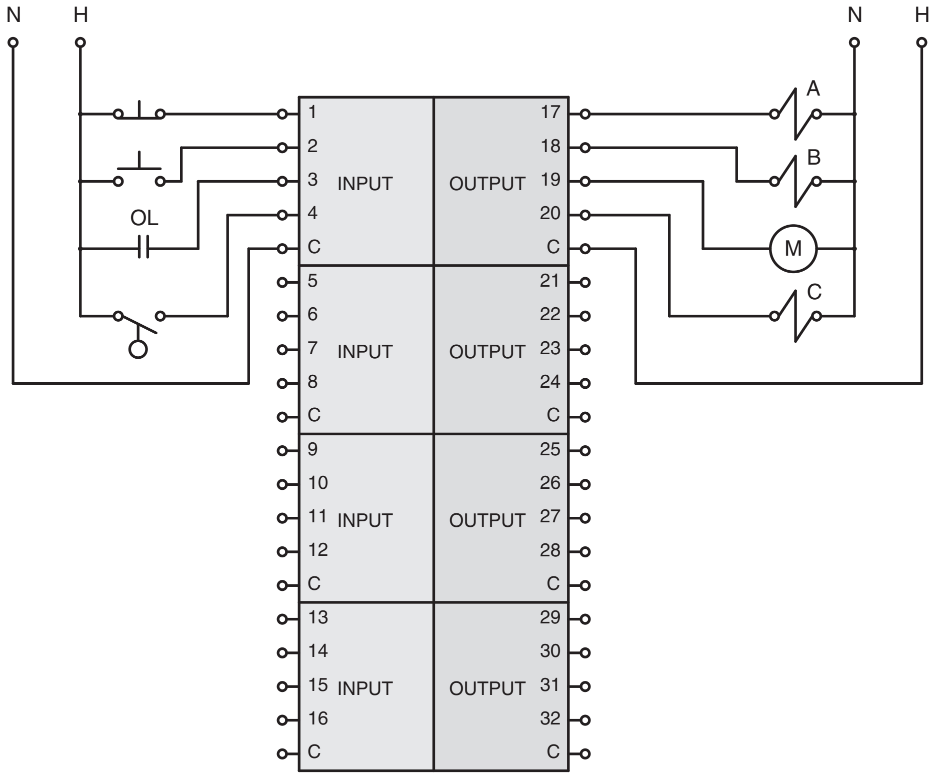

Figure 59–4
Component connection to I/O rack. (Source: Delmar/Cengage Learning)

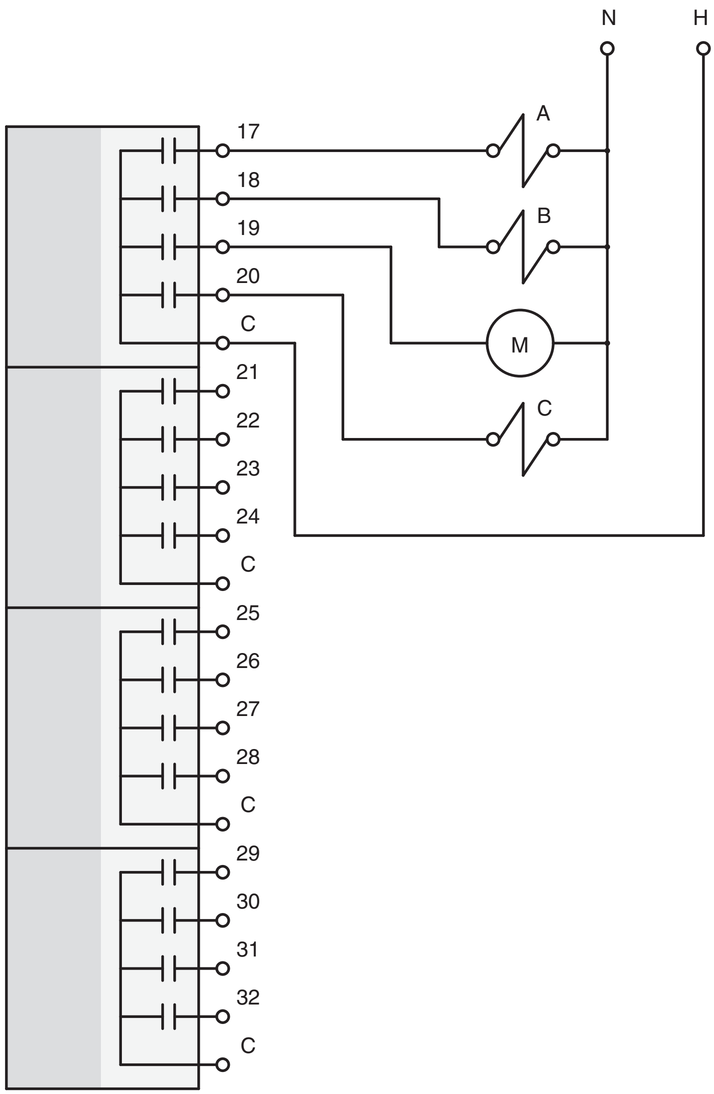

Figure 59–5
Output modules complete a circuit to connect the load to the line. (Source: Delmar/Cengage Learning)

the four outputs. A good way to understand this is to imagine a set of contacts controlled by each output as shown in Figure 59–5. When programming the PLC, if a coil is given the same number as one of the outputs it will cause that contact to close and connect the load to the line.

Unfortunately, programmable logic controllers are not all programmed the same way. Almost every manufacturer employs a different set of coil numbers to perform different functions. It is necessary to consult the manual before programming a PLC with which you are not familiar. In order to program the PLC in this example, refer to the information in Figure 59–6. This chart indicates that numbers 1 through 16 are inputs. Any contact assigned a number between 1 and 16 will be examined each time the programmable logic controller scans the program. If an input has a low (0 volt) state, the contact assigned that number will remain in the state it was programmed. If the input has a high (120-volt) state the program will interpret that contact as having changed position. If it was programmed as open the PLC will now consider it as closed.

Outputs are 17 through 32. Outputs are treated as coils by the PLC. If a coil is given the same number as an output, that output will turn on (close

Inputs	1 – 16
Outputs	17 – 32
Internal Relays	33 – 103
Timers and Counters	200 – 264
Retentative Relays	104 – 134

Figure 59–6
Numbers that correspond to specific PLC functions.
(Source: Delmar/Cengage Learning)

the contact) when the coil is energized. Coils that control outputs can be assigned internal contacts as well. Internal contacts are contacts that exist in the logic of the program only. They do not physically exist. Because they do not physically exist, a coil can be assigned as many internal contacts as desired and they can be normally open or normally closed.

The chart in Figure 59–6 also indicates that internal relays number from 33 to 103. Internal relays are like internal contacts. They do not physically exist. They exist as part of the program only. They are programmed into the circuit logic by inserting a coil symbol in the program and assigning it a number between 33 and 103.

Timers and counters are assigned coil numbers 200 through 264, and retentive relays are numbered 104 through 134.

CONVERTING THE PROGRAM

Developing a program for a programmable logic controller is a little different from designing a circuit with relay logic. There are several rules that must be followed with almost all programmable logic controllers.

1. Each line of logic must end with a coil. Some manufacturers permit coils to be connected in parallel and some do not.
2. Generally, coils cannot be connected in series.
3. The program will scan in the order that it is entered.
4. Generally, coils cannot be assigned the same number. (Some programmable logic controllers require reset coils to reset counters and timers. These reset coils can be assigned the same number as the counter or timer they reset.)

The first two lines of logic for the circuit shown in Figure 59–2 can be seen in Figure 59–7. Notice that contact symbols are used to represent inputs instead of logic symbols such as pushbuttons, float switches, and so on. The programmable logic controller recognizes all inputs as open or closed contacts. It does not know what device is connected to which input. This is the reason that you must first determine which device connects to which input before a program can be developed. Also notice that input 1 is shown as a normally open contact. Referring to Figure 59–4, it can be seen that input 1 is connected to a normally closed pushbutton. The input is programmed as normally open because the normally closed pushbutton will supply a high voltage to input 1 in normal operation. Because input 1 is in a high state, the PLC will change the state of the open contact and consider it closed. When the stop pushbutton is pressed, the input voltage will change to low and the PLC will change the contact back to its original open state and cause coil 33 to deenergize.

Referring to the schematic in Figure 59–2, a control relay is used as part of the circuit logic. Because the control relay does not directly cause any output device to turn on or off, an internal relay will be used. The chart in Figure 59–6 indicates that internal

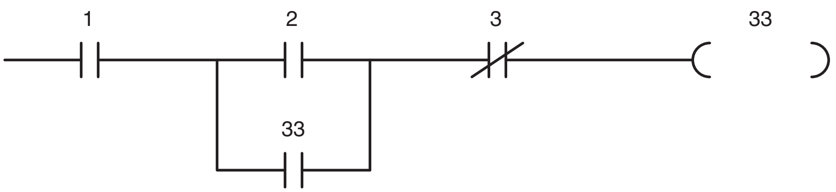

Figure 59–7
Lines 1 and 2 of the program.
(Source: Delmar/Cengage Learning)

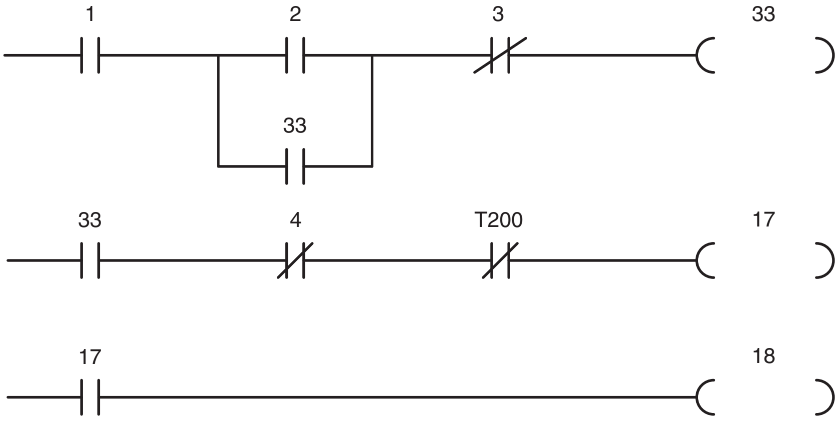

Figure 59–8 Lines 3 and 4 of the circuit are added. (Source: Delmar/Cengage Learning)

relays number between 33 and 103. Coil number 33 is an internal relay and does not physically exist. Any number of contacts can be assigned to this relay, and they can be open or closed. The number 33 contact connected in parallel with input 2 is the holding contact labeled CR-1 in Figure 59–2.

