

**Study Unit**

# **Understanding and Using Electronic Diagrams**

By

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In your studies so far, you've learned the basic principles of how electrical circuits provide power for useful work. Basic circuits consist of a power source, components that regulate the flow of current, and loads such as motors, lights, heaters, and more complex devices like computers or televisions. Electrical and electronic technicians may work installing, servicing, maintaining, and troubleshooting hundreds of different electrical and electromechanical devices from many different manufacturers, on a regular basis. Over the years a standard visual language has evolved that allows designers, engineers, and technicians to effectively describe these electrical devices' functions.

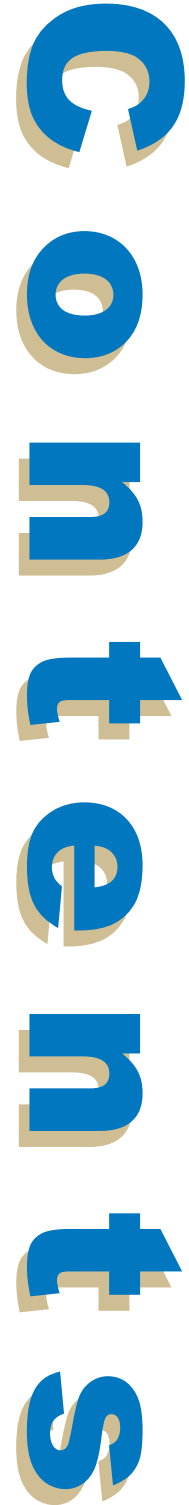
In this unit you'll learn how circuits are described by drawings called *schematics*. These drawings use standard symbols that allow technicians to quickly understand how a circuit is constructed, what function it performs, and how to troubleshoot the equipment. Schematics are also sometimes called *prints* or *blueprints*. Each electrical component has a universally recognized symbol, and schematic drawings typically show the connections between the components. As you learn how the different types of components can be connected, you'll begin to recognize common circuit configurations that occur repeatedly in many different types of electrical equipment. Knowing these circuit conventions and configurations will help you quickly spot likely problems based on the type of equipment and the symptoms you observe. You'll also know how circuits can be modified to alter their function, add capabilities, or improve their behavior.

# Preview

**When you complete this study unit, you'll be able to**

- Understand the difference between schematics, wiring diagrams, and block diagrams, and how each is used to describe circuit performance and function
- Recognize common electrical component symbols and drawing conventions that describe circuits
- Recognize and describe the configuration of common circuit building blocks such as power supplies, oscillators, amplifiers, load drivers, and digital circuits
- Understand how schematics can supply important information for troubleshooting electrical circuits

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# Understanding and Using Electronic Diagrams

## DRAWINGS REPRESENTING ELECTRONIC EQUIPMENT

Electrical and electronic technicians are often called on to install and maintain hundreds of different types of devices. As these devices have grown in variety and complexity, a system of symbols and conventions evolved to describe the circuits in a shorthand method of documentation. This allows engineers, designers, and technicians to understand how the circuits that make up a device work, and how its components connect with each other. Although the *schematic diagram* is the most common document for this function, there are also *block diagrams* and *wiring diagrams*. Each of these documents has a unique function in describing the circuit to aid in understanding and troubleshooting.

Technicians encounter some differences between U.S. company schematics and those produced in European or Asian countries. In this unit you'll study mostly the schematics you'll see from American companies, but once you're accustomed to reading these, you'll recognize common characteristics in all schematics.

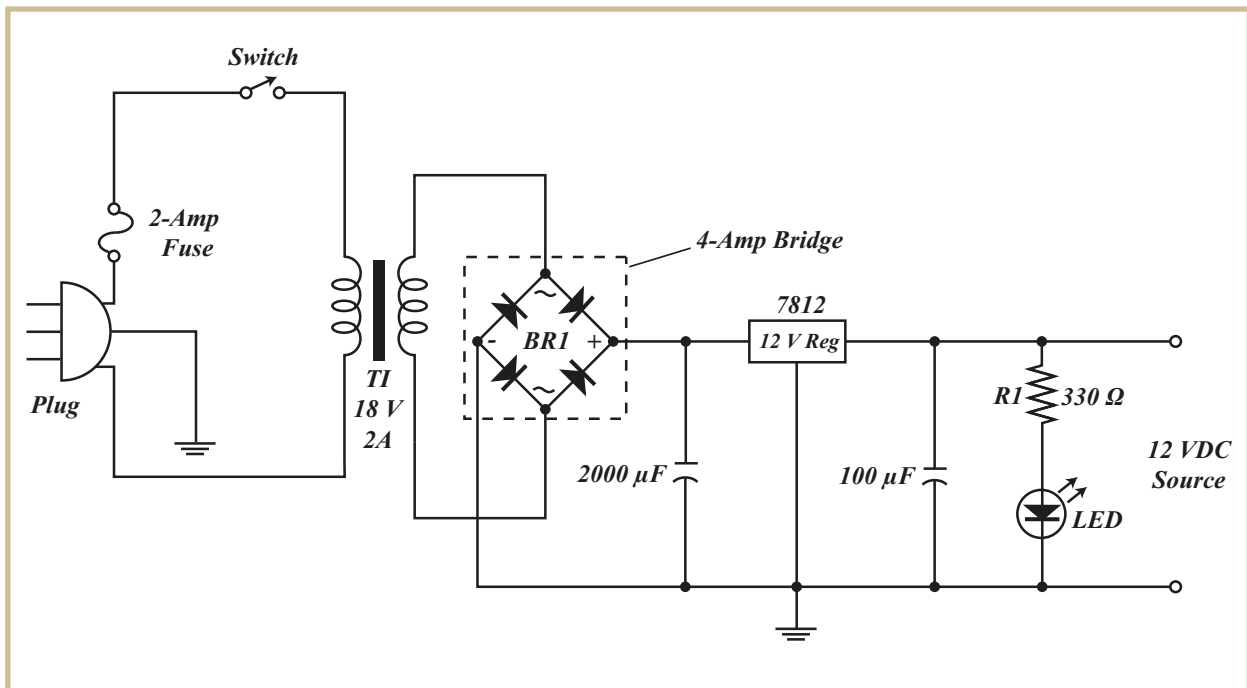
### Schematic Diagrams

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Schematic diagrams document the connection points and construction methods of electrical and electronic circuits. Figure 1 shows a simple schematic diagram of a power supply; on it you can see some of the conventions used. Figure 2 shows the symbols for such basic components as wires and

connections, switches, power sources, transformers, fuses, and ground connections. In addition to these standard symbols, you'll sometimes run across symbols that are variations of these, or ones that are specific to certain companies, especially in older schematic diagrams.

Schematic diagrams are often read from left to right, like a book, with inputs on the left and outputs on the right. This isn't a universal practice, but it's a good way to begin your analysis of the schematic. Schematic diagrams show the connections of the components in a clear, easily readable format, but they don't show how the components are physically arranged. In the schematic in Figure 1 you'll see a plug on the left side; this means the supply (or any device with this symbol) is powered by an AC source, which isn't shown. The fuse is in series with the power transformer to prevent damage from overloads, and the switch controls the on/off status of the supply. Note that neither of the transformer primary wires are grounded.



**FIGURE 1**—This is a simple schematic of a power supply, containing some commonly encountered symbols.

This schematic uses the convention of dots to indicate connected wires (see the left side of BR1); unconnected wires simply cross each other. To avoid confusion, unconnected wires that cross sometimes have *jumpers* to show that the wires aren't connected (see Figure 2). This is an older convention, but you'll still find it on many diagrams.

You'll also see that the components often have text written next to them: the component number, component value or rating, and perhaps the catalog number. Components often have standard alphanumeric designators, such as  $D_1$ ,  $D_2$ , etc., for diodes;  $Q_1$ ,  $Q_2$ , etc. for transistors;  $U_1$ ,  $U_2$ , etc., for integrated circuits; and  $C_1$ ,  $C_2$ , etc., for capacitors. The numbers advance for each designator, so if there are 22 resistors in a circuit, they'll be numbered  $R_1$  through  $R_{22}$ , and the values and specifications will often be listed in a bill of materials on the side of the schematic. When there are multiple devices within a single physical package, as with quad op-amp packages or hex inverter integrated circuits, the individual amp or gate will be labeled  $U_{1A}$  or  $U_{1B}$  to indicate that it's one of several components in one package.

For some components such as capacitors, you have to determine what standard units are being used. A capacitor  $C_1$  in a schematic might be listed as  $C_1$  3300. The  $C_1$  designation will more often be printed simply as  $C_1$ . Throughout the study unit, we'll treat these two styles of designation as interchangeable. The number 3300 refers to the capacity value in *microfarads*. Capacitors and other components often have voltages listed. If a voltage rating of 50 V is specified on the print, a replacement capacitor for  $C_1$  should have a value of 3300 microfarads and a minimum voltage rating of 50 volts. A 100-volt capacitor would be acceptable as a replacement, but a 25-volt capacitor wouldn't.

In the case of the transformer, the voltage listed refers to the secondary voltage. The primary side is connected to line voltage of 120 volts, so the step-down transformer in Figure 1 has a turns ratio of  $120\text{ V}/18\text{ V} = 6.67:1$ . Since the secondary voltage is 18 volts and the maximum current is 2 amps, you know that the maximum volt-amp (VA) rating of the transformer is  $18\text{ V} \times 2\text{ A} = 36\text{ VA}$ . A replacement transformer would need to have the same secondary voltage, but could have a larger VA rating if overall size isn't a factor, since larger VA ratings usually require larger transformers.

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Throughout most of this study unit and in some schematics, components are identified with numbers that are printed as subscripts (such as  $C_1$ , representing "capacitor number 1"). While printing the numbers as subscripts makes them easier to recognize, most schematics will just place the number immediately after the letter as in C1. You should recognize that these two identification methods are interchangeable and realize that you'll find both labeling styles used throughout documentation related to electronic systems.

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In this simple power supply, all the voltage regulation functions are done by  $U_1$ , which is a 7812 positive voltage regulator. This is an integrated circuit that has regulation and protection circuits built into one package. These circuits are easy to use, and are found in many applications. You'll start to recognize the numbers after you see them a few times. In this case, the 78 means this is a positive voltage regulator, and the 12 means 12 V output. A designation of 79 means a negative regulator, so a 7905 would mean a negative 5 V regulator.

Often, you'll see numbers at the top or bottom of the transformer such as 4:1, and the number on either side of the colon will refer to the side of the transformer it applies to. For example, a power transformer marked 4:1 with the 120 V input on the left and the output voltage on the right (as in Figure 1), will have a turns ratio of four primary turns of wire for every secondary turn, making it a step-down transformer with an output voltage of  $120 \text{ V} / 4 = 30 \text{ V}$ .

The best way to analyze a schematic is to first identify all inputs and outputs, and then find the power supply outputs and the distribution of voltage to other parts of the circuit. In general, troubleshooting a circuit that isn't functioning correctly begins by confirming the presence of the correct power supply voltage at all points throughout the circuit.

## Abbreviations

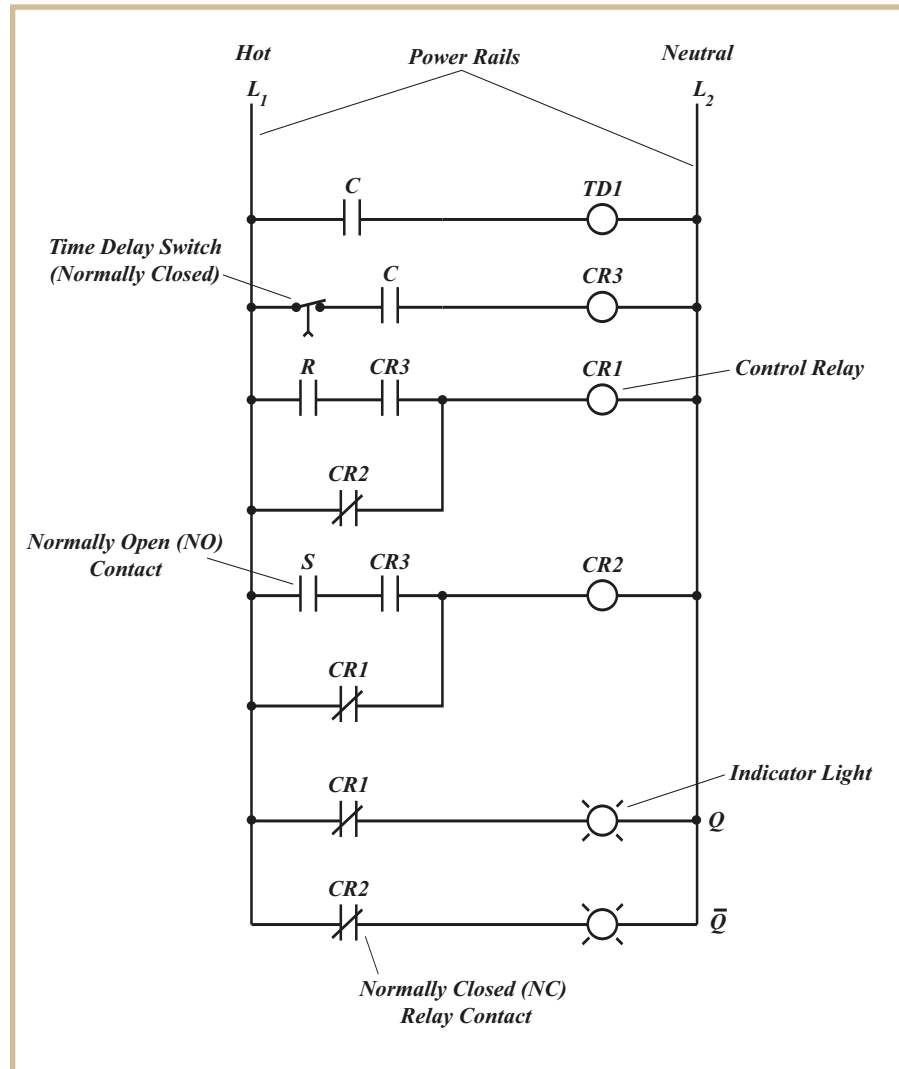
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To save time and space when preparing schematics, engineers and designers have adopted many abbreviations. In addition to the standard component identification numbers and letters, such as L1, Q3, and R24, you'll see notes and text on the drawings that use shorthand abbreviations. For example, if you see a note that says XMTR SECTION 4W MAX, you would know that it refers to a transmitter, probably with a maximum of 4 watts of maximum output power. With practice, you'll begin to recognize these notes on schematic drawings, especially in context. You might also see some nonstandard abbreviations and text at various places on the drawing that are used for specific purposes by the company that produced the drawing; unless you have inside company information, however, you may never know what they mean.

## Ladder Diagrams

In your work, you may encounter a type of schematic called a *ladder diagram*, as shown in Figure 3. The general layout of the wires and components resembles a ladder, with vertical rails and horizontal rungs. The input voltage is usually on the left vertical rail; the ground or neutral is on the right vertical rail; and the components are found on the horizontal rungs that connect the two rails.

**FIGURE 3—Ladder diagrams generally have a recognizable shape of a ladder, with the side rails usually representing the power supply and the rungs showing the logical sequence of electrical actions. Newer schematics such as this one usually incorporate the symbols used in software that generates the schematics.**



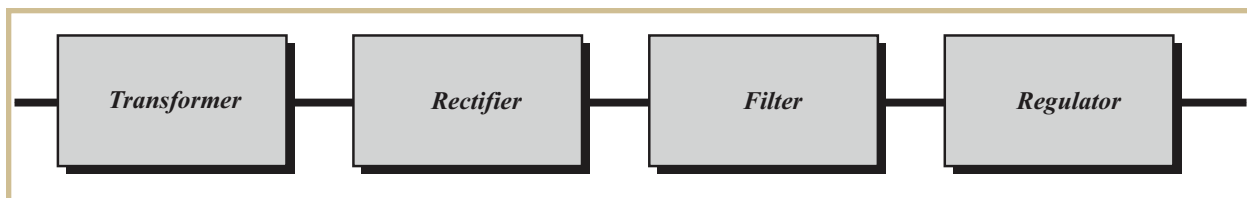
This type of schematic is used in control applications for equipment that controls a sequence of operations. For example, a washing machine goes through predefined steps each time a cycle is started, and there are a number of options available at the beginning of and during the wash cycle. Depending on the settings of switches, different actions are possible. In industrial applications, a *programmable logic controller (PLC)* is often used to control the steps and options with a program installed in the controller. You'll find PLCs in a variety of industrial applications such as robotic welders, assembly lines, and packaging operations.

Figure 4 shows some of typical symbols used in PLC diagrams. You'll see that the symbols on the rungs are switches, motors, contacts, timers, and other high-level devices, and not individual components such as capacitors, diodes, amplifiers, or transistors. Ladder diagrams are usually best understood by reading them from top to bottom and left to right, since the cycle of operations is often performed in that sequence. The power connections are generally at the top of the ladder, and the left rail is the hot side, while the right rail is the neutral, or common. Options in the sequence are determined by the condition of sensors or control settings. Relays, switches, and other controls are always shown in the *unenergized state*, meaning that the equipment hasn't been activated to perform the operation.

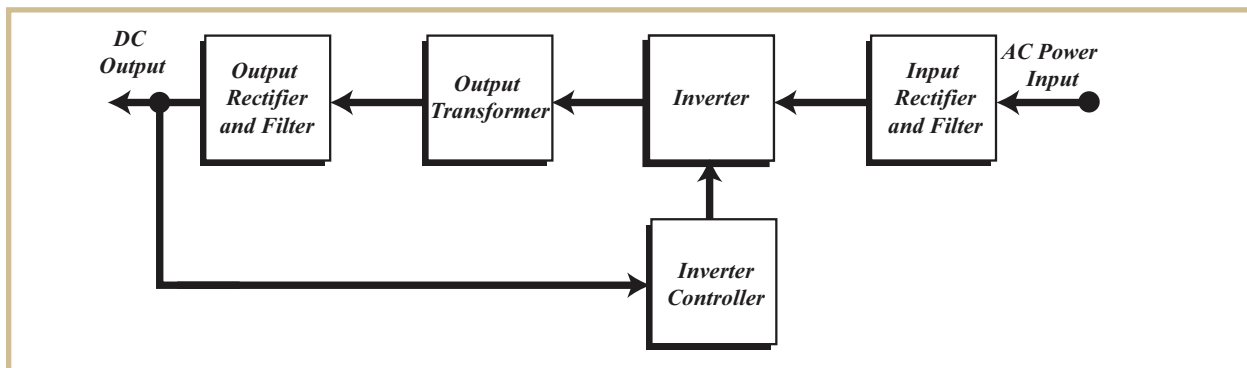


## Block Diagrams

*Block diagrams* portray the general operation and construction of a circuit using blocks connected by lines or arrows (see Figure 5). In a block diagram, each block describes the function of a circuit building block with a label and perhaps a brief description, rather than the details of the circuit. For example, Figure 5 shows a simple power-supply block diagram with the functional components and their arrangement in the circuit. Each block represents the function of that part of the circuit: rectifier, filter, regulation, and output. There are no details of how the circuit is constructed, but you can see how each part of the circuit is connected to the others to make a complete power supply. Figure 6 shows the block diagram of another common type of modern power supply, the *switching-mode power supply (SMPS)*. You can see that these power supplies have extra sections, including *feedback* from the output to some point in the beginning stages. Feedback is used in many electronic circuits, and finding and analyzing the feedback circuit is important when troubleshooting a defective circuit. *Note:* Different power supplies can have the same or a similar block diagram yet differ significantly in their construction.

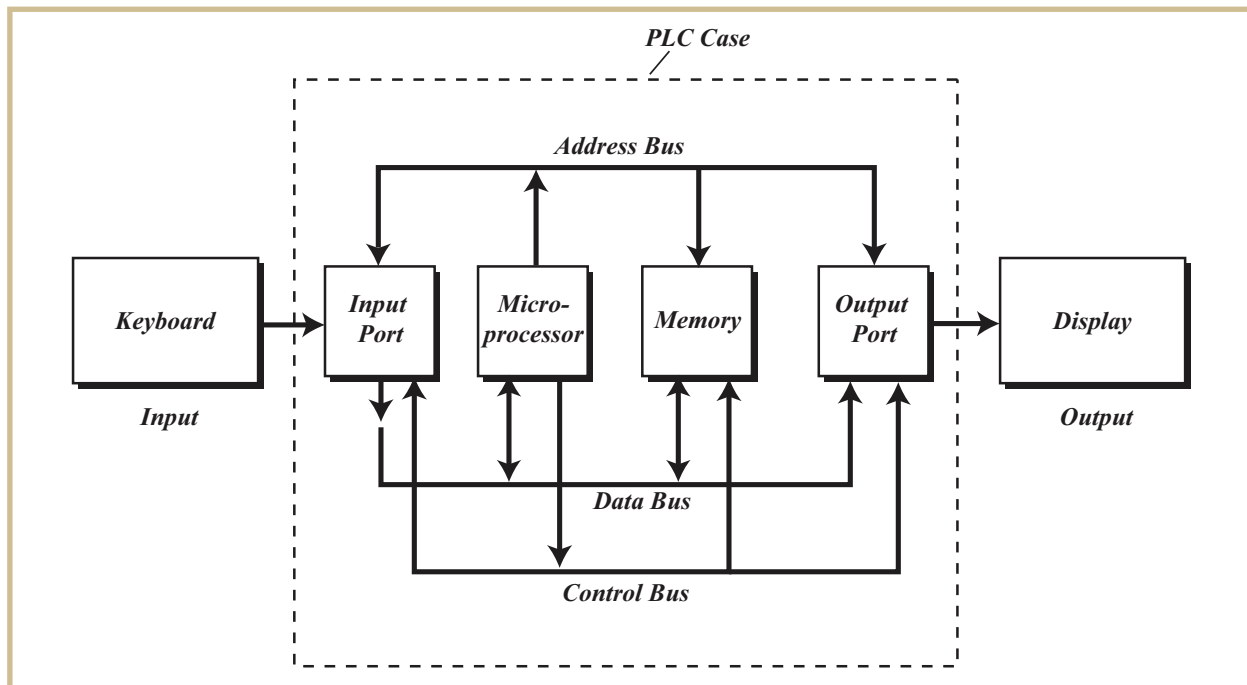


**FIGURE 5**—Block diagrams are a shorthand way of showing the function and connections of complex circuits. The blocks represent parts of a circuit that perform specific functions, but without showing the details.



**FIGURE 6**—Block diagrams help technicians understand more complex equipment by showing the functional blocks of the circuit and how they're connected.

Block diagrams give technicians an overview of the whole circuit, so any significant variations between the circuit you're studying and other common designs will be immediately apparent, regardless of differences in the actual components within the blocks. Different types of blocks shown in different circuits often contain similar components. For example, the circuit components inside a typical *output amplifier* block will be the same as those found in many other output amplifiers. Figure 7 shows the block diagram of a more complex electronic device, a relatively simple micro-computer. Notice that the diagram gives a clear picture of functional blocks and their inputs and outputs, and how they're connected. In fact, the detailed schematic of a modern computer is extremely complex. Because many of the functions are built into integrated circuits, the schematic diagram won't necessarily help the technician troubleshoot a problem.



**FIGURE 7—Modern computers are extremely complex, but block diagrams show their major components and connections in a relatively simple format. Some of the functions are physically located in the same integrated circuit. For example, some modern controllers include the microprocessor and the memory on the same chip.**

## Wiring Diagrams

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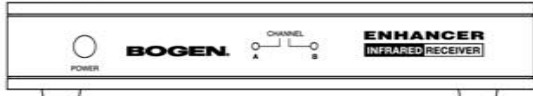
Schematic diagrams are drawn in a way that makes the connections between the component clear and easy to interpret. However, because of the different sizes and mounting requirements for components such as power transistors, transformers, electrolytic capacitors, and relays, the actual wires connected to them may be in very different locations. So *wiring diagrams* are used to show the physical arrangements of the components as they're actually mounted in the equipment. Pictures or drawings often illustrate the physical mounting and connecting wires for the components. You can easily see the difference between a schematic and a wiring diagram. Figure 8 shows a wiring diagram for an amplifier and speaker system.

Wiring diagrams are especially useful in things such as appliances, automobiles, welders, and any equipment that uses large components such as transformers, motors, and relays mounted some distance from the control circuits. Today, wiring diagrams are often photographs of actual equipment, with labels added to point out key wires, components, and mounting configurations.

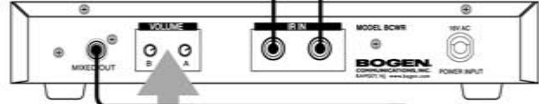


**ENHANCER ESYS4(M)**

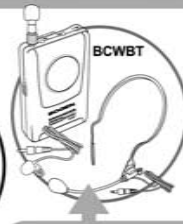
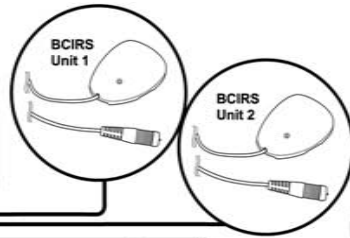
**ENHANCER IR Receiver**  
FRONT VIEW



REAR VIEW



The Enhancer Receiver's mixed output level (for each channel) is controlled by the "A" and "B" Volume Controls.