The next two lines of logic are shown in Figure 59–8. The third line of logic in the schematic in Figure 59–2 contains a normally open CR-2 contact, a normally closed float switch contact, a normally closed on-delay timed contact, and solenoid coil A. The fourth line of logic contains solenoid coil B connected in parallel with solenoid coil A. Line three in Figure 59–8 uses a normally open contact assigned the number 33 for contact CR-2. A normally closed contact symbol is assigned the number 4. Because the float switch is connected to input number 4, it will control the action of this contact. As long as input 4 remains in a low state, the contact will remain closed. If the float switch should close, input 4 will become high and the number 4 contact will open.

The next contact is timed contact TR-1. The chart in Figure 59–6 indicates that timers and counters are assigned numbers 200 through 264. In this circuit, timer TR will be assigned number 200. Line three ends with coil number 17. When coil 17 becomes energized, it will turn on output 17 and connect solenoid coil A to the line.

The schematic in Figure 59–2 shows that solenoid coil B is connected in parallel with solenoid coil A. Most programmable logic controllers do not permit coils to be connected in parallel. Each line of logic must end with its own coil. Because solenoid coil B is connected in parallel with A, they both operate at the same time. This logic can be accomplished by assigning an internal contact the same number as the coil controlling output 17. Notice in Figure 59–8 that when coil 17 energizes it will cause contact 17 to close and energize output 18 at the same time.

In Figure 59–9, lines 5 and 6 of the schematic are added to the program. A normally open contact assigned number 33 is used as for contact CR-3. A normally open contact assigned the number 4 is controlled by the float switch, and a second normally closed timed contact controlled by timer 200 is programmed in line 5. The output coil is assigned the number 19. When this coil energizes it turns on output 19 and connects motor starter coil M to the line.

Line 6 contains timer coil TR. Notice in Figure 59–2 that coil TR is connected in parallel with contact TR-2 and coil M. As was the case with solenoid coils A and B, coil TR cannot be connected in parallel with coil M. According to the schematic in Figure 59–2, coil TR is actually controlled by contacts CR-3 and the normally open float switch. This logic can be accomplished as shown in Figure 59–9 by connecting coil T200 in series with contacts assigned the numbers 33 and 4. Float switches do not normally contain this many contacts, but because the physical float switch is supplying a high or low voltage to input 4, any number of contacts assigned the number 4 can be used.

The last line of the program is shown in Figure 59–10. A normally open contact assigned

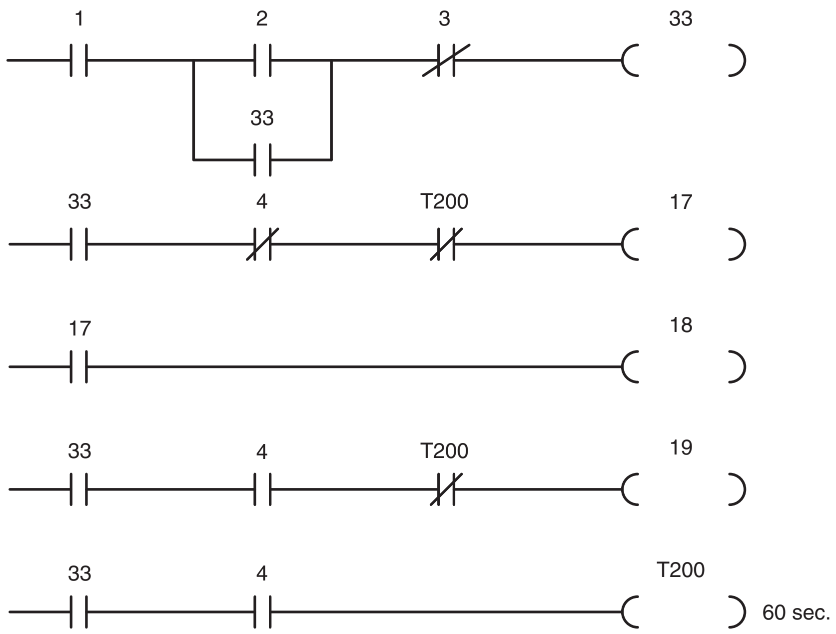

Figure 59–9
Lines 5 and 6 are added to the program. (Source: Delmar/Cengage Learning)

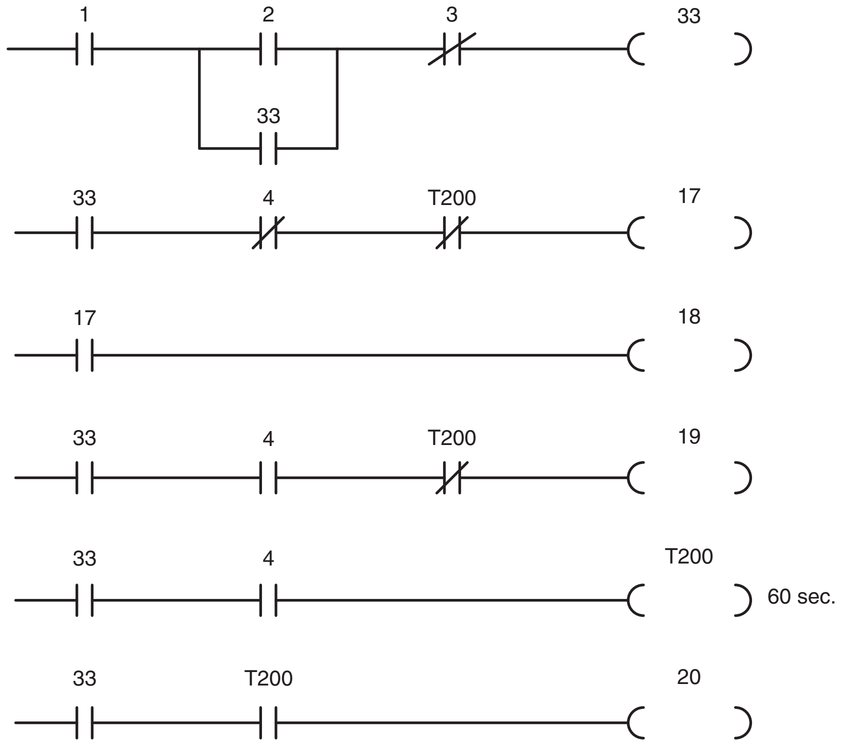

Figure 59–10
Line 7 of the program. (Source: Delmar/Cengage Learning)

the number 33 is used for contact CR-4 and a normally open contact controlled by timer T200 is used for the normally open timed contact labeled TR-3. Coil 20 controls the operation of solenoid coil C.

The circuit shown in Figure 59–2 has now been converted to a program that can be loaded into a programmable logic controller. The process is relatively simple if the rules concerning PLCs are followed.

ENTERING A PROGRAM

The manner in which a program is entered into the memory of the PLC is specific to the manufacturer and type of programming terminal used. Some programming terminals employ keys that contain contact, coil, and rung symbols to basically draw the program as it is entered. Small programming terminals may require that the program be entered in a language called **Boolean**. Boolean uses statements such as *and*, *or*, *not*, and *out* to enter programs. Contacts connected in series, for example, would be joined by *and* statements, and contacts that are connected in parallel with each other would be programmed with *or* statements. In order to program a contact normally closed instead of normally open, the *not* statement is used. Different PLCs also require the use of different numbers to identify particular types of coils. One manufacturer may use any number between 600 and 699 to identify coils that are used as timer and counters. Another manufacturer may use any number between 900 and 999 to identify coils that can be used as timers and counters. When programming a PLC, it is always necessary to first become familiar with the programming requirements of the model and manufacturer of the programmable logic controller being programmed.

PROGRAMMING CONSIDERATIONS

When developing a program for a programmable logic controller, there are certain characteristics of a PLC that should be considered. One of these is the manner in which a programmable logic controller performs its functions. Programmable logic controllers operate by scanning the program that has been entered into memory. This process is very similar to reading a book. It scans from top to bottom and from left to right. The computer scans the program one line at a time until it reaches the end of the program. It then resets any output conditions that have changed since the previous scan. The next step is to check all inputs to determine if they are high (power applied to that input point) or low (no power applied to that input point). This information is available for the next scan. The next step is to update the display of the programming terminal if one is connected. The last step is to reset the **"watchdog" timer**. Most PLCs contain a timer that runs continually when the PLC is in the RUN mode. The function of this timer is to prevent the computer from becoming hung in some type of loop. If the timer is not reset at the end of each scan, the watchdog timer will reach zero and all outputs will be turned off. Although this process sounds long, it actually takes place in a few milliseconds. Depending on the program length, it may be scanned several hundred times each second. The watchdog timer duration is generally set for about twice the amount of time necessary to complete one scan.