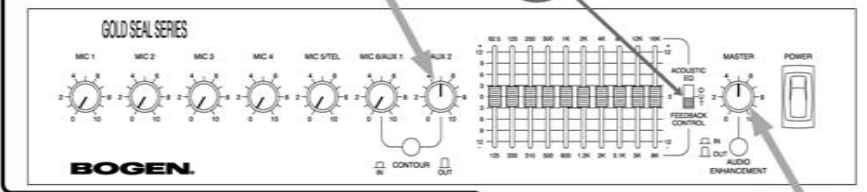


The Enhancer Body-Pack Transmitter (BCWBT) output level is controlled by the body-pack's volume control.



The (BCWHT) Wireless Handheld Microphone operates solely on channel "B". The BCWHT Mic is available with the ESYS "M" package.

**Gold Seal Series Amplifier**  
FRONT VIEW



Volume Control for Enhancer

Fig. B (see NOTE 2)  
ACUSTIC EQ FEEDBACK CONTROL

Master Volume Control for System Output

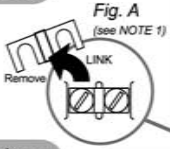


Fig. A (see NOTE 1)

LINK Connection jumper should remain in place

**HFCS1 Ceiling Speakers (4)**  
FRONT VIEW

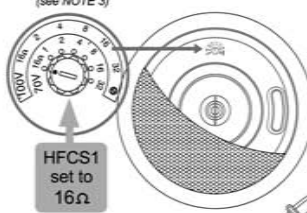
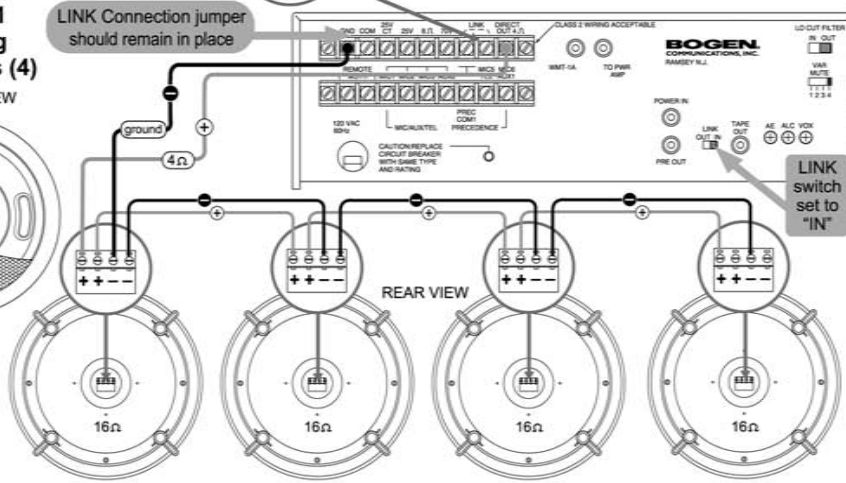


Fig. C (see NOTE 3)

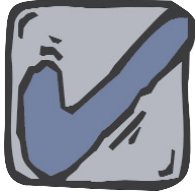


- ESYS4 NOTES:**
1. On rear panel of the amplifier, remove the "LINK" connection. (see Fig. A)
  2. When switch is set to "FEEDBACK CONTROL," the amplifier can be used to improve "Max Volume before Feedback". (see Fig. B)
  3. On each HFCS1 speaker, turn the Tap Selector setting to 16Ω. (see Fig. C)

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**FIGURE 8—A wiring diagram shows technicians how wires are physically connected in electrical equipment, often showing the location of the wires within the device. Wiring diagrams are helpful in locating the components and tracing the connections when trying to find faults or check voltages.**  
(© 2006 Bogen)





# Self-Check 1

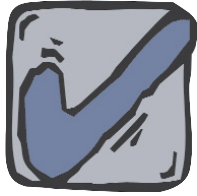
At the end of each section of *Understanding and Using Electronic Diagrams*, you'll be asked to pause and check your understanding of what you've just read by completing a "Self-Check" exercise. Answering these questions will help you review what you've studied so far. Please complete *Self-Check 1* now.

## Fill in the blanks.

1. A \_\_\_\_\_ is used to show the function and connections of different parts of a circuit.
2. A square block labeled U2 on a schematic is probably a(n) \_\_\_\_\_.
3. The \_\_\_\_\_ is used to show the physical location of the wires and components in the equipment.
4. In schematics, outputs are usually on the \_\_\_\_\_ side of the drawing.
5. A capacitor next to the diode bridge in a power supply is marked C1 1000 50 V. The capacitance value of this component is \_\_\_\_\_ microfarads.
6. A transformer that has a turns ratio of 2:1, primary to secondary, with an input voltage of 230 V, will have an output voltage on the secondary of \_\_\_\_\_.
7. Switches in schematics are always shown in the \_\_\_\_\_ state.

(Continued)

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# Self-Check 1

For questions 8 through 15, match the description with the letter corresponding to the correct symbol in the following figure. (Note: Not all of the letters will be used.)

\_\_\_\_\_ 8. Chassis ground

\_\_\_\_\_ 9. Variable resistor

\_\_\_\_\_ 10. Air-core transformer

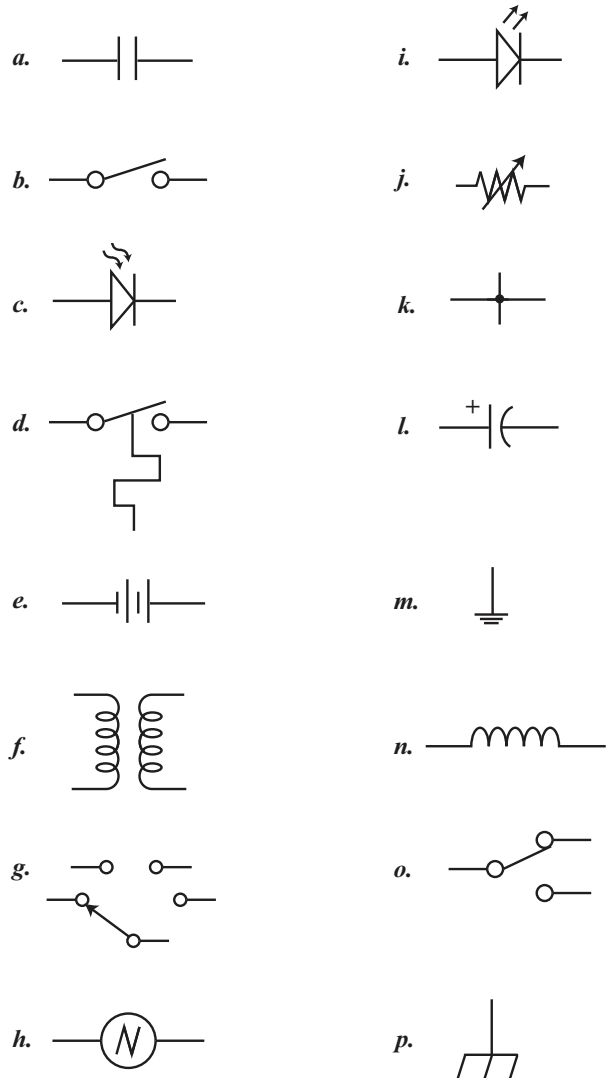
\_\_\_\_\_ 11. Single-pole, double-throw switch

\_\_\_\_\_ 12. Thermal switch

\_\_\_\_\_ 13. DC voltage source

\_\_\_\_\_ 14. Inductor

\_\_\_\_\_ 15. Polarized capacitor

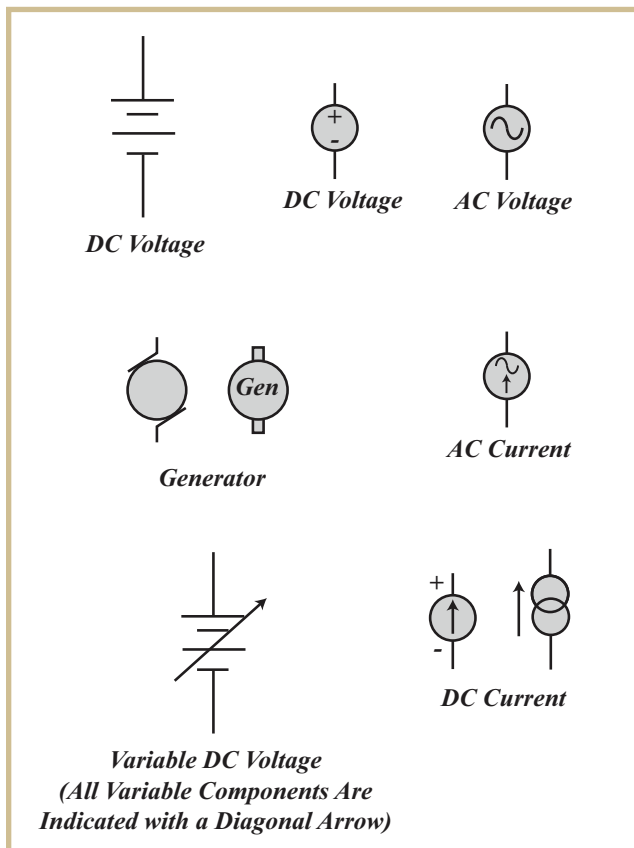


Check your answers with those on page 79.

# ELECTRONIC COMPONENTS IN SCHEMATICS

The first step in understanding electrical schematics is to learn and understand the symbols used. Schematics contain symbols representing *active devices* like transistors, op-amps, and diodes; *passive components* like resistors and capacitors; and *mechanical components* like switches and relays. In this section of the study unit, you'll learn the most common symbols for components and some commonly encountered standard circuit configurations that combine several components.

All electronic circuits require energy to operate, so a source of electric power will be indicated somewhere on the schematic. The power source for positive DC supplies will be indicated by a terminal marked something like  $V_{In}$ ,  $V_+$ , or  $V_{CC}$ . Negative DC supplies are often labeled  $V_-$ , or  $V_{ee}$ . The symbol for the power source is included in many schematics; Figure 9 shows some common sources for electrical energy.



**FIGURE 9—Electronic equipment requires a source of AC or DC voltage or current to function. These symbols indicate various ways circuits are supplied with power.**

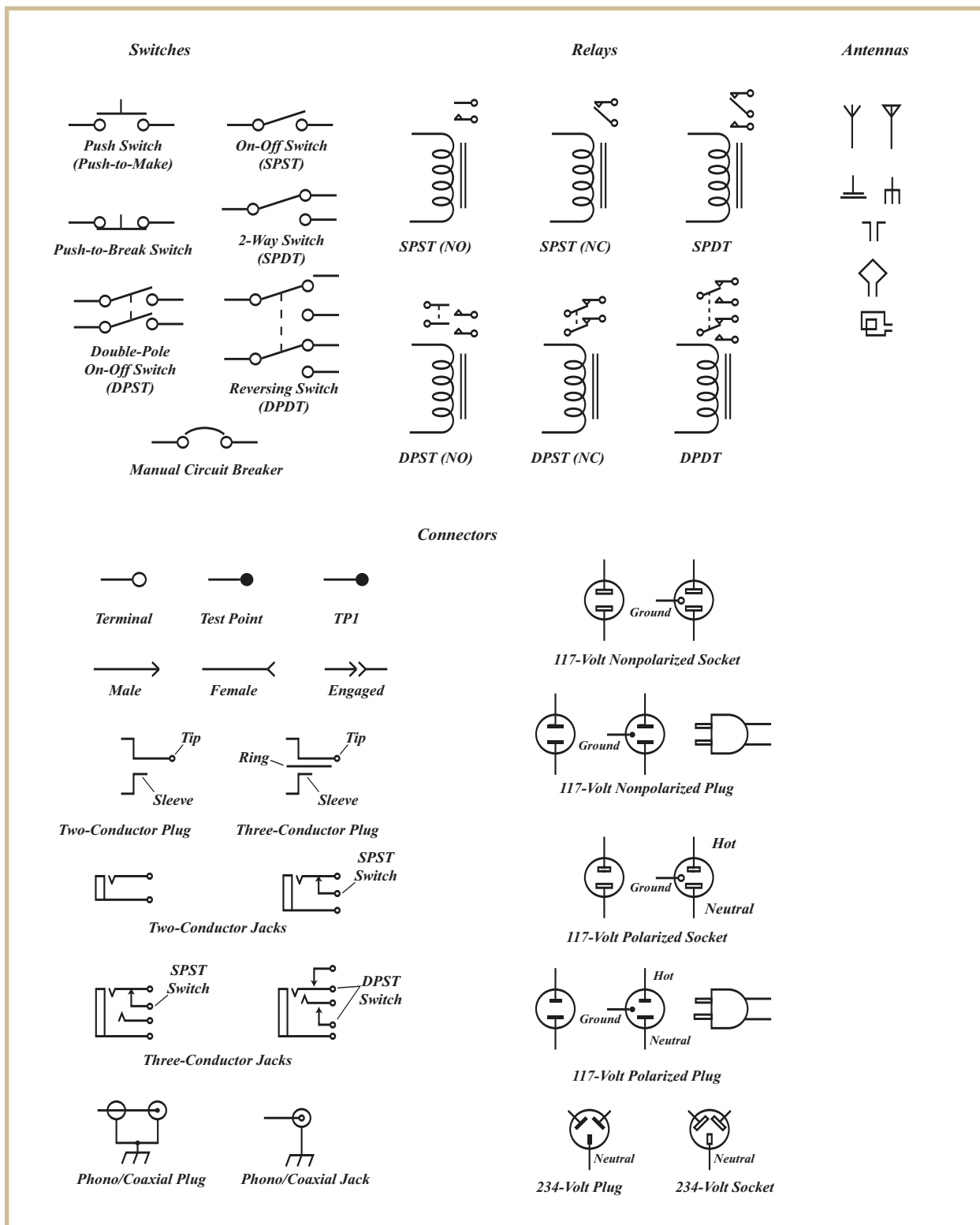
## Mechanical Devices

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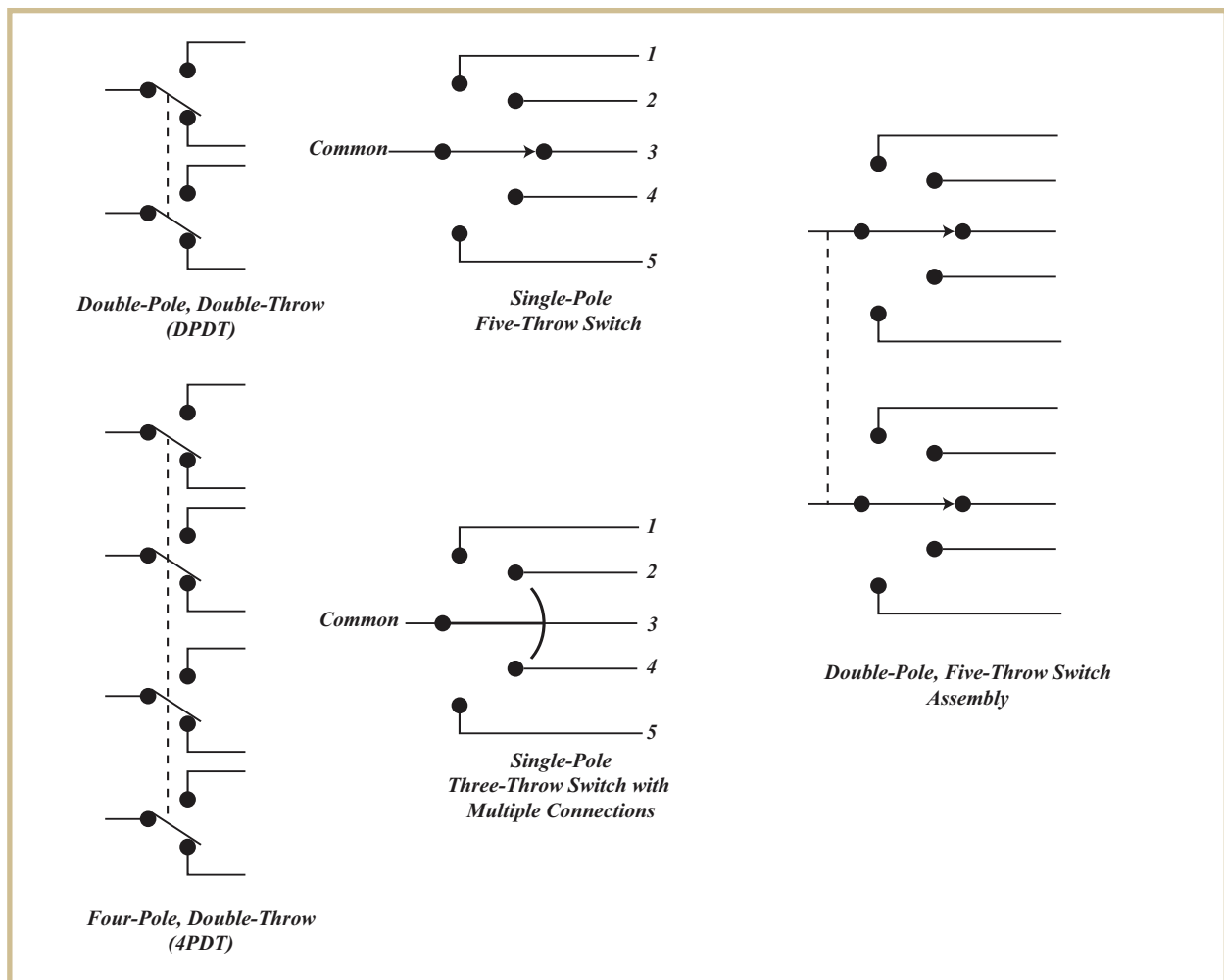
At the heart of electronic circuits are the resistors, transistors, and other components that perform the electronic function of the device. However, important *mechanical components* interface with controls, conduct input and output signals, and provide power to the circuits. Figure 10 shows schematic symbols representing such important mechanical components as switches, plugs and jacks, relays, and connectors.

Several different types of switches are common in electronic equipment. *Single-pole switches* interrupt only one conductor. *Double-pole switches* interrupt two conductors. Special switches called *gang switches* can interrupt three or more conductors. Switches can also be classified as *single throw* or *double throw*, meaning that they can be in one or two different closed positions. On schematics, the symbol shows the possible connections. On the parts list, the switch may be designated as SPST for a single-pole, single-throw switch, or DPDT. Figure 11 also shows multiposition and multiple-contact switches.

Switches are shown on schematics in the de-energized condition—the normal condition of the switch when the equipment is turned off. Sometimes a note appears on the schematic or the parts list that designates a normally open (NO) or normally closed (NC) switch or contact, but these notes are more common in PLC or equipment control schematics. Most of the time a switch's normal position isn't important, but when you're troubleshooting equipment that controls sequencing of other devices or other parts of the circuit, it's important to know the proper starting position of the switch or contact. A dashed line connecting two or more arms of the switch indicates a mechanical link between them, meaning that they must move together. You'll see these lines on switches with multiple sections, such as ganged rotary switches.

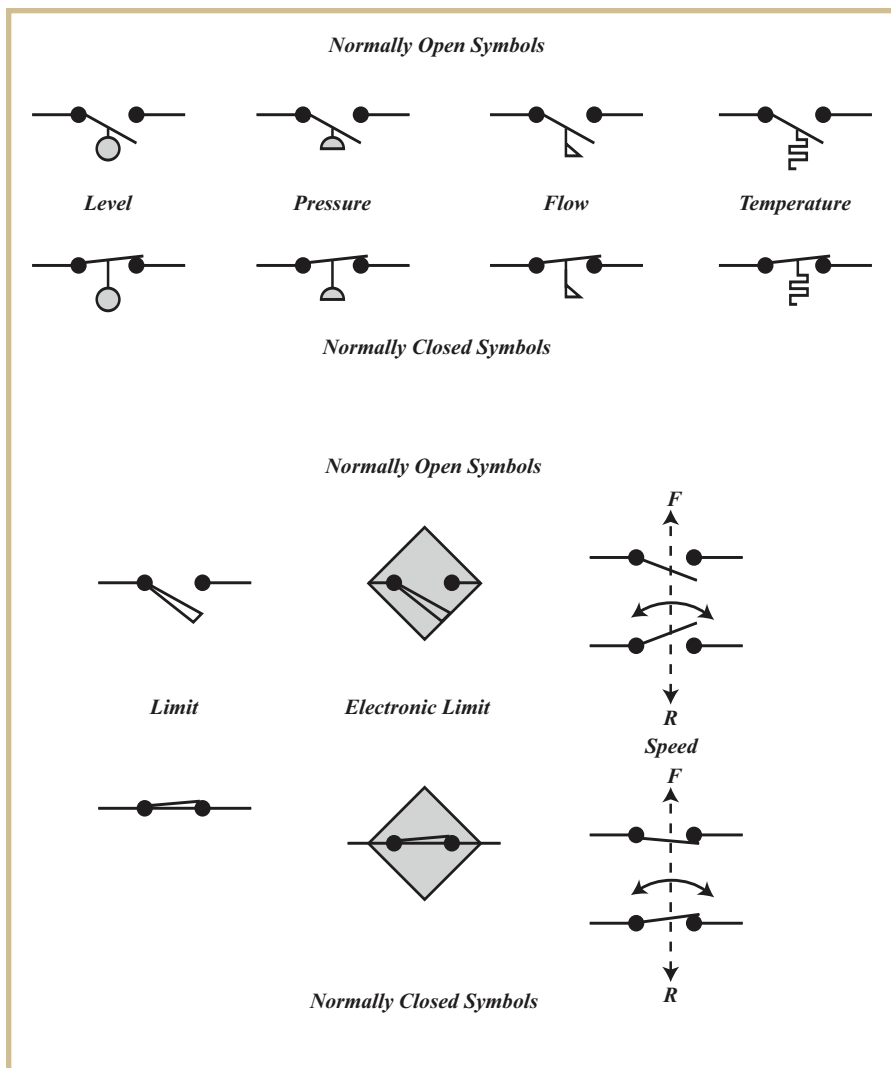


**FIGURE 10**—These are common symbols you'll encounter in various schematics. You may see variations of these on older prints, and drawing standards used by different organizations may use slightly different symbols.



**FIGURE 11—Switches are classified by the number of contacts and the method of making/breaking contacts. The dashed line indicates a physical connection between mechanisms.**

Electronic equipment uses many different types of mechanical switches. Figure 12 shows some switches used in controls that operate on temperature levels, liquid level, vacuum, and fluid flow rates, or are mechanically actuated by cams or levers on moving equipment. On schematics, these types of mechanical switches are shown with the basic switch symbol and actuating symbol attached to the switch arm. The actuating symbol will give you a hint about the operating mechanism even if you don't recognize the symbol itself. For example, a *limit switch* has a triangular wedge attached to the arm, reminding you of the fact that limit switches are often cam operated. A *float-operated switch* is shown with a round circle attached to the arm, symbolic of a flotation bulb. These types of switches are very common in industrial settings, where



**FIGURE 12—Industrial applications include many switches activated by process conditions such as liquid level, fluid flow, temperature, position, or speed. These switches are often located far from the electronic circuit.**

they're physically located long distances from the actual control circuits, such as on control valves or on hydraulic or pneumatic actuators.

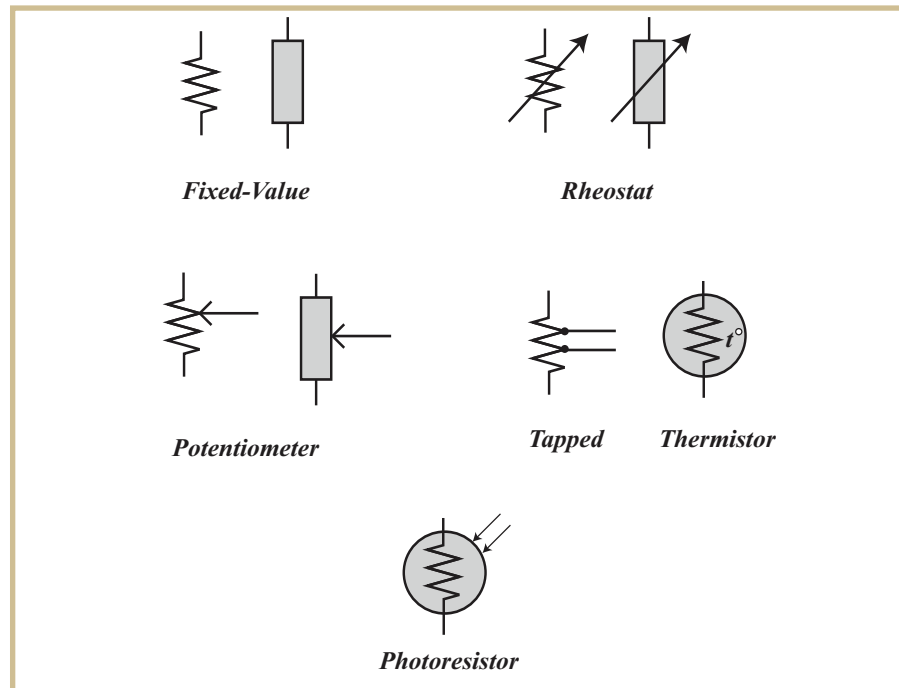
## Passive Devices

Passive devices include resistors, capacitors, coils, and transformers. These components don't rely on quantities of voltage, current, or polarity to operate. In general, they have electrical characteristics that depend on their physical properties—materials and dimensions—and aren't controllable, as transistors or amplifiers are.