Scanning can eliminate some of the problems with **contact races** that occur with relay logic. The circuit shown in Figure 59–11 contains two control relay coils. A normally closed contact, controlled by the opposite relay, is connected in series with each coil. When the switch is closed, which relay will turn on and which will be locked out of the circuit? This called a contact race. The relay that is turned on depends on which one managed to open its normally closed contact first and break the circuit to the other coil. There is no way to really know which relay will turn on and which will remain off. There is not even a guarantee that the same relay will turn on each time the switch is closed.

Programmable logic controllers eliminate the problem of contact races. Because the PLC scans the program in a manner similar to reading a book, if it is imperative that a certain relay turn on before another one, simply program the one that must turn on first ahead of the other one. A similar circuit is shown in Figure 59–12. When contact 1 closes, coil 100 will always be the internal relay that turns on because it is scanned before coil 101.

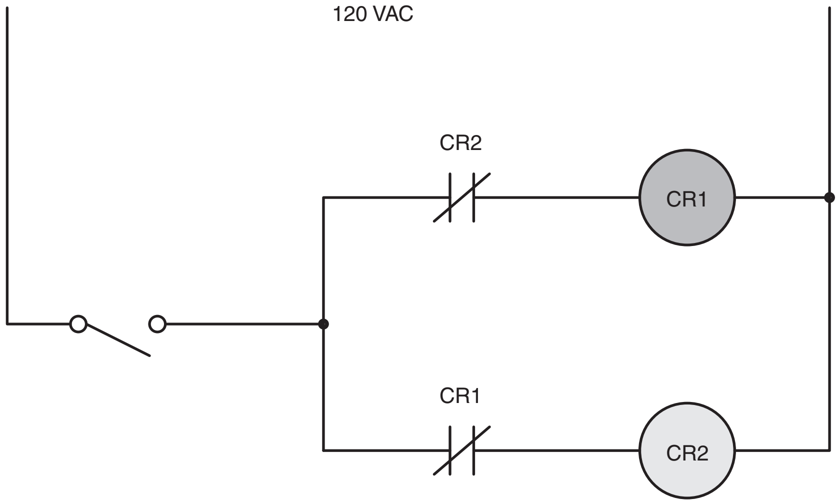

Figure 59–11
A contact race can exist in relay control circuits. (Source: Delmar/Cengage Learning)

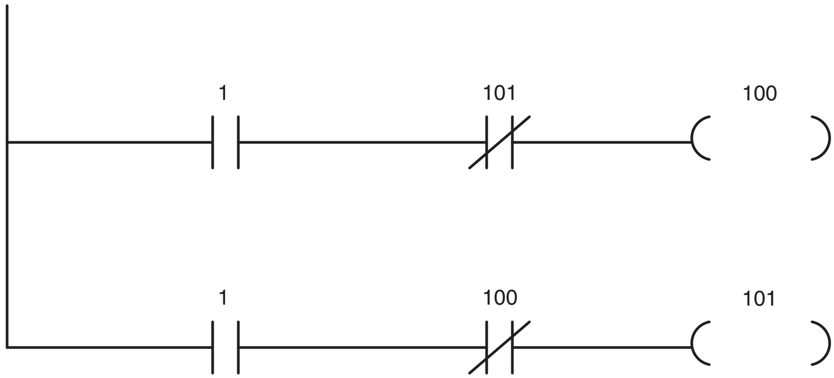

Figure 59–12
Scanning eliminates contact races in PLC logic. (Source: Delmar/Cengage Learning)

SUMMARY

- As a general rule, the schematic diagrams used for relay logic must be changed before they can be loaded into a programmable logic controller.
- Each line of logic must end with a coil.
- All inputs are assumed to be normally open.
- When a normally closed component is connected to the input of a programmable logic controller, the logic of the program must be reversed for that input.
- Before a program can be developed, the sensor devices such as pushbuttons, limit switches, and float switches must be assigned to an input. Outputs such as solenoid coils, pilot lights, and relay coils must be assigned to an output.
- Outputs do not supply power to operate devices.

KEY TERMS

Boolean
contact race
input
output
relay schematic
watchdog timer

REVIEW QUESTIONS

1. Why are NEMA symbols such as pushbuttons, float switches, and limit switches not used in programmable logic controller schematics?
2. How are such components as coils and contacts identified and distinguished from others in a PLC schematic?
3. Why are normally closed components such as stop pushbuttons programmed normally open instead of normally closed when entering a program into the memory of a PLC?
4. What is an internal relay?
5. Why is the output of a PLC used to energize the coil of a motor starter instead of energizing the motor directly?
6. List four basic rules for developing a program for a PLC.
7. A programmable logic controller requires that times be programmed in 0.1-second intervals. What number should be entered to produce a time delay of 3 minutes?
8. When programming in Boolean, what statement should be used to connect components in series?
9. When programming in Boolean, what statement should be used to connect components in parallel?
10. In a control circuit, it is imperative that a coil energize before another one. How can this be done when entering a program into the memory of the PLC?
11. What is the function of a watchdog timer?

UNIT 60

Analog Sensing for Programmable Controllers

OBJECTIVES

After studying this unit the student should be able to:

- Describe the differences between analog and digital inputs
- Discuss precautions that should be taken when using analog inputs
- Describe the operation of a differential amplifier

Many of the programmable controllers found in industry are designed to accept analog as well as digital inputs. Analog means continuously varying. These inputs are designed to sense voltage, current, speed, pressure, proximity, temperature, and so on. When an **analog input** is used, such as a thermocouple for measuring temperature, a special module that mounts on the I/O rack is used. These types of sensors are often used with set point detectors that can be used to trigger alarms and turn on or off certain processes. For example, the voltage produced by a thermocouple will increase with a change of temperature. Assume that you want to sound an alarm if the temperature of an object reaches a certain level. The detector is preset with a particular voltage. As the temperature of the thermocouple increases, its output voltage increases also. When the voltage of the thermocouple becomes greater than the preset voltage, an alarm sounds.

INSTALLATION

Most analog sensors can produce only very weak signals. Zero to 10 volts or 4 to 20 milliamps is common. In an industrial environment where intense magnetic fields and large voltage spikes abound, it is easy to lose the input signal amid the electrical noise. For this reason, special precautions should be taken when installing the signal wiring between the sensor and input module. These precautions are particularly important when using analog inputs, but they should be followed when using digital inputs also.

KEEP WIRE RUNS SHORT

Try to keep wire runs as short as possible. The longer a wire run is, the more surface area of wire there is to pick up stray electrical noise.

PLAN THE ROUTE OF THE SIGNAL CABLE

Before starting, plan how the signal cable should be installed. Never run signal wire in the same conduit with power wiring. Try to run signal wiring as far away from power wiring as possible. When it is necessary to cross power wiring, install the signal cable so that it crosses at a right angle as shown in Figure 60–1.

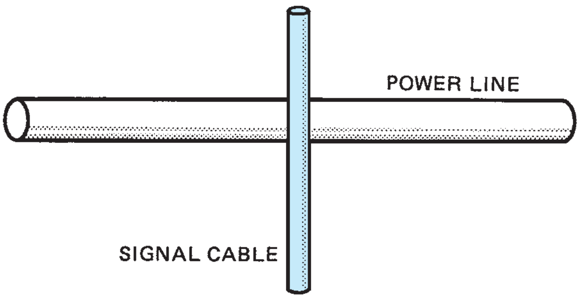

Figure 60–1
Signal cable crosses power line at right angle.
(Source: Delmar/Cengage Learning)

USE SHIELDED CABLE

Shielded cable is generally used for the installation of signal wiring. One of the most common types, Figure 60–2, uses twisted wires with a **Mylar foil shield**. The ground wire must be grounded if the shielding is to operate properly. This type of shielded cable can provide a **noise reduction ratio** of about 30,000:1.

Another type of signal cable uses a twisted pair of signal wires surrounded by a braided shield. This type of cable provides a noise reduction of about 300:1.

Common coaxial cable should be avoided. This cable consists of a single conductor surrounded by a braided shield. This type of cable offers very poor noise reduction.

GROUNDING

Ground is generally thought of as being electrically neutral or zero at all points. This may not be the case in practical application, however. It is not uncommon to find different pieces of equipment that have ground levels that are several volts apart, Figure 60–3.

One method that is sometimes used to overcome this problem is to use large cable to tie the two pieces of equipment together. This forces them to exist at the same potential. This method is sometimes referred to as the **brute force method**.

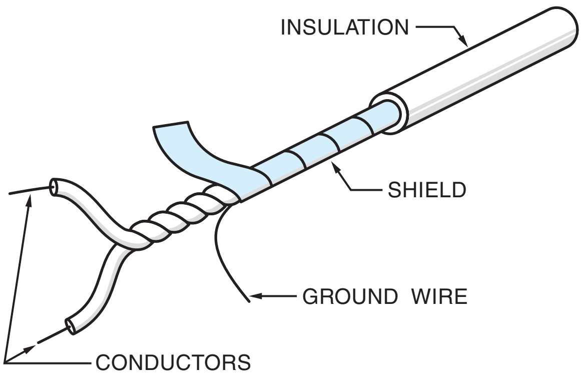

Figure 60–2
Shielded cable. (Source: Delmar/Cengage Learning)

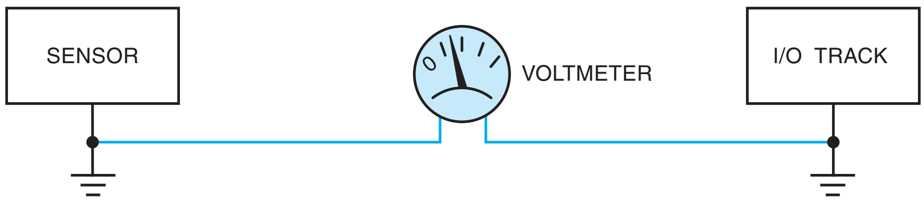

Figure 60–3
All grounds are not equal. (Source: Delmar/Cengage Learning)

Where the brute force method is not practical, the shield of the signal cable is grounded at only one end. The preferred method is generally to ground the shield at the sensor.