## Resistors

*Resistors* are specified by their value in ohms, an accuracy tolerance (1%, 5%, 10%, etc.), and their power rating in watts. Schematics usually have the *resistance* value labeled next to the resistor symbol on the print, as well as any important information for that particular resistor, such as tolerance or power rating. Many resistors are labeled with only their ohm value. In that case, you'll usually find a note on the schematic in the notes area of the title block indicating that any unmarked resistors are assumed to have a specified minimum tolerance and wattage value. In schematics, resistors sometimes have the letter E included or next to the number; this indicates the decimal point in the value of the resistor. For example, 270E means a 270-ohm resistor, and 4E7K is a 4700-ohm resistor. Another standard is to place the multiplier letter in place of the decimal. For instance, a 4K7 resistor is 4700 ohms. Figure 13 shows some examples of schematic symbols for variable and fixed resistors. Specially made resistors can also be used as sensors for light, temperature, pressure, or force. For example, a light-sensitive resistor, or *photoresistor*, senses the presence of a flame in an oil burner controller, with the resistor having a low resistance when light from the flame is shining on it, and a high resistance when it's in darkness.

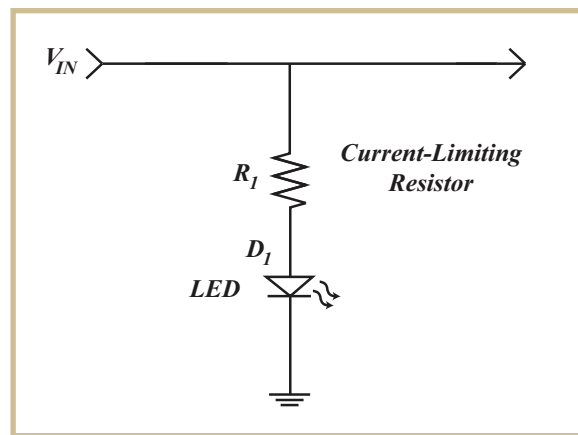
**FIGURE 13—Resistors are commonly employed in electrical circuits as current limiters and sensors.**



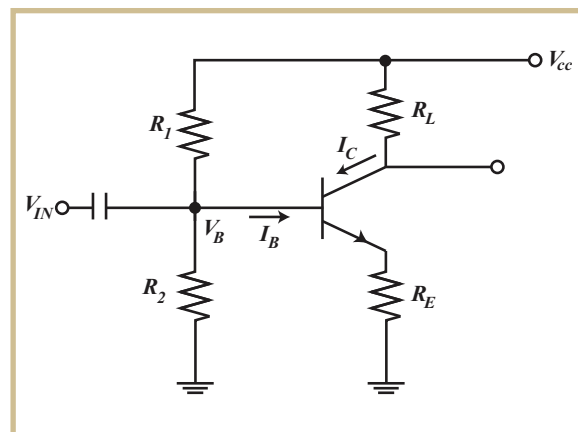


Resistors are said to be *linear devices*, and they follow Ohm's law with regard to voltage and current. They play several important functions in circuits, and you should learn to recognize their role in each application. For example, in power supply circuits they're often used to limit charging current in *filter capacitors*. In Figure 14 you can see a resistor used to limit the current to an *LED* (*light-emitting diode*) indicator light. Because the voltage across a resistor is proportional to the current through it, resistors are used as *voltage dividers* to provide a reference or control voltage for other parts of a circuit, as shown in Figure 15. You'll often see variable resistors used in this way, providing a variable voltage that can be used for controls such as light brightness, or speed controls.

Resistors are also used in *timing circuits*, where they control the rate at which a capacitor can be charged. These are called *RC networks*; like voltage dividers, they establish a reference voltage that can be used in other parts of a circuit for control purposes. The voltage rise or fall in an RC circuit is an exponential function that's easily calculated using the concept of *time constants*. An uncharged capacitor can be fully charged—or a fully charged capacitor can be fully discharged—in five time constants, where one time constant (measured in seconds) is the product of the capacitance value in farads times the resistance value in ohms. By using various resistors, or perhaps a variable resistor, reliable timing circuits from milliseconds to hours can be produced. These types of RC circuits are used to make oscillators, function generator circuits, and industrial timing devices. Figure 16 shows some typical RC circuit configurations you'll encounter in electronic work.

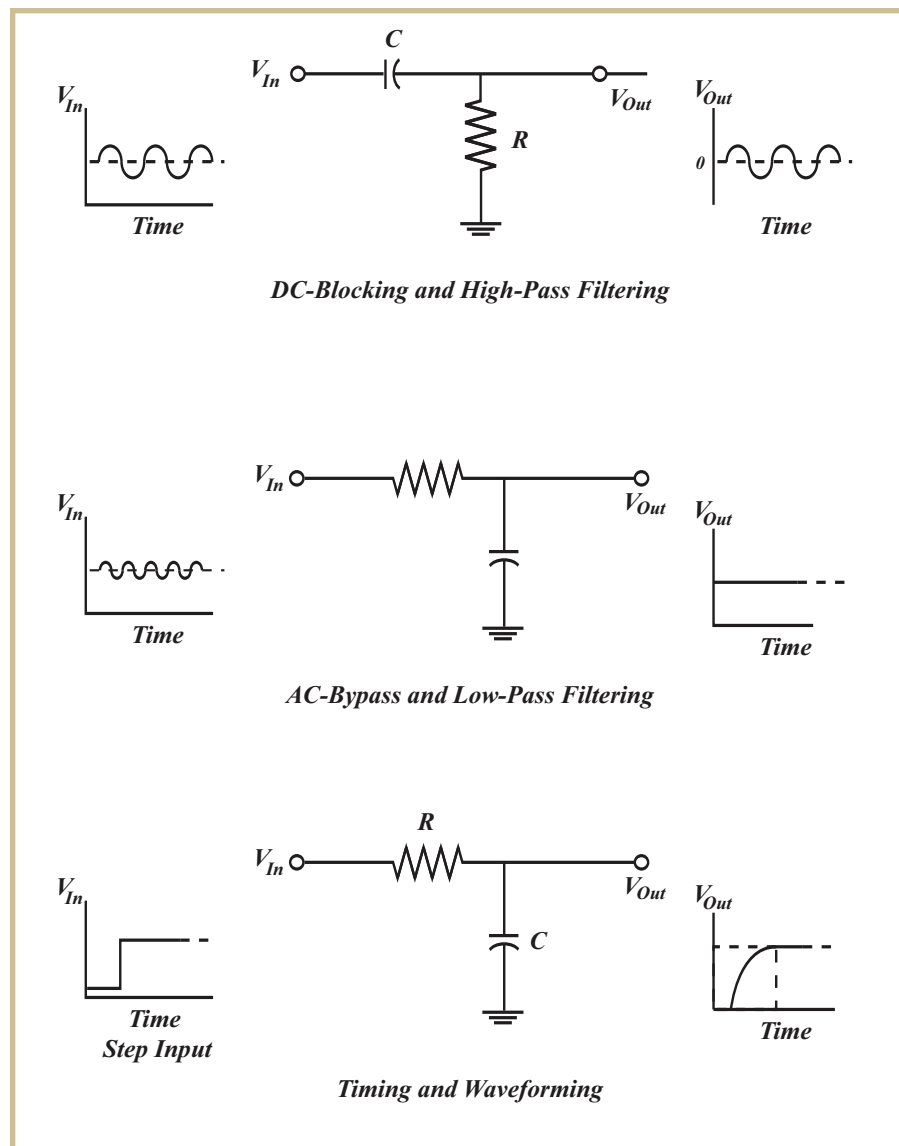


**FIGURE 14**—LEDs are used in many devices as indicator lights, but they're limited to a maximum of about 1.5 V or they can be destroyed. A resistor is used to limit the current through the LED, usually a maximum of 30–50 milliamperes.



**FIGURE 15**—In this simple transistor amplifier, resistors  $R_1$  and  $R_2$  form a voltage divider to set  $V_B$  to the proper value for correct transistor bias. If  $R_1 = R_2$ , and  $I_B = 0$ , then  $V_B$  would be exactly half of  $V_{CC}$ .

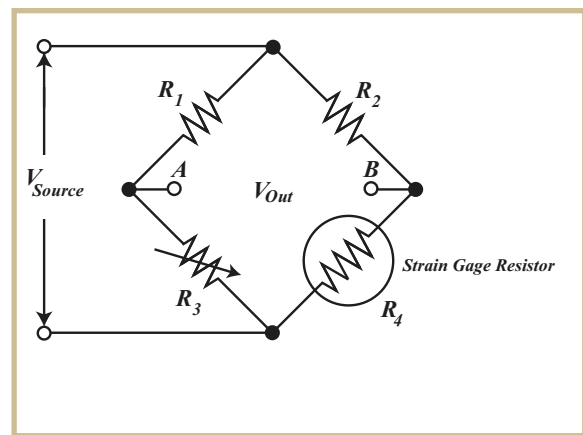
**FIGURE 16—RC networks are used for many different functions and can serve to pass or reject AC or DC voltages depending on how the R and C are arranged in the circuit. Feedback in amplifiers through RC networks can form band-pass filters or oscillators.**



Another important circuit you'll encounter using resistors as part of the design are *bridge circuits*. A resistor bridge circuit is essentially two resistive voltage dividers in parallel (Figure 17). If all the resistors are identical, the voltages at the two junctions between the resistors will be equal. In fact, they'll be equal if the two top resistors are the same and the two bottom resistors are the same, regardless of their relative values.

A common practical application uses a sensor for one of the resistors in the bridge, as shown in Figure 17. This resistor configuration is called a *Wheatstone bridge* and was developed as a way to measure small voltage differences due to variations in resistance. In this example, a *resistive strain*

*gage* replaces one of the bridge resistors; another resistor is used to zero the voltage measured between the resistor junctions. The voltage at these junctions is measured by another part of the circuit with a sensitive differential amplifier and used to display a measured value, weight, or a force, as in this case. It can be used as a control voltage that controls other functions, such as opening a valve or turning on a heater. Bridge circuits may look like diode bridges when drawn on a schematic, or they may be drawn with the resistors in various other arrangements. You need to look for the common junctions at the top and bottom of the resistor pairs, and the output voltage taken at the junction of the pairs. Bridge circuits are simple, and they make very accurate instrumentation circuits that can be temperature compensated if necessary. Other types of sensors that can be used include photoresistors (or CAD cells), pressure sensors, or any other sensor that uses a resistor element.

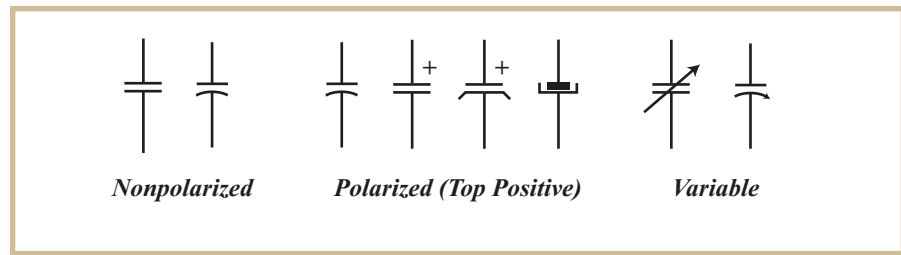


**FIGURE 17**—A resistor bridge can be made part of a sensing circuit, as shown in this instrumentation circuit. For any source voltage, if all the resistances are the same then  $V_{Out}$  is 0 volts. In this case  $R_4$  is a strain gage and  $R_3$  functions as a trimmer to “zero” the scales before measurement. Variations in  $R_4$  due to force or weight turn into voltage differences at terminals A and B, which are sent on for further amplification and processing.

## Capacitors

As you know, *capacitors* are devices that store electric charge, making it available for use at various times during operation of the circuit. Figure 18 shows some of the symbols used for capacitors in electronic schematics. Because capacitors can store charge, they’re used to resist changes in voltage across the capacitor, as when they’re used in power supply filter circuits. In power supplies, very large-value capacitors are used to minimize the amount of AC *ripple voltage* on the power supply output. The power supply in Figure 1 uses a 2200-microfarad capacitor at the input of the regulator and a 100-microfarad capacitor on the output. Note that this schematic uses the symbol for a *polarized capacitor*, with a curved line for the negative terminal. Another way of marking a polarized capacitor is to use a + sign indicating the

**FIGURE 18—Capacitors store electrical energy and are very common on electronic circuits for timing, wave shaping, and filtering. Polarity of capacitors, especially large electrolytic ones, is very important. However, use caution when interpreting schematics as the typical symbol for a polarized capacitor (one curved line) is sometimes also used for nonpolarized devices. In this case, the curved line represents the capacitor terminal that's attached to the more negative side of the circuit.**



positive terminal. This is extremely important where electrolytic and other types of capacitors are used in DC applications. If polarized capacitors are installed in a circuit incorrectly they can explode, causing damage and injuries.