THE DIFFERENTIAL AMPLIFIER

An electronic device that is often used to help overcome the problem of induced noise is the **differential amplifier** shown in Figure 60–4. This device detects the voltage difference between the pair of signal wires and amplifies this difference. Because the induced noise level should be the same in both conductors, the amplifier will ignore the noise. For example, assume an analog sensor is producing a 50 millivolt signal. This signal is applied to the input module, but induced noise is at a level of 5 volts. In this case the noise level is 100 times greater than the signal level. The induced noise level, however, is the same for both of the input conductors. The differential amplifier, therefore, ignores the 5-volt noise and amplifies only the voltage difference which is the 50 millivolts.

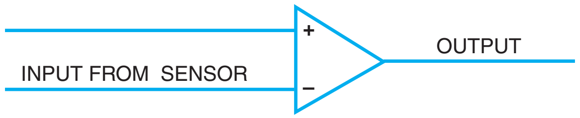

Figure 60–4
Differential amplifier detects difference of signal level.
(Source: Delmar/Cengage Learning)

SUMMARY

- Analog inputs sense a range of values instead of operating in an on or off mode.
- Most analog inputs operate with a standard of 4 to 20 milliamps.
- Special precautions should be used when installing analog inputs.
- Wire runs should be kept as short as possible. This reduces the surface of the wire that is susceptible to electrical noise.
- Signal wiring should never be run close to power wiring.
- When a signal wire must cross power wiring, it should cross at a 90° angle.
- Signal inputs should be run with shielded cable.
- The shield of shielded cable should be grounded, generally at the sensor.
- Differential amplifiers are sometimes used to help eliminate electrical noise induced in the signal cable.

KEY TERMS

analog input
brute force method
differential amplifier
mylar foil shield
noise reduction ratio
shielded cable

REVIEW QUESTIONS

1. Explain the difference between digital inputs and analog inputs.
2. Why should signal-wire runs be kept as short as possible?
3. When signal wiring must cross power wiring, how should the crossing be done?
4. Why is shielded wire used for signal runs?
5. What is the brute force method of grounding?
6. Explain the operation of the differential amplifier.

GLOSSARY

A

AC (alternating current) Current that reverses its direction of flow at regular intervals.

AC electrolytic capacitor Can house a large amount of capacitance in a small case size, is designed for short-term use only, and used as the starting capacitor on single-phase motors.

across-the-line A method of motor starting that connects the motor directly to the supply line on starting or running. (Also known as full voltage starting.)

adjustable Describes construction of pressure switches used for commercial or industrial systems that allows service technicians to use the switch on different systems.

alternator A machine used to generate alternating current by rotating conductors through a magnetic field.

ambient air temperature The temperature in the surrounding area of a device.

ammeter A low impedance device used to measure current in a circuit.

amortisseur Winding named for the set of type "A" squirrel-cage bars in a synchronous motor rotor.

ampacity The maximum current rating of a wire or device.

ampere (amp) A measurement of the actual amount of electricity that flows through a circuit; defined as one coulomb per second.

amplifier A device used to increase a signal.

amplitude The highest value reached by a signal, voltage, or current.

analog Device that can be adjusted to different states since it represents continuously changing quantities.

analog input An input sensor designed to sense voltage, current, speed, pressure, proximity, temperature, and other quantities in programmable computers that can trigger alarms or start/stop processes.

analog meter (voltmeter) A voltmeter that uses a meter movement to indicate the voltage value.

anode The positive terminal of an electrical device.

antifreeze protection Feature in some differential thermostats that turns the pump on and circulates warm water through the collector when its temperature is near freezing. Avoids damage to the collector.

anti-short-cycling A control that prevents the compressor from being restarted within a certain time after it has stopped.

apparent power (Volt-Amps) In an AC circuit, the applied voltage multiplied by the current flow in the circuit.

applied voltage The amount of voltage connected to a circuit or device.

arc-over Spark or illumination that occurs in a gap or breakage in a circuit.

armature The movable arm attracted by the magnetic field of the iron core of a solenoid.

ASA American Standards Association.

atom The smallest part of an element that contains all the properties of that element.

attenuator A device that decreases the amount of signal voltage or current.

auger Device used for boring, forcing, or moving material. Presses ice and excess water out of flaker-type ice maker.

automatic Self-acting; operation by its own mechanical or electrical mechanism.

automatic reset overload Used to protect single-phase motors. Constructed of bimetal strips that snap open contacts when overheated.

autotransformer Transformer that uses only one coil that is tapped to provide the correct voltage.

auxiliary contacts Small contacts located on relays and motor starters used to operate other control components.

auxiliary limit One of two high-limit contacts connected in series with an automatic gas valve.

AWG (American Wire Gauge) Standard units of measure for wiring.

B

base The semiconductor region between the collector and emitter of a transistor. The base controls the current flow through the collector-emitter circuit.

bellows Device that draws in air through a valve and expels it through a tube. Used to operate pressure switches in most air conditioning units.

bellows-type thermostat A thermostat that uses a refrigerant filled bellows to operate a set of contacts.

bias A DC voltage applied to the base of a transistor to preset its operating point.

bidirectional Able to move in two directions.

bimetal strip A strip made by bonding two unlike metals together that, when heated, expand at different temperatures. This causes a bending or warping action.

bimetal type One of two basic kinds of overload relays. Uses bimetal strips in construction of unit.

bin thermostat Senses the level of ice in the ice storage bin.

bipolar transistors Dual-poled transistors used by operational amplifiers for input.

Boolean A type of language using statements such as and, or, and not to program a programmable controller.

branch circuit That portion of a wiring system that extends beyond the circuit protective device such as a fuse or circuit breaker.

breakdown torque The maximum amount of torque that can be developed by a motor at rated voltage and frequency before an abrupt change in speed occurs.

bridge circuit A circuit that consists of four sections connected in series to form a closed loop.

bridge rectifier A device constructed with four diodes that converts both positive and negative cycles of AC voltage into DC voltage. The bridge rectifier is one type of full-wave rectifier.

brushless Generally refers to a motor that does not contain brushes.

brute force method When several pieces of equipment have unequal ground levels, the method of using a large cable to tie the equipment together, forcing them to exist at the same potential.

busway An enclosed system used for power transmission that is voltage and current rated.

C

cabinet thermostat One of two thermostats in a refrigerator using a flex tray ice maker that, if opened, interrupts the water fill cycle.

cadmium sulfide cell (CAD cell) A solid-state device that changes its resistance in accordance with the amount of light it is exposed to.

cam A rotating or sliding piece that moves freely on its roller or by notches picked up by pins or gears.

capacitance The electrical size of a capacitor.

capacitive reactance Symbolized by X_C, reactance caused by capacitance.

capacitor A device made with two conductive plates separated by an insulator or dielectric.

capacitor-start induction run motor A single-phase induction motor that uses a capacitor connected in series with the start winding to increase starting torque.

carbon brushes Material connected to slip rings on rotors to create resistance.

case Style of transistor that permits the leads to be quickly identified; sometimes the collector of the transistor.

cathode The negative terminal of an electrical device.

center-tapped transformer A transformer that has a wire connected to the electrical midpoint of its winding. Generally, the secondary winding is tapped.

central processing unit (CPU) The brains of a programmable controller, contains the microprocessor chip and related integrated circuits to perform all the logic functions.

centrifugal force The law that states a spinning object will pull away from its centerpoint; the faster the spin, the greater the force.

centrifugal switch Used to disconnect start windings from the circuit, configured to move when the centrifugal force spins parts upward.

CFM (condenser fan motor) relay Its coil energizes and starts the condenser fan motor in a flow-switch operated air conditioning system.

CFS (condenser flow switch) Airflow switch operated by the force of air created by the condenser fan in an air conditioning circuit.

choke An inductor designed to present an impedance to AC current, or to be used as the current filter of a DC power supply.

circuit breaker A device designed to open under an abnormal amount of current flow. The device is not damaged and may be used repeatedly. They are rated by voltage, current, and horsepower.

circular mils Measurement for the cross-sectional area of wire, equal to 1/1000 (0.001) of an inch.

clamp-on Type of ammeter where the jaw of the meter is clamped around one of the conductors supplying power to the load.

clock timer A time-delay device that uses an electric clock to measure the delay time.

code letter Provided on AC motors nameplates, indicates the type of bars used in the rotor.

collapse (of a magnetic field) Occurs when a magnetic field suddenly changes from its maximum value to a zero value.

collector A semiconductor region of a transistor that must be connected to the same polarity as the base.

combination A circuit that contains both series and parallel connections within the same circuit.

common denominator In fractions, the number all the denominators will divide into.

compact Type of household ice maker.

comparator A device or circuit that compares two like quantities, such as voltage levels.

compressor The component of an air conditioning or refrigeration system that maintains the difference in pressure between the high and low sides.

compressor relay coil Can be energized only after the condenser fan and evaporator fan relay coils have energized in an air conditioning unit.

condensing unit The component of an air conditioning or refrigeration system in which heat is removed from the refrigerant and dissipated to the surrounding air or liquid.

conduction level The point at which an amount of voltage or current will cause a device to conduct.

conductor A device or material that permits current to flow through it easily.

consequent pole motor A multispeed AC motor that changes the motor speed by changing the number of its stator poles.

contact A conducting part of a relay that acts as a switch to connect or disconnect a circuit or component.

contact race A condition that can occur in relay control circuits when coils are energized at the same time.

contactor Similar to relays, though may contain large-load contacts designed to control large amounts of current, may also contain auxiliary contacts. Used to connect power to resistance heater banks.

contact section Section of a solder-melting type overload relay that is connected in series with the coil of the motor starter.

continuity A complete path for current flow.

continuous run timer A defrost timer connection (pigtail to terminal 1, terminal 3 to neutral) that permits the motor to operate on a continuous basis.

control connector The connector that is connected to the control system.

control contacts In an oil-pressure failure switch, conducting parts of a relay that act as switches and provide power to the heater of the timer.

control transformers Used to change the value of line voltage to the value needed for the control circuit.

control valve The heart of a gas heating system, controls the flow of gas to the main burner and pilot light (if used).

conventional current flow theory Assumes the current flows from positive to negative.

cooling anticipator A resistive heating element that operates in an opposite sense to the heat anticipator. While the air conditioning unit is not running, it slightly heats the thermostat to close the contacts before the ambient temperature closes them.

coulomb A quantity of measurement for electrons at rest on a surface area. One coulomb contains 6.25×10^{18} electrons.

CR (control relay) Electrically operated switch whose coil energizes and closes its contacts, starting other operations in a circuit.

crankcase heater A component of a commercial air conditioning unit that, as long as power is connected, is energized at all times.

cube-size thermostat Mounted on the evaporator plate of a cube-type ice maker, its closed contacts complete the circuit to the timer motor for ice harvest.

cumulative compressor run timer This defrost timer connection (pigtail to terminal 2, timer contact between terminals 1 and 4) allows the timer motor to operate only when the compressor is in operation and the thermostat is closed.

current The rate of flow of electrons.

current flow The amount of current in a circuit.

current-limiting resistor A component of a time-delay circuit that is center tapped to allow either 240 volts to be connected in series with the heater, or for 120 volts to be connected to the center tap.

current rating The amount of current flow a device is designed to withstand.

current relay A relay that is operated by a predetermined amount of current flow. Current relays are often used as one type of starting relay for air conditioning and refrigeration equipment.

current transformer Used with an ammeter to provide multiscale capability.

D

DC (direct current) Current that does not reverse its direction of flow.

DC excitation current Adjusted to change the power factor of the synchronous motor to normal, overexcited, or underexcited depending on adjustment.

definite time control A method to short out the steps of resistance by using time relays to control when resistance is shorted out of the circuit.

defrost control A heat pump control that reverses the flow of refrigerant in a system to heat the outside heat exchange unit and remove frost.

defrost heater thermostat One of two thermostats in a flex tray ice maker that when closed permits the water fill cycle to operate.

defrost thermostat Heat sensor located on the outside heat exchanger of a heat pump.

defrost timer The “brain” of frost-free appliances, this disconnects the compressor circuit and connects a resistive heating element located near the evaporator to melt frost at regular time intervals. Operated by a single-phase synchronous motor.

delta, delta connection A triangular-shaped circuit, resembling the Greek letter *delta*, for three-phase current transformers and motor windings. A circuit formed by connecting three electrical devices in series to form a closed loop. It is used most often in three-phase connections.

diac A bidirectional diode used to phase shift a triac. It is a voltage-sensitive switch that operates on AC current.

dielectric An electrical insulator.

dielectric stress In a charged capacitor, the electron orbit of the atoms in the dielectric extend and are considered to be in tension, or dielectric stress.

differential amplifier Helps overcome induced noise by detecting voltage difference between pairs of signal wires and amplifying the difference so noise is ignored.

differential pressure switch Used to measure the difference between the suction pressure and the discharge pressure of an oil pump, e.g., device used to measure actual oil pressure in an oil-pressure failure switch.

differential thermostat Found mostly in solar-powered heating systems, uses two separate temperature sensors and is activated by the difference of temperature between them.

digital, digital device A device that has only two states of operation: on or off.

digital logic Circuit elements connected in such a manner as to solve problems using components that have only two states of operation.

digital meter (voltmeter) A voltmeter that uses direct reading numerical display as opposed to a meter movement.

diode A two-element device that permits current to flow through it in only one direction.

disconnecting means (disconnect) Device(s) used to disconnect a circuit or device from its source of supply.

door interlock A switch that permits a heating unit to operate only when the furnace door is closed.

double-acting Describes the circuitry in a thermostat permitting it to be used for both heating and cooling.

double-break contact A contact that breaks connection at two points.

dual-pressure switch Switch that has both high- and low-pressure switches in the same housing.

dynamic braking (1) Using a DC motor as a generator to produce counter torque and thereby produce a braking action. (2) Applying direct current to the stator winding of an AC induction motor to cause a magnetic braking action.

E

eddy current Circular-induced current contrary to the main currents. Eddy currents are a source of heat and power loss in magnetically operated devices.

EFM (evaporator fan motor) relay Its coil energizes and starts the evaporator fan motor.

EFS (evaporator flow switch) Airflow switch operated by the force of air created by the evaporator fan.

ejector blades Blades in ice makers that rotate and push ice cubes out of the mold tray and into a bin.

electrical interlock When the contacts of one device or circuit prevent the operation of some other device or circuit.

electrical pressure The electromotive force (voltage) that pushes electrons through a wire.

electric arc Used to ignite the gas flame in gas-operated appliances. Permits gas to flow but turns the gas off if no flame is soon detected.

electric controller Device(s) used to govern in some predetermined manner the operation of a circuit or piece of electrical apparatus.

electricity The flow of electrons through a completed path.

electric resistance heating element Component in an air conditioner sued to provide heat in cool weather.

electromagnetic field Created in windings when DC current is applied to the rotor. This field of the rotor locks in step with the rotating magnetic field of the stator.

electromotive force (EMF) The force that pushes electrons through a wire. Also known as voltage and electrical pressure.

electron One of the three major parts of an atom. The electron carries a negative charge.

electron flow theory Assumes that current flows from negative to positive.

electrostatic charge The energy of a capacitor stored in the dielectric; permits production of extremely high currents under certain conditions.

emitter The semiconductor region of a transistor that must be connected to a polarity different from the base.

enclosure Mechanical, electrical, or environmental protection for components used in a system.

eutectic alloy A metal with a low and sharp melting point used in thermal overload relays.

evaporator An air conditioning or refrigeration system component that removes heat from the surrounding air or liquid to cause a change of state in the refrigerant.

expansion Method for sensing temperature determined by the expansion of metal, considers the type of metal and the amount of heat used.

F

fan-limit switch Contains both a fan switch and a high-limit switch in one housing. Its operation will cause the burner to turn off and prevent damage to a heating system.

fan switch A single-pole, double-throw switch, connected on one side to the thermostat control on the other to the control voltage.

fan switches (heating) Operated by a bimetal strip that closes a set of contacts when the temperature of the heat exchanger reaches a high enough level so no cold air is blown into the living area.

farad Rating or unit of measurement of a capacitor.

feeder The circuit conductor between the service equipment, or the generator switchboard of an isolated plant, and the branch circuit overcurrent protective device.

field discharge resistor Used across a winding to prevent excessive voltage; helps to reduce the voltage induced into the rotor by the collapsing magnetic field when current is disconnected.

field effect transistors High input impedance transistors used by op amps that require little current to operate the amplifier.

filter A device used to remove the ripple produced by a rectifier.

"fire eye" A gas flame sensing device that changes its resistance in the presence of light.

flaker-type Ice maker that produces ice chips or flakes.

"flame rod" A flame-sensing device that operates by using the gas flame as a conductor of electricity.

flex tray Type of ice maker that fills with water and turns at an angle to dump ice cubes into a bin.

flow switch (sail switch) Used in air conditioning systems to sense the flow of air instead of the flow of liquid. Operates on the principal of a sail.

flow washer Part of an electric solenoid valve in an ice maker that meters the amount of water used.

forward biased A diode is forward biased when a positive voltage is connected to the anode and a negative voltage is connected to the cathode.

4-way valve (reversing valve) A common solenoid valve used to change the direction of refrigerant flow in a heat-pump system. Composed of a main valve and a pilot valve operating together.

FR (fan relay) Controls the fan motor. Designed so that a switch can be used to turn the circuit completely off, operate the fan manually, or permit the fan to be operated by a thermostat.

freezer assembly A hollow tube surrounded by a cylindrical container that is the evaporator in the refrigeration unit.

frequency The number of complete cycles of AC voltage that occur in one second.

FSCR (flow switch control relay) The coil of relay connected to the line when the flow switch closes.

full-load torque The amount of torque necessary to produce the full horsepower of a motor at rated speed.

full-wave rectifier Rectifier that uses two diodes to convert AC to DC. Both halves of the AC waveform are used.

fuse A device used to protect a circuit or electrical device from excessive current. Fuses operate by melting a metal link when current becomes excessive.

G

gain The increase in signal power produced by an amplifier.

gate (1) A device that has multiple inputs and a single output. There are five basic types of gates, the and, or, nand, nor, and inverter. (2) One terminal of some electronic devices, such as SCRs, triacs, and field effect transistors.

germanium Gray-white, hard, and brittle chemical element used in the manufacture of semiconductor materials such as transistors and diodes.

gun-type An oil furnace ignited by an electric arc.