In power supply schematics you'll often notice that smaller value capacitors are used on the output side of regulator circuits. This is because large *electrolytic capacitors* don't filter high AC frequencies very well, so designers include smaller, nonpolarized capacitors on the outputs to remove any high-frequency AC present in the power supply wires. This high-frequency AC can be present because of other nearby electrical components such as motors and computers, which cause electrical interference transmitted through common wires.

Capacitors are labeled in various ways on schematics, but usually with values specified in *picofarads* ( $pF$ ), *nanofarads* ( $nF$ ), or *microfarads* ( $\mu F$ , often written  $uF$  for convenience). Sometimes you'll see a capacitor on a print marked 104, which you should read as the number 1 followed by a 0, followed by four zeros: 1 0 0000, or 100,000. This is the value of the capacitor in picofarads. We don't normally express values in picofarads when they're this high, so the normal practice is to convert the values to nanofarads or microfarads. This capacitor would have a value of 100 nF. Table 1 shows examples of this type of marking.

| Table 1   |             |               |          |
|---|-------------|---------------|----------|
| Common Capacitor Values and Their Possible Markings |             |               |          |
| microfarads   | nanofarads  | picofarads    | EIA code |
| 0.0001 $\mu\text{F}^*$                              | 0.1n*       | 100 pF        | 101      |
| 0.00022 $\mu\text{F}^*$                             | 0.22n (n22) | 220 pF        | 221      |
| 0.001 $\mu\text{F}$                                 | 1n (1n0)    | 1000 pF       | 102      |
| 0.0033 $\mu\text{F}$                                | 3.3n (3n3)  | 3300 pF       | 332      |
| 0.01 $\mu\text{F}$                                  | 10 n        | 10,000 pF*    | 103      |
| 0.047 $\mu\text{F}$                                 | 47 n        | 47,000 pF*    | 473      |
| 0.1 $\mu\text{F}$ ( $\mu\text{1}$ )                 | 100 n       | 100,000 pF*   | 104      |
| 0.82 $\mu\text{F}$                                  | 820 n       | 820,000 pF*   | 824      |
| 1.0 $\mu\text{F}$                                   | 1000 n*     | 1,000,000 pF* | 105      |

(\*) Not normally expressed in this form.

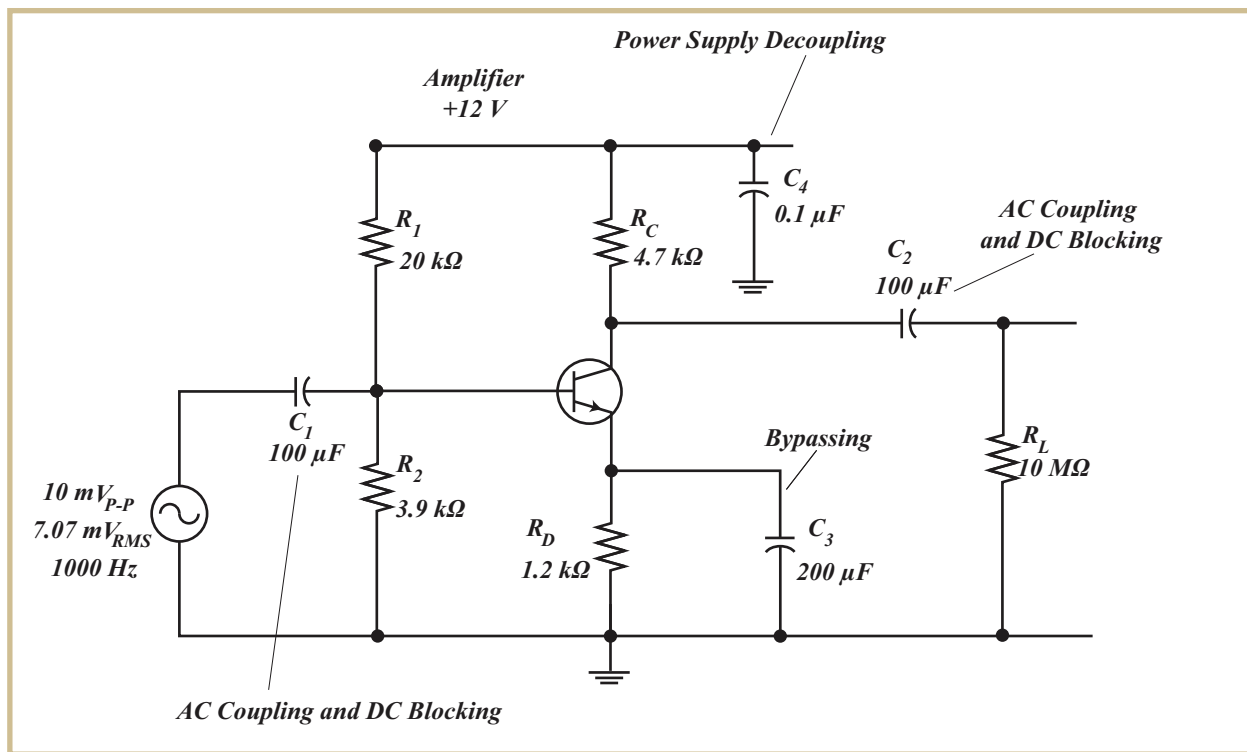
Capacitors called *coupling capacitors* are also used to block DC voltage between various parts of a circuit while allowing AC voltages to pass, as in the case of multistage amplifiers. Capacitors oppose AC electrical current with a *reactance*—an opposition to AC current—depending on the AC frequency:

$$X_C = 1/(2 \times \pi \times F \times C)$$

where  $X_C$  is the reactance in ohms,  $F$  is the AC frequency in hertz (Hz), and  $C$  is the capacitance value in farads. This means that as the frequency goes higher for a given capacitance value, the reactance in ohms goes down. Coupling capacitors are chosen to have a very low reactance at the lowest operating frequency of the amplifier. Figure 19 shows a schematic of a simple *transistor amplifier* using coupling capacitors between stages.

## Inductors

*Inductors* are passive components that use the creation of magnetic fields by electric current to oppose current changes in AC and DC circuits. They're sometimes called *chokes* because they tend to “choke off” changes in current values, especially when used in constant current sources such as power supplies.

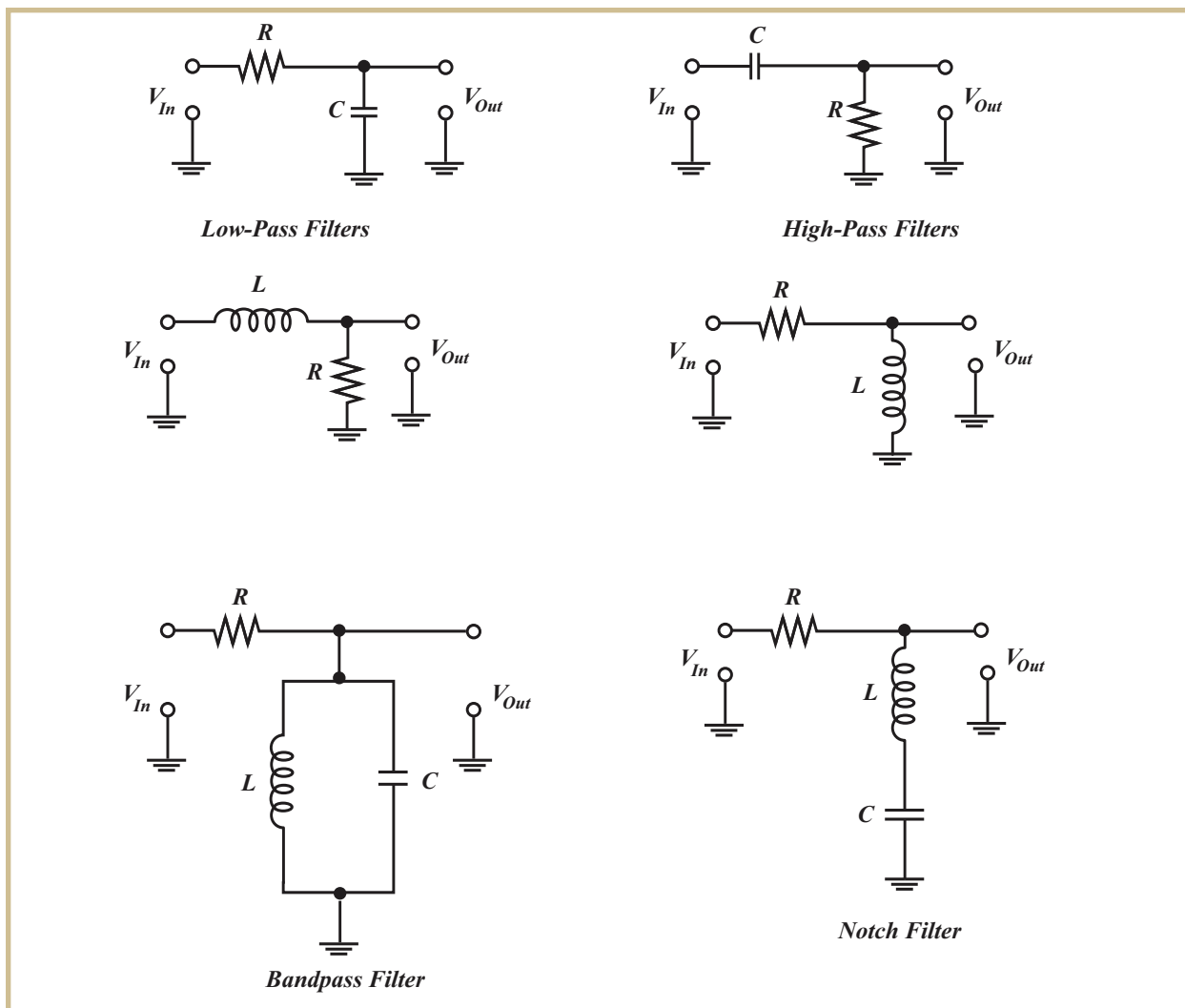


**FIGURE 19**—This simple transistor amplifier circuit shows how capacitors can be used for multiple functions such as DC blocking, coupling amplifier stages, and filtering or bypassing.

Inductors have a reactance that's dependent on the frequency of the AC. The higher the frequency, the higher the reactance. The reactance can be calculated by the formula:

$$X_L = 2 \times \pi \times F \times L$$

Inductors are used in many applications in conjunction with capacitors in circuits designed to respond to different frequencies in different ways. Inductor-capacitor combinations can be designed to make circuits responsive to certain frequencies, or they can be made to block certain frequencies from being transmitted to other parts of the circuit. In amplifiers, for example, band-pass filters can be made to transmit only higher frequencies, only lower frequencies, or only a certain band of frequencies. Figure 20 shows how inductors, capacitors, and resistors can be configured to pass or reject certain frequencies. Band-pass circuits can be made with active devices using op-amps, which we'll discuss later.



**FIGURE 20—Resistors, capacitors, and inductors connected in various series and parallel arrangements can affect the frequency response of a passive network. If you recognize that inductors increase reactance with increasing frequency while capacitance reactance goes down, you’ll understand what the intended function of the RLC network is.**

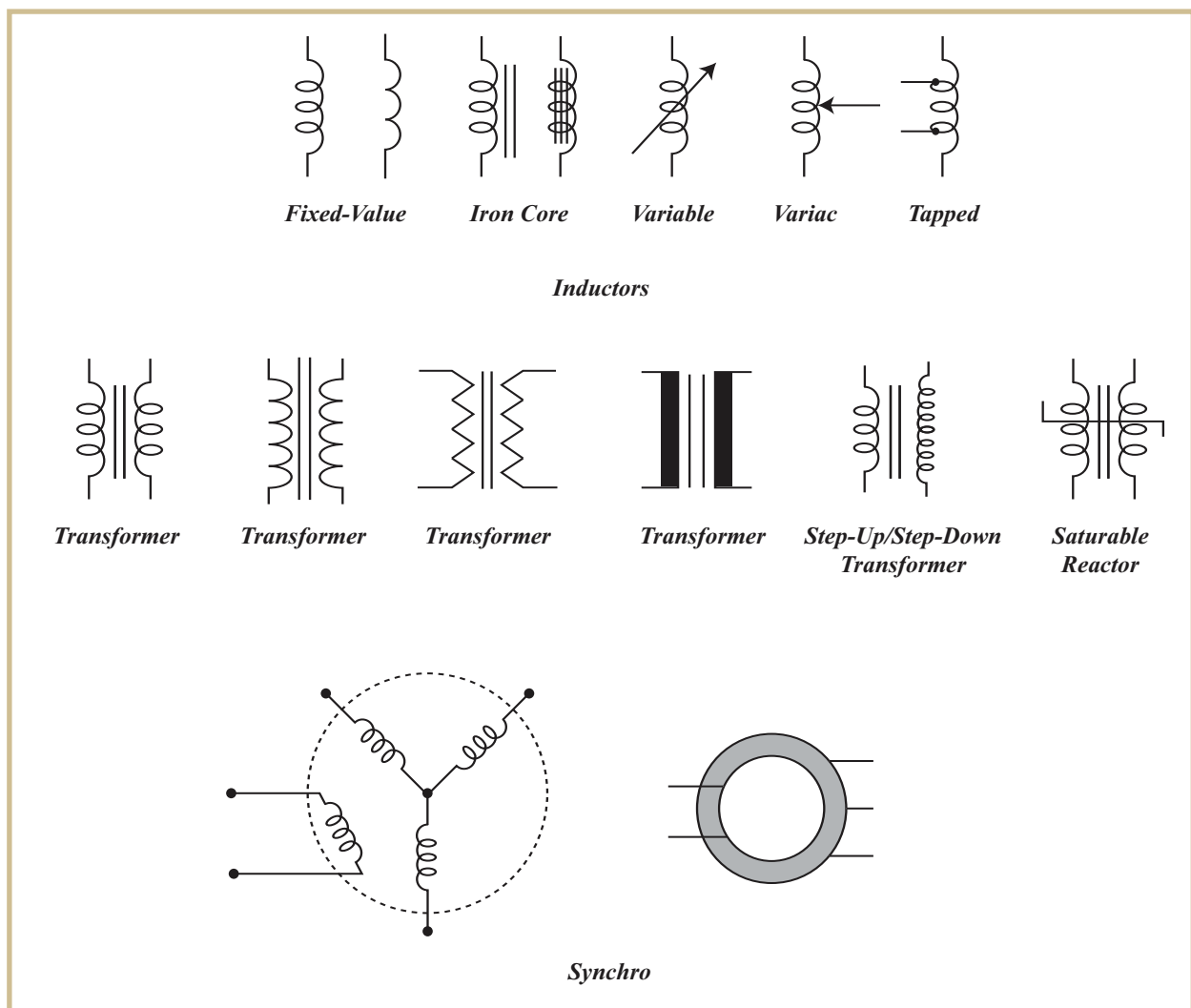
Resonant circuits contain combinations of inductors, capacitors, and resistors in either series or parallel arrangements, depending on the intended function of the circuit. These circuits have a central resonant frequency that can be calculated by the formula:

$$F_R = 1/(2\pi \sqrt{LC})$$

Series resonant circuits have their highest impedance at the resonant frequency, while parallel resonant circuits have their lowest impedance at the resonant frequency. Resonant circuits can be used in tuned amplifiers, antenna and tuning circuits, notch filters, oscillators, and other frequency-specific applications. Resistors don’t significantly affect the frequency of

operation, and you should learn to recognize the presence of a resonant circuit or frequency sensitive circuits when you see inductors and capacitors connected to each other or through a resistor.

The family of inductors also includes *transformers*, which come in many different varieties with many different functions. Both transformers and inductors can have different types of cores: air, ferrite, or iron. In the transformer and inductor symbols shown in Figure 21, a solid line next to the coil symbol means the transformer or inductor has an iron core; a dotted line means it has a ferrite core, and no line means it has an air core (no physical core).



**FIGURE 21—Transformers and inductors serve a variety of functions. Core types are indicated by the type of line next to the coil symbol. No line means air core; a dotted line means a ferrite core; a solid line means an iron core.**



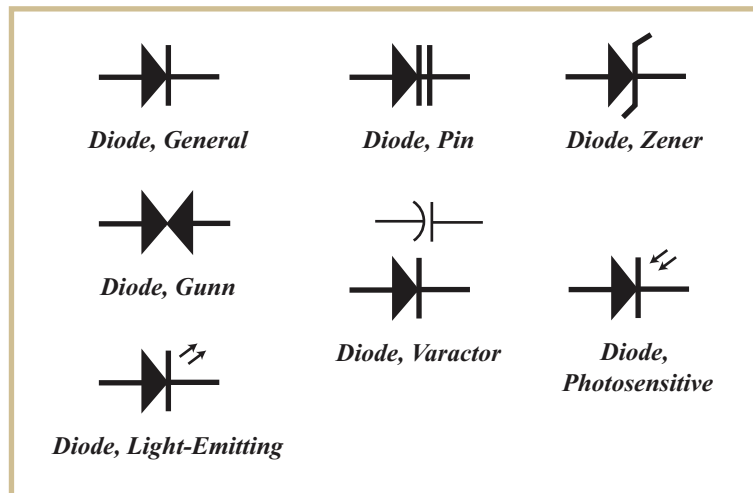
## Active Devices

*Active devices* are electronic components that require voltage or current to perform their intended function. Common active devices include transistors, diodes, *operational amplifiers* (*op-amps*), and electronic switches. Active devices usually require a power supply of a specific voltage, current and polarity for proper operation.

### Diodes

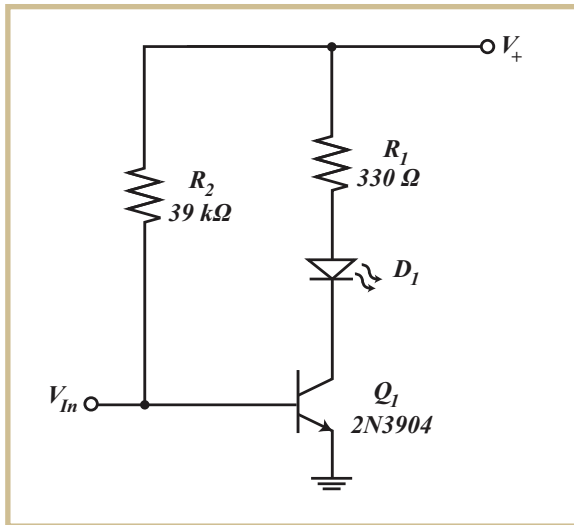
*Diodes* are active devices that allow current flow in one direction only, and are usually used in a circuit that's *forward biased*, that is, with the voltage applied in a way to allow current to flow. Figure 22 shows symbols of several different types of diodes you may see in electronic circuits. A forward-biased diode will have the more positive voltage on the arrow-head side of the diode. Diodes are sometimes marked on schematics with a + sign next to the diode's anode. A diode that's *reversed biased*—connected with the anode more negative than the cathode—will either not allow current to flow, or else allow current flow under controlled conditions to accomplish the circuit function, as in the case of a reverse-biased *zener diode*. A forward-biased silicon diode that's functioning correctly will have a voltage drop of about 0.7 volts, while a germanium diode should have lower voltage, about 0.3 volts. A diode that's reverse biased will have the entire source voltage across what's essentially an open circuit.

Perhaps the most common use of diodes is to produce rectified DC from the output of a transformer. Figure 1 shows a very common arrangement of a bridge circuit called a *full-wave rectifier*. Power-supply diodes must be able to conduct the full load current plus an adequate safety factor. They must also



**FIGURE 22—Diodes are active devices that allow current flow in only one direction.**

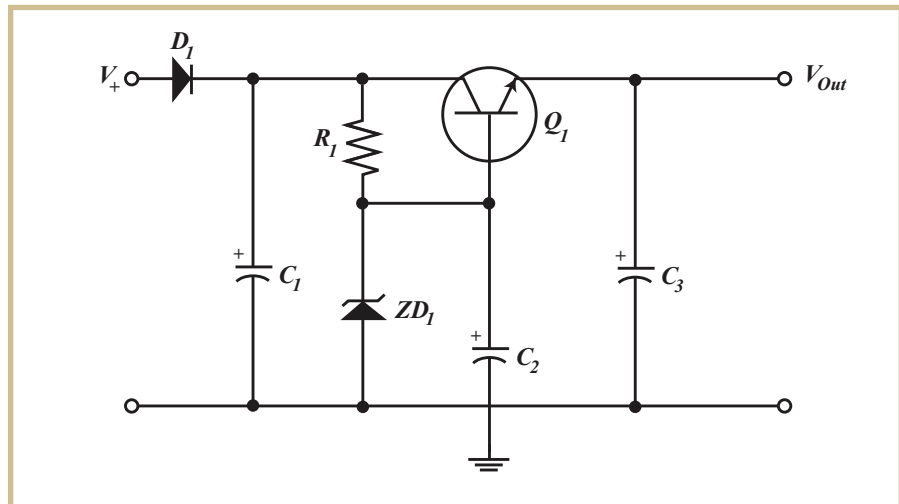
withstand a minimum peak-inverse-voltage (PIV) to avoid breakdown when reversed biased. The polarity of the diodes in the circuit determines the polarity of the rectified output with respect to ground.



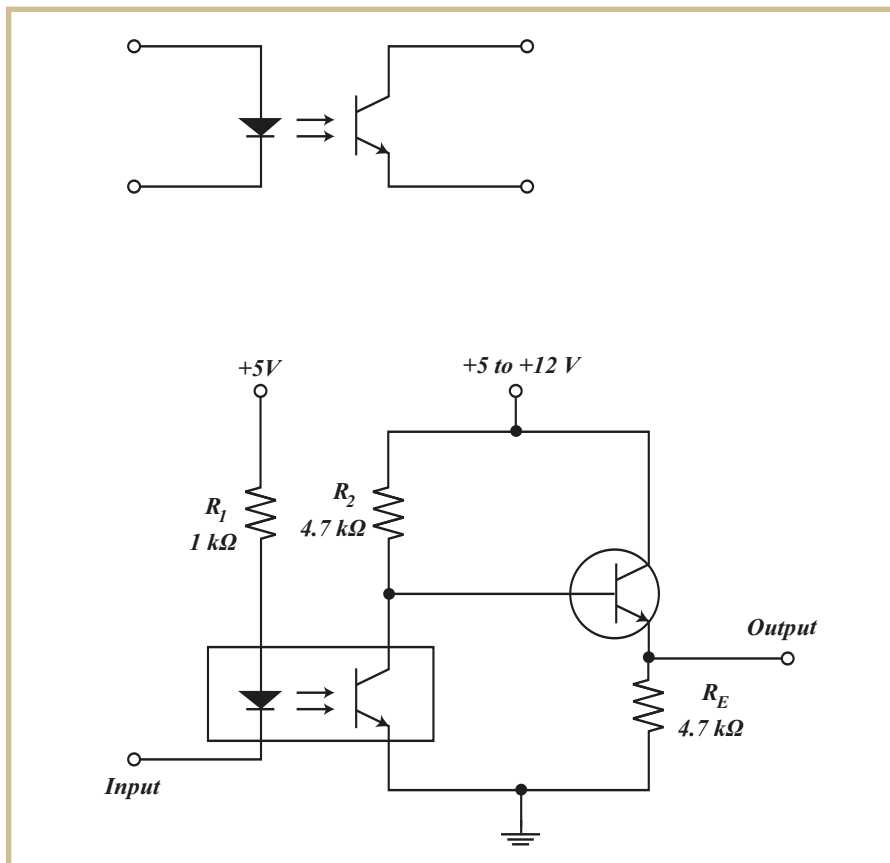
**FIGURE 23**—LEDs require a current-limiting resistor in applications where they're used as indicator lights. In this circuit, the LED turns on when a voltage of greater than about 1 V is applied to the base of  $Q_1$ .

Many different types of diodes have been developed that all behave differently. For example, diodes can be made to emit colored and laser light, detect light from other sources, oscillate at very high frequencies, or regulate voltage precisely. Figure 23 shows a typical biasing arrangement for a transistor switch controlling an LED. Figure 24 shows a zener diode used as a voltage regulator in a reverse bias configuration for a power supply. This is a very common arrangement using the fixed voltage characteristic of the zener to control a large current in a variable load. The voltage on the emitter of the transistor—what's supplied to the output load—will be about 0.7 volts below the rated zener voltage, because of the 0.7 V drop across the base-emitter diode in the transistor.

**FIGURE 24**—Zener diodes have a fixed breakdown voltage when reverse biased. In this circuit, the zener has current limiting protection by  $R_1$ . The output voltage will be about 0.7 volts less than the zener voltage due to the emitter voltage drop in  $Q_1$ . This is a very common voltage regulator circuit.



Since diodes can both emit and detect light, combinations of LEDs and photodiodes are often used in communication circuits, electronic counting circuits, and proximity detectors. Figure 25 shows the schematic symbol for an *optocoupler*, a device made from an LED and a phototransistor in the same physical package. These devices can be made to isolate one part of a circuit from another using variable light intensity as the electronic signal. If there's a physical separation between the LED and the phototransistor, it can be used to detect objects that interrupt the beam, for either counting or proximity detection. Optical coupling circuits can also be made from discrete components using LEDs and phototransistors.