H

hair Human hair is used in some humidistats to sense humidity, since it contracts and expands with changes in the amount of humidity in the air.

half-wave rectifier The simplest type of rectifier, it is one diode that changes or converts AC voltage into DC voltage over half an AC waveform.

heat anticipator The component of a thermostat that preheats the sensing element and causes the thermostat contacts to open before the room heat has reached the set point of the thermostat.

heater section Section of a solder-melting type overload relay that is connected in series with the motor.

heating element In a solder-melting type of overload relay, it is wound around the tube and is calibrated to produce a certain amount of heat when a predetermined amount of current flows through it.

heat pump A system that uses refrigerant to supply both heating and cooling to a dwelling.

heat sink A metallic device designed to increase the surface area of an electronic component for the purpose of removing heat at a faster rate.

henry Unit of measurement for inductors, or inductance. One henry is present when the current through a coil, changing 1 ampere per second, produces 1 volt across the coil terminals.

hermetic compressor A compressor that is completely enclosed and airtight.

hertz (Hz) The international unit of frequency.

high leg A configuration in a delta connection where one transformer is larger and center tapped.

high-pressure switch Used to sense amount of pressure in air conditioning and refrigeration units. The bellows in this switch is connected to the discharge side of the compressor via the tube; activates if pressure becomes too great.

holding current The amount of current needed to keep an SCR or triac turned on.

holding relay (HR) Used with short-cycling timers, this relay energizes and changes holding contacts during short-cycling recovery time.

holding, sealing, or maintaining contacts Contacts used to maintain continuous current flow to the coil of a relay.

holding switch Functions in an ice maker by changing positions to maintain the circuit until the cam returns to the freeze, or off, position.

horsepower A measure of power for electrical and mechanical devices.

hot-gas solenoid valve In harvest cycle of ice making, opens and permits high pressure hot gas to be diverted to the evaporator plate.

hot-wire relay A type of starting relay used to disconnect the start windings of a single-phase motor; so named because it uses a length of resistive wire connected in series with the motor to sense motor current.

humidistat A device that can sense the amount of humidity in the air and activate a set of contacts if the humidity should become too high or too low.

hysteresis loop A graphic curve that shows the value of magnetizing force for a particular type of material.

I

illuminate Act or state of being highlighted by light or color. In a PC, illuminated contacts prove they are closed and providing current paths.

impedance The total opposition to current flow in an electrical circuit.

indoor fan relay (IFR) A relay that may control the coils of other relays, which connect the fan motors to the line; may operate several fans at once.

indoor resistance heat Part of a schematic drawing of a heat-pump control system depicting the indoor circuits.

induced current Current produced in a conductor by the cutting action of a magnetic field.

induction motor A motor whose current flow in the rotor is produced by induced voltage from the rotating magnetic field of the stator.

inductive reactance The opposition to current flow in an AC circuit, caused by an inductor. Measured in ohms; its symbol is X_L.

inductor A coil.

inlet Side of a solenoid valve that is connected to the side of the system with the highest pressure (for liquid or gas to flow).

inline Being directly connected into the circuit.

in phase In pure-resistive circuits, the voltage and current are *in phase* when they cross the zero line at the same point, and have their peak positive and negative values at the same time.

input The section of a programmable controller where information is supplied to the CPU.

input impedance Resistance or opposition to current flow in an AC or DC circuit.

input voltage The amount of voltage connected to a device or circuit.

insulation Material that inhibits or slows current.

insulator A material used to electrically isolate two conductive surfaces.

interlock, interlocking A device/method used to prevent some action from taking place in a piece of equipment or circuit until some other action has occurred.

internal relay An imaginary device that exists only in the logic of a computer, programmed by assigning a coil a number greater than the I/O capacity.

inverting amplifier Connection in an op amp that renders the input signal out of phase with the feedback voltage of the output, reducing input voltage and gain.

inverting input Inverts the output of an op amp: if positive-going AC is applied, the output produces negative-going voltage.

I/O capacity Measure of input and output ability of a programmable controller. Number of tracks $\times$ I/O track (32) $=$ I/O capacity (8 I/O tracks $=$ 256 I/O capacity).

I/O rack Contains input and output modules (typically from 2 to 8 each) used to connect the central processing unit to the outside world.

isolation transformer A transformer whose secondary winding is electrically isolated from its primary winding.

J

jumper A short piece of conductor used to make connection between components or a break in a circuit.

junction diode A diode that is made by joining together two pieces of semiconductor material.

K

kick-back diode A diode used to eliminate the voltage spike induced in a coil by the collapse of a magnetic field.

L

lattice structure The pattern that semiconductor material molecules arrange themselves in when refined into a pure form.

leakage current The small amount of current leaked when a very sudden increase of resistance opens a set of contacts. This leakage maintains the temperature of the thermistor and prevents it from returning to a low resistance.

LED (light-emitting diode) A diode that will produce light when current flows through it.

legend In a schematic diagram, a list that shows a symbol or notation and gives the definition of that symbol or notation.

level detector Detects when one voltage becomes greater than another; a comparator.

limit switch A mechanically, generally bimetal-operated switch that detects the position or movement of an object.

line voltage thermostat Used to control loads such as blower fans and heating elements without an intervening relay.

load (1) Anything that may draw current from an electrical power source. (2) In a motor schematic, the large motor (M) contacts that are connected in series with the overload heater element and the motor.

load center Generally the service entrance. A point from which branch circuits originate.

loading terminal Either a handheld device or cathode ray tube (CRT) used to program the programmable controller. Same as program terminal.

locked rotor current The amount of current produced when voltage is applied to a motor and the rotor is not turning.

locked rotor torque The amount of torque produced by a motor at the time of starting.

lockout A mechanical device used to prevent the operation of some other component.

loop A closed electric circuit.

low-pressure switch Used to sense the amount of pressure in an air conditioning and refrigeration system. This switch is connected to the suction side of the compressor and activates if pressure becomes too low.

low voltage controls Section of a heat-pump schematic detailing low voltage circuitry.

low voltage protection A magnetic relay circuit so connected that a drop in voltage causes the motor starter to disconnect the motor from the line.

M

magnetic contactor A contactor operated electromechanically.

magnetic field 1. The space in which a magnetic force exists.

magnetic field 2. Lines of force used to represent magnetic induction.

main limit One of two high-limit contacts connected in series with automatic gas valve of a heating unit. May be located in a fan-limit switch.

maintaining contact Also known as a holding or sealing contact. It is used to maintain the coil circuit in a relay control circuit. The contact is connected in parallel with the start push button.

major components The basic necessary elements, devices, and connections that make up a unit (switch, fan motor, compressor, etc.) and described in schematic diagrams.

manual controller A controller operated by hand at the location of the controller.

metering device Area in a heat pump where liquid or gas is changed to low-pressure liquid.

micro-farad A measurement of capacitance; one-millionth of a farad, symbolized by µf.

microprocessor A small computer. The central processor unit is generally made from a single integrated circuit.

mil-foot Standard measurement of resistance of wire. A mil-foot of wire is one circular mil in diameter and one foot long.

mode A state or condition.

mold heater Part of an ice maker that warms the mold enough to release ice cubes.

motor A device used to convert electrical energy into rotating motion.

motor controller A device used to control the operation of a motor.

motor starters Contactors (designed to control large amounts of current) with the addition of overload relays. Usually contain auxiliary contacts as well as load contacts.

movable contact A contact that moves to make connection with another contact.

multiranged Ability to use one meter movement to measure several ranges of voltage.

multispeed AC motor A motor that can be operated at more than one speed.

mutual induction Induction that results when there is an interaction of adjacent inductors. When the magnetic field of the primary induces a voltage into the secondary winding wound on the same core.

Mylar foil shield Material used in installations to shield cable for signal wiring to reduce noise ratio.

N

nameplates Plates on electric motors that provide important information describing the characteristics of the motor (horsepower, volts, etc).

negative One polarity of a voltage, current, or charge that has an excess of electrons.

negative feedback Reduces the gain and makes the amplifier more stable in an op amp.

negative temperature coefficient (NTC) A thermistor that has this type of coefficient will decrease its resistance as the temperature increases.

NEMA National Electrical Manufacturers Association.

NEMA ratings Electrical control device ratings of voltage, current, horsepower, and interrupting capability given by NEMA.

neutron One of the principle parts of an atom. The neutron has no charge and is part of the nucleus.

node In schematic drawings, the dot in the center of the cross created by connecting wires.

noise reduction ratio Ratio of ability to diminish stray electrical noise or interference in circuits.

nonadjustable Type of pressure switch that must be matched to the refrigerant system, unlike adjustable switches which can be used to switch different systems.

noninductive load An electrical load that does not have induced voltages caused by a coil. Noninductive loads are generally considered to be resistive, but can be capacitive.

noninverting amplifier One of two input connections in op amps that outputs in phase with the feedback: positive in produces positive out.

noninverting input Signal voltage applied to this input will output voltage the same polarity: positive in produces positive out.

nonreversing A device that can be operated in only one direction.

normally closed The contact of a relay that is closed when the coil is deenergized.

normally open The contact of a relay that is open when the coil is deenergized.

NPN Transistor with N and P materials in N-P-N order. Must have positive connected to the collector and negative connected to the emitter.

NPNP Rectifier junction made by joining four layers of semiconductor material together in N-P-N-P order.

N-type material Semiconductor material that has been impurified and rendered with excess electrons, resulting in a net negative charge.

nucleus Central part of an atom, containing neutrons and protons.

nylobraid tube Carries ice to the ice storage bin in an ice maker.

nylon Synthetic material used as a sense element in some humidistats.

O

off-delay timer A timer that delays changing its contacts back to their normal position when the coil is deenergized.

offset null Connection in an op amp used and adjusted to produce 0 volts at the output.

ohm The measure of resistance to the flow of current.

ohmmeter A device used to measure resistance.

Ohm's law Current is equal to the voltage divided by the resistance ($I = E/R$). It takes 1 volt to push 1 amp through 1 ohm.

oil-filled capacitor Made with two metal foil plates separated by paper that has been soaked in a special dielectric oil.

oil-pressure failure switch Switch containing several control functions in the same unit, used in a forced-oil system to protect the compressor from insufficient oil pressure.

on-delay timer A timer that delays changing the position of its contacts when the coil is energized.

open-delta system Type of three-phase service that needs only two transformers to provide three-phase voltage.

operational amplifier (op amp) An integrated circuit used as an amplifier.

opposition Resistance or repelling movement.

optoisolated Situation when the load side of the relay is optically isolated from the control side of the relay and controlled by a light beam.

optoisolator A device used to connect different sections of a circuit by means of a light beam.

orifice Passage on each side of a 4-way reversing valve, each provides a path for a very small amount of refrigerant to flow.

oscillator A device used to change DC voltage into AC voltage; produces a waveform that has positive and negative pulses of equal voltage and time.

oscilloscope A voltmeter that displays a waveform of voltage in proportion to its amplitude with respect to time.

outdoor compressor controls Section of a schematic detailing outdoor circuitry of a heat-pump system.

outlet Side of solenoid valve at which, if reversed and applied to the outlet side of the system, the pressure could cause valve leakage.

out-of-phase The condition in which two components do not reach their positive or negative peaks at the same time.

output The section of the programmable controller where information is supplied to the outside circuits by the CPU.

overload Potentially damaging situation where too much current flows through a circuit not built to sustain the excess, thus overloading or overheating.

overload relay A relay used to protect a motor from damage due to overloads. The overload relay senses motor current and disconnects the motor from the line if the current is excessive for a certain length of time.

P

panelboard A metallic or nonmetallic panel used to mount electrical controls, equipment, or devices.

parallel circuit A circuit that contains more than one path for current flow.

peak-inverse/peak-reverse voltage The rating of a semiconductor device that indicates the maximum amount of voltage in the reverse direction that can be applied to the device.

peak-to-peak voltage The amplitude of AC voltage measured from its positive peak to its negative peak.

peak voltage The amplitude of voltage measured from zero to its highest value.

permanent magnet rotor The rotor of a motor or generator that is constructed using permanent magnets.

permanent split-capacitor motor (PSC) A single-phase induction motor similar to the capacitor start motor except that the start windings and the starting capacitor remain connected in the circuit during normal operation.

phase shift, phase shifted A change in the phase relationship between two quantities of voltage or current (lead and lag), from one to another.

photoconductive A device that changes resistance in accord with the amount of light present.

photodetector Connected to a triac gate to control the output; permits current flow.

photodiode Semiconductor device for detecting and measuring radiant energy (light) by means of its conversion into an electric current.

photovoltaic A device that produces a voltage in the presence of light. Generally called a solar cell.

pico-farad Used in extremely small capacitors; one millionth of a micro-farad, symbolized by µµf or pf.

pilot device A control component designed to control small amounts of current. Pilot devices are used to control larger control components.

pilot light A small gas flame that burns continuously near the main burner of a gas burner.

pilot valve Operates with the main valve in a 4-way reversing valve. Controls the operation of the main valve which controls the flow of refrigerant in a system.

plunger-type Type of solenoid that is generally used with relays that use double-break contacts. The coil is surrounded by the iron core that has an opening in it for the shaft of the armature to pass.

pneumatic timer A device that uses the displacement of air in a bellows or diaphragm to produce a time delay.

PN junction An accurate and linear device, or diode, that measures temperature.

PNP Transistor with P and N materials in P-N-P order. Must have positive connected to the emitter and negative connected to the collector.

PNPN Rectifier junction made by joining four layers of semiconductor material together in P-N-P-N order.

polarity The characteristic of a device that exhibits opposite quantities within itself: positive and negative.

positive temperature coefficient (PTC) A thermistor with this type of coefficient will increase its resistance as temperature increases.

potential relay Operates by sensing an increase in the voltage developed in the start winding when the motor is operating.

potentiometer A variable resistor with a sliding contact that is used as a voltage divider.

power connector The connector that is connected to the incoming power.

power factor A comparison of the true power (watts) to the apparent power (volt amps) in an AC circuit.

power rating The rating of a device that indicates the amount of current flow and voltage drop that can be permitted.

power supply Part of a programmable controller used to lower the incoming AC voltage to desired level, rectify it to DC, then filter and regulate it.

power transistor Used to connect the load to the line in a relay designed to control a DC load.

pressure regulator Internal component of many control valves, it maintains a constant pressure to the main burner.

pressure switch A device that senses the presence or absence of pressure and causes a set of contacts to open or close.

primary control The major part of an oil-fired control system, it ensures that when the thermostat calls for heat, the flame will be created within a predetermined amount of time.

printed circuit A board on which a predetermined pattern of printed connections has been made.

programmable logic controllers (PLCs) Comprised of a power supply, central processing unit, program loader or terminal, and I/O rack, these machines are generally designed to be programmed with relay schematic and ladder diagrams instead of computer languages for quick, versatile changes and use.

programmable thermostat Can be set to automatically operate at different temperature settings at different times.

programming terminal Used to load or amend a program in a programmable controller. Same as loading terminal.

proton One of the three major parts of an atom. The proton has positive charge.

PSCR (pressure switch control relay) Used in a circuit designed to turn off a compressor if the pressure in the system reaches a predetermined (high) level. If power is disconnected, a warning light will appear and the circuit must be manually reset.

psig (pounds per square inch gauge) Standard measuring system to measure pressure.

P-type material Semiconductor material that has only 3 valence electrons, leaving a hole in its lattice structure, resulting in it having a net positive charge.

pulse generator Op amp that produces a waveform of positive and negative pulses of inconsistent voltage and time (pulse duration changes).

pure-capacitive circuit The current in this type of circuit is limited by the voltage of the charged capacitor.

pure-inductive circuit A circuit in which the current lags behind the voltage by 90°. There is no true power or watts in this circuit.

pure-resistive circuit Similar to a DC circuit in having true power or watts equal to the voltage times the current. In this circuit the voltage and current are in phase with each other.

push button A pilot control device operated manually by being pushed or pressed.

R

rapid cool down Removing heat from an object in a short period of time.

reactance The opposition to current flow in an AC circuit offered by pure inductance or pure capacitance.

reciprocal A pair of numbers whose product is 1, can be found by dividing that number into 1.

rectifier A device or circuit used to change AC voltage into DC voltage.

reed relay A small set of reed contacts connected to the gate of the triac; these contacts are closed by a magnetic field and in turn cause the triac to turn on. Used to control solid-state relays.

regulator A device that maintains a quantity at a predetermined level.

relay A magnetically operated switch that may have one or more sets of contacts.

relay schematic Schematic diagram used for relay logic. These must be adapted to be loaded into a programmable computer.

remote control Controls the functions of some electrical device from a distant location.

resistance The opposition to current flow in an AC or DC circuit.

resistance-start induction run motor One type of split-phase motor that uses the resistance of the start winding to produce a phase shift between the current in the start winding and the current in the run winding.

resistance temperature detector (RTD) Made of platinum wire, this measures temperature accurately, since the resistance of platinum changes greatly with temperature.

resistive heating element Heating component located near the evaporator of a frost-free appliance, connected at set intervals by a defrost timer to melt any frost on the evaporator.

resistor A device used to introduce some amount of resistance into an electrical circuit.

reversed biased When negative voltage is connected to the anode and positive voltage is connected to the cathode resulting in an open connection with no current flow.

reversing valve (4-way valve) used to change the direction of flow of refrigerant in a heat-pump system.

reversing valve solenoid A device in a heat-pump system that, if deenergized, indicates the unit is in the heating mode.

rheostat A variable resistor.

RMS value The value of AC voltage that will produce as much power when connected across a resistor as a like amount of DC voltage.

rotating field speed Determined by the number of stator poles and the frequency.

rotating magnetic field The principle of operation for all three-phase motors. A magnetic field that rotates due to either voltages being out of phase, voltages changing polarity, or the arrangement of stator winding in a motor.

rotor A large electromagnet that is the moving part of the alternator.

rotor bars Bars that are part of the rotor in a squirrel-cage induction motor.

rotor slip Condition produced by a weakening magnetic field due to series impedance, eventually causing the motor speed to decrease.

run winding In the stator of a split-phase motor, it is made of large wire and is placed in the bottom of the stator core.

S

sail switch (Flow switch) Used in air conditioning systems to sense the flow of air instead of the flow of liquid. Operates on the principle of a sail.

saturation The maximum amount of magnetic flux a material can hold.

schematic An electrical drawing showing components in their electrical sequence without regard for physical location.

SCR (silicon-controlled rectifier) A semiconductor device that can be used to change AC voltage into DC voltage. The gate of the SCR must be triggered before the device will conduct current.

semiconductor A material that contains four valence electrons and is used in the production of solid-state devices.

sensing device A pilot device that detects a quantity and converts it into an electrical signal.

sequence timer Used to turn the strip heaters (heating elements) on in stages instead of all at once.

series circuit A circuit that contains only one path for current flow.

service The conductors and equipment necessary to deliver energy from the electrical supply system to the premises served.

service factor An allowable overload for a motor indicated by a multiplier that, when applied to a normal horsepower rating, indicates the permissible loading.

shaded-pole induction motor An AC induction motor that develops a rotating magnetic field by shading part of the stator windings with a shading loop.

shading coil A large loop of copper wire or a copper band wound around one end of a shaded pole.

shading loop A large copper wire or band connected around part of a magnetic pole piece to oppose a change of magnetic flux.

shielded cable Cable that has been wrapped in protective covering to provide noise reduction in signal wiring.

short circuit An electrical circuit that contains no resistance to limit the flow of current.

short cycling The starting and stopping of a compressor in rapid succession.

short-cycling timer A cam-operated, motor driven, on-delay timer that allows time to operate and reset short-cycled contacts to their original positions.

silicon Most common element used to make semiconductor devices due to its ability to withstand heat.

silicon bilateral switch (SBS) A solid-state component in a primary control of an oil burner that, if disconnected, behaves like a diac and will conduct current to the primary control's triac.

silicon-controlled rectifier (SCR) A thyristor, also called the PNPN junction, used when an electronic device is needed to control large amounts of power.

sine-wave voltage A voltage waveform whose value at any point is proportional to the trigonometric sine of the angle of the generator producing it.

single-phase Formed by connecting a single transformer to a three-phase line.

single-pole breaker A circuit breaker used for connecting a 120-volt circuit.

slip The difference in speed between the rotating magnetic field and the speed of the rotor in an induction motor.

slip ring When present on rotor shafts, permits the connection of external resistance to the rotor windings. Always used in pairs.

snap-action The quick opening and closing action of a spring-loaded contact.

solder-melting type An overload relay that uses a heating element to detect overloads.

solenoid A magnetic device used to convert electrical energy into linear motion.

solenoid coil Component of a heat-pump system which, if energized, will change the position of the plunger of the pilot valve.

solenoid valve A valve operated by an electric solenoid used to control the flow of gasses or liquids.

solid-state hard starting kit Used to increase the starting torque of a permanent-split capacitor motor; contains a solid-state relay and an AC electrolytic capacitor.

solid-state relay A device or an electronic component constructed from semiconductor material, used to control either AC or DC loads. Advantages are that it has no moving parts, is resistant to vibration, and is sealed against dirt and moisture.

solid-state starting relay Actually an electronic component known as a thermistor, intended to replace the current-type starting relay.

split-phase motor A type of single-phase motor that uses resistance or capacitance to cause a shift in the phase of the current in the run winding and the current in the start winding. The three primary types of split-phase motors are: resistance start induction run, capacitor start induction run, and permanent split-capacitor.

squirrel-cage induction motor An induction motor whose rotor contains a set of bars that resemble a squirrel cage.

staging thermostat A thermostat that contains more than one set of contacts that operate at different times in accord with the temperature.

star Also known as the wye connection, one of the three-phase wiring configurations.

starter A relay used to connect a motor to the power line.

starting relay Located away from the motor and used to disconnect the start windings when the motor has reached about 75% of its full speed. Used especially in single-phase motors that are hermetically sealed and unable to use a centrifugal switch.

start winding In the stator of a split-phase motor, it is made of small wire and is placed near the top of the stator core.

stationary contact A contact that is fixed and cannot move.

stator The stationary winding of an AC motor.

step-down transformer A transformer that produces a lower voltage at its secondary than is applied to its primary.

stepstarting Similar to shifting gears in the transmission of an automobile, method used in most large wound motors, as opposed to actual variable resistors. Starts with maximum resistance and with increasing speed shorts out resistance.

step-up transformer A transformer that produces a higher voltage at its secondary than is applied to its primary.

surge A transient variation in the current or voltage at a point in the circuit. Surges are generally unwanted and temporary.

switch A mechanical device used to connect or disconnect a component or circuit.

synchronous condenser A synchronous motor operated at no load and used for power factor correction.

synchronous motor A three-phase motor that is *not* an induction motor; it will run at a constant speed from no load to full load and can correct its own power factor and the power factors of other motors connected to the same line.

synchronous speed The speed of the rotating magnetic field of an AC induction motor.

T

tapped A circuit that has been cut in on by another circuit, or split in its configuration by a circuit.

temperature Affects resistance of wire; resistance increases as temperature increases.

temperature relay A relay that functions at a predetermined temperature. Generally used to protect some other component from excessive temperature.

terminal, terminal board A fitting attached to a device for the purpose of connecting wires to it.

terminal markings Identification letters and symbols assigned to circuitry in schematic drawings to aid in tracing the circuits.

termination temperature Temperature at which the terminals of devices connected to the conductor will be withstood.

test points Labeled on a plate behind the ice maker's front cover, provide option of testing different parts of the electrical circuit with volt- or ohmmeter.

thermistor A resistor that changes its resistance with a change of temperature.

thermocouple Made by joining two dissimilar metals together at one end. The voltage produced is proportional to the types of metals used and the difference in temperature of the two junctions.

thermopile A series connection of thermocouples to permit the voltages to add and produce a higher output voltage.

thermostats Temperature-sensitive switches that employ a variety of methods to sense temperature and can be found with different contact arrangements.

three phase Having three separate voltage waveforms produced by the alternator.

three-phase motors Motors operated by a rotating magnetic field: squirrel-cage induction motor, wound rotor induction motor, and synchronous motor.

three-phase squirrel-cage induction motor A wye-connected motor with no external resistors for the rotor circuit and no DC circuit to excite the rotor.

three-pole breaker A circuit breaker used for connecting a three-phase circuit.

three-wire control circuits More flexible than two-wire control circuits, these are characterized by the fact that they are operated by a magnetic relay or motor starter.

thyristor An electronic component that has only two states of operation: on or off.

time-delay circuit Consists of a current-limiting resistor, a resistance heating element, and a bimetal strip; permits the compressor to operate long enough for oil pressure to build up in a system.

timer clock Device used in place of a defrost timer to activate defrost cycles. Its construction, including a separate timer release solenoid, allows the defrost cycle to be activated during minimum use periods.

timer motor Part of a short-cycle timer that is geared to permit a delay of about 3 minutes before contacts change position to restart a compressor.

torque The turning force developed by a motor.

transducer A device that converts one type of energy into another type of energy. Example: A solar cell converts light into electricity.

transformer An electrical device that changes one value of AC voltage into another value of AC voltage.

transistor A solid-state device made by combining three layers of semiconductor material together. A small amount of current flow through the base-emitter can control a larger amount of current flow through the collector-emitter.

triac A bidirectional thyristor used to control AC voltage.

troubleshoot To locate and eliminate problems in a circuit.

true power The wattage, or measure of the amount of power that is being used in a circuit.

turns ratio Relationship between the number of turns in the primary of a transformer and the number of turns in the secondary.

two-conductor romex A cable used in circuit breaking containing three wires—black (hot), white (neutral), and bare copper (grounding).

two-phase power Produced by having an alternator with two sets of coils wound 90° out of phase with each other.

two-pole breaker Circuit breaker used for connecting a 240-volt single-phase circuit.

two-speed compressors The systems that maintain the difference in pressure between the high and low sides, that have two speeds.

two-wire control circuit In this circuit, a simple switch is used to control the power applied to a small motor. Switch open means no complete path for current to flow; switch closed supplies power.

U

unijunction transistor A digital transistor that has two bases and one emitter made by combining three layers of semiconductor material.

unity Pure-resistance, or having a power factor of 100%.

V

valence electrons Electrons located in the outer orbit of an atom.

valence shell The outer shell of an atom.

variable resistor A resistor whose resistance value can be varied between its minimum and maximum values.

variable speed A motor or device that permits a change of speed.

variable-speed motors Shaded-pole or permanent-split capacitor motors able to change speeds without disconnecting by a switch or relay. Commonly used to operate light loads such as ceiling fans and blower motors.

varistor A resistor that changes its resistance value with a change of voltage.

VARs (volt-amps-reactive) In a pure-inductive circuit, the value of the voltage multiplied by the current. Also known as wattless power.

voltage An electrical measurement of potential difference, electrical pressure, or electromotive-force (EMF).

voltage drop The amount of voltage required to cause an amount of current to flow through a certain resistance.

voltage follower A basic op amp circuit in which the output is connected directly back to the inverting input, producing a gain of 1; used for impedance matching purposes.

voltage rating A rating that indicates the amount of voltage that can be safely connected to a device.

voltage regulator A device or circuit that maintains a constant value of voltage.

volt-amps The apparent power of an AC circuit; the applied voltage multiplied by the current flow.

voltmeter An instrument used to measure a level of voltage.

volt-ohm-milliammeter (VOM) A test instrument so designed that it can be used to measure voltage, resistance, or milliamperes.

W

watchdog timer A time that runs continually to ensure that the program does not become locked in a loop.

water solenoid valve Valve in an ice maker that opens and permits fresh water to flow into the sump.

watt, wattage A measure of true power, or the amount of power being used in a circuit. It is proportional to the amount of voltage and the amount of current flow.

waveform The shape of a wave obtained by plotting a graph of voltage with respect to time.

wiring diagram An electrical diagram used to show components in their approximated physical location with connecting wires.

wound motor induction motor A three-phase induction motor used for large air conditioning units. Stator winding is the same as squirrel-cage stator; however, the rotor contains wound coils of wire instead of squirrel-cage rotor bars, and will contain as many poles as there are stator poles.

wye, wye connection A three-phase wiring configuration that resembles the letter Y when the three coils are connected and schematically drawn. Also known as star, or the star connection.

Z

zener diode A diode that has a constant voltage drop when operated in the reverse direction. Zener diodes are commonly used as voltage regulators in electronic circuits.

zero switching Occurs when a relay is told to turn off while the AC voltage is in the middle of a cycle. The relay will continue to conduct until the AC voltage drops to a zero level and then turn off.

zone Generally refers to heating or cooling a certain section of a dwelling.

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Note: "f" indicates a figure

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