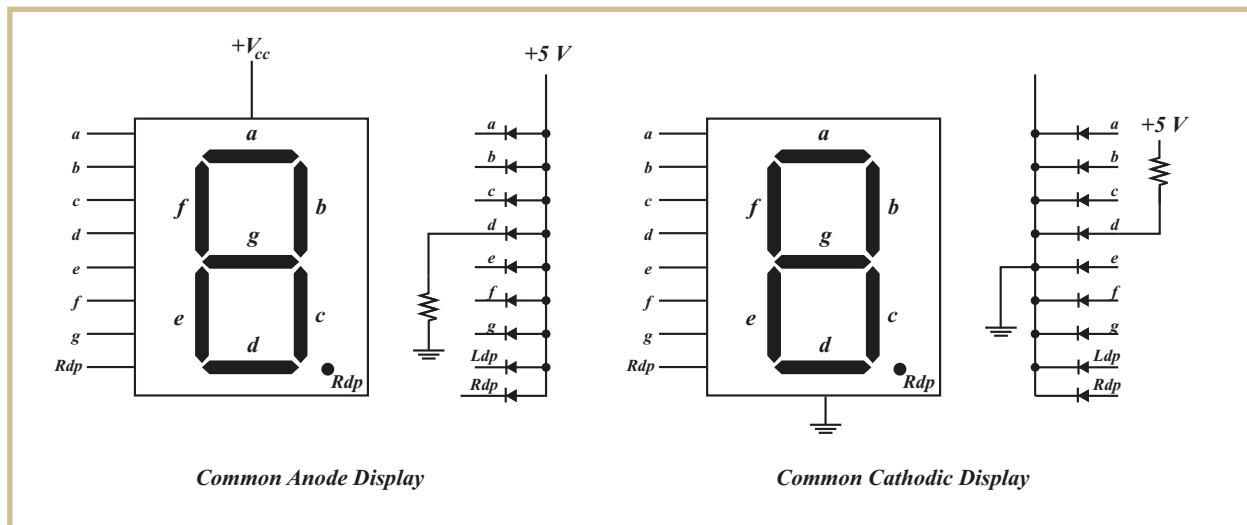
**FIGURE 25—Optocouplers can be used to isolate parts of a circuit to work with different voltages and power levels. They're also used in proximity detection and counting circuits.**

Another increasingly important class of diode is the *laser diode*. These devices are used in circuits that perform functions such as bar scanning, machine-tool guidance, range finding, construction leveling, and weapons targeting. The schematic symbol of a laser diode is the same as the symbol for an LED, so when examining a schematic, you'll need to

know for certain whether the component is a simple LED or a laser diode. In circuits, they're biased the same way as a conventional LED, but you'll often find them controlled by pulse circuits to limit the average output power of the diode. Pulse circuits are controlled by oscillators, which we'll cover later in this unit.

## Numeric Displays

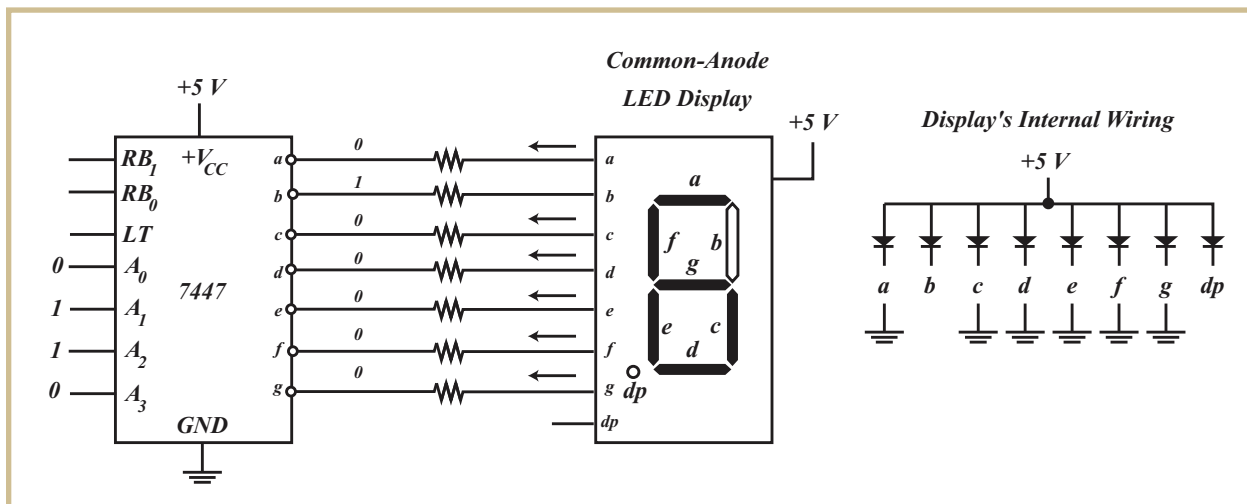
Electronic equipment so often uses numeric displays as an output that modern devices integrating all the requirements of generating a displayed number are available in complete packages. There are single-digit, seven-segment displays that use LEDs to create numbers and decimal points from combinations of LED diode segments, as shown in Figure 26. Also available are displays containing multiple digits, usually with three or four digits, plus decimal point. You might see a display labeled as a  $3\frac{1}{2}$  digit display, which means it can display three digits, plus another number—usually a 1—to indicate that a higher range is needed.



**FIGURE 26—Seven-segment LED displays are used as output devices for voltmeters, frequency counters, calculators, and other numeric displays. The circuits running to or from the LED “d” are typical of those that normally exist for all segments. Only one circuit path is shown here for clarity purposes.**

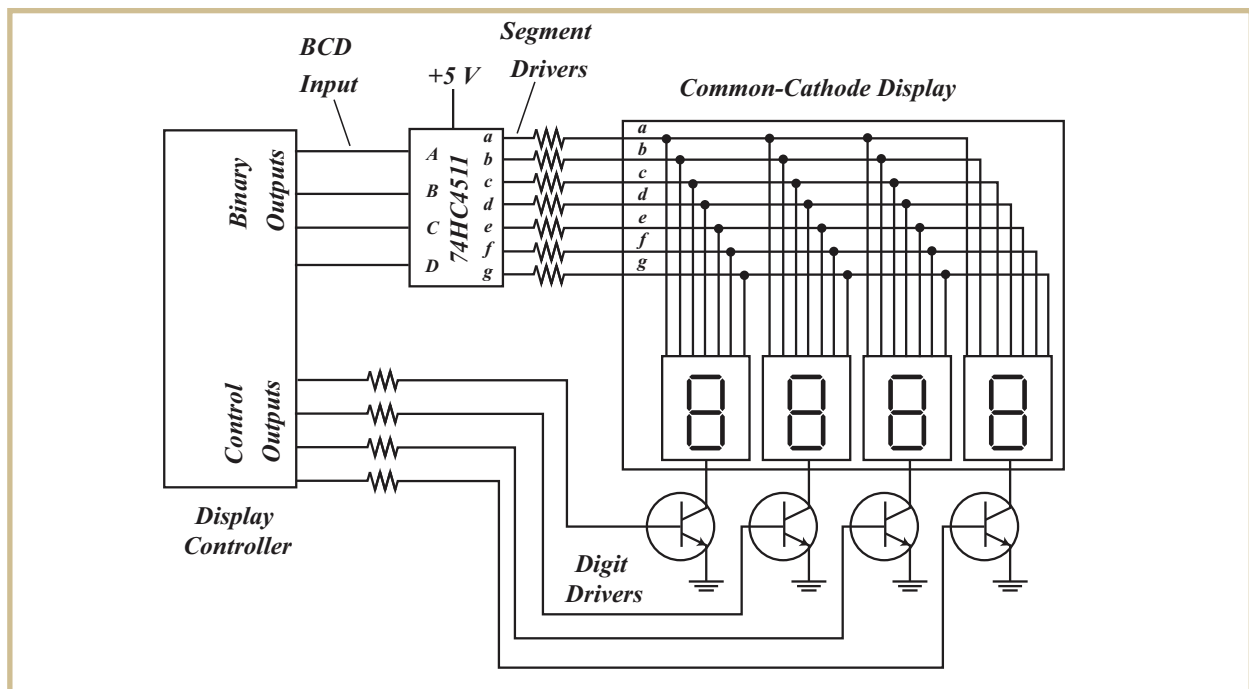
LED displays are available either as *common-anode* or *common-cathode* displays, which refer to the terminal that's common to all segments. In common-anode displays, the segments are turned on by grounding the pin corresponding to the segment desired to be lit. In common-cathode displays, the segments are lit by supplying the logic voltage (+5 V) to the pin corresponding to the segment. The segments are labeled a, b, c, d, e, f, and g, with a decimal point DP also included.

Segments can be driven directly from the circuit, but they're most commonly driven from another integrated circuit such as the one shown in Figure 27, called a *decoder driver*, or simply *display driver*. These are integrated circuits designed to work with either a common-cathode or common-anode display, and are available with 4-bit binary inputs that decode a binary number to a decimal display number, or with a binary-coded decimal input to a seven-segment display output, such as the 7447 BCD-to-seven-segment decoder. Combinations of these displays and drivers can be used in displays for digital multimeters, frequency counters, and even text.



**FIGURE 27**—LED displays use a decoder to change a binary string of 1's and 0's into a decimal number. They're seldom driven from independent voltage sources.

In digital equipment, you'll often see multiplexing schemes that use one display driver and another control chip to turn the display on only during the time the input signal is at the decoder that's intended for that display. This is a technique intended to save board space and minimize parts count. Figure 28 shows an example of a simple multiplexing arrangement. The circuit turns on each of the displays in a rapidly changing sequence that the eye sees as a continuous display. Each of the transistors is actuated sequentially at the same time the input to the decoder is changed to the value needed for that particular segment. Multiplexing helps minimize the number of circuits and wires, making the circuit share portions of the wiring at different times.



**FIGURE 28—Multiplexing is a way to conserve board space and electronic components.**

Another type of display is the *liquid crystal display (LCD)*. These displays are similar in concept to an LED but require much less voltage and current to operate, and are thus better suited for portable or battery-driven equipment. They're passive devices, in that nothing lights up, unlike an LED. They use natural light that's filtered or blocked from transmitting through the material to make a segment of a number. In dark areas, they must be supplied with a backlight so the the display number can be seen.

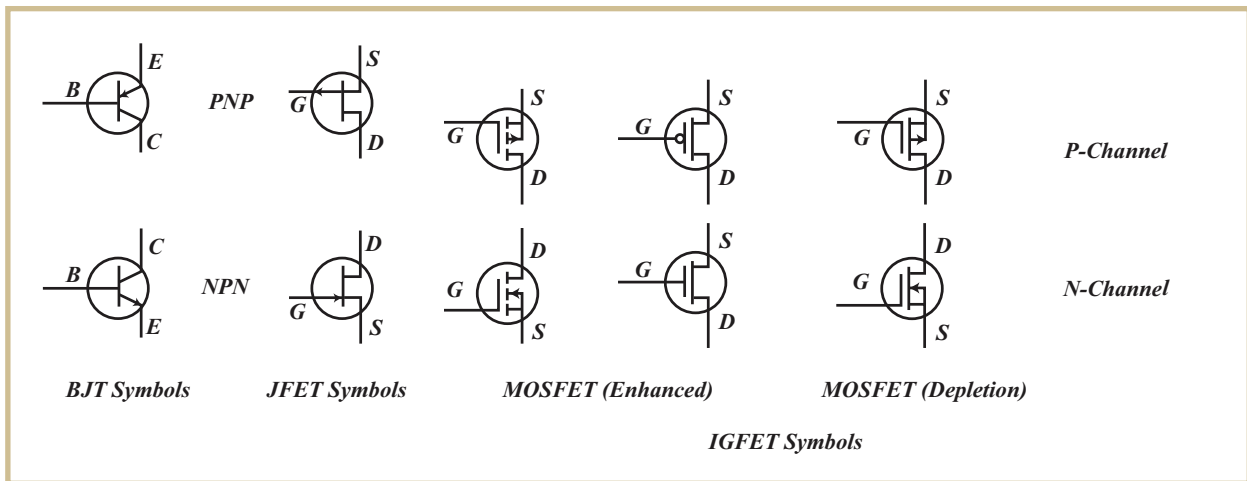
Another type of display is the *dot-matrix display*. These are very similar to LED displays except that they have many more individual LEDs arranged in a square matrix, and they can display many types of numeric and letter characters. The control of these displays is more complex due to the number of elements in the display. Newer types often have a controller built into the display rather than have separate controllers connected externally.

## Transistors

Since its invention in 1947, the *transistor* has become the workhorse of electronic systems. As the primary component in millions of electronic devices, transistors can both amplify current or voltage and act as an on/off switch. The first transistors were made from semiconductor materials—silicon or germanium—that were deliberately contaminated, or *doped*, with small amounts of impurities that affected current flow. Transistors most commonly consist of layers of P and N type silicon (there are very few germanium transistors) and two types of doped material are P-type and N-type. On a schematic, the direction of the arrow in the symbol points from the P to the N layers, which is also the polarity of the forward-biased condition.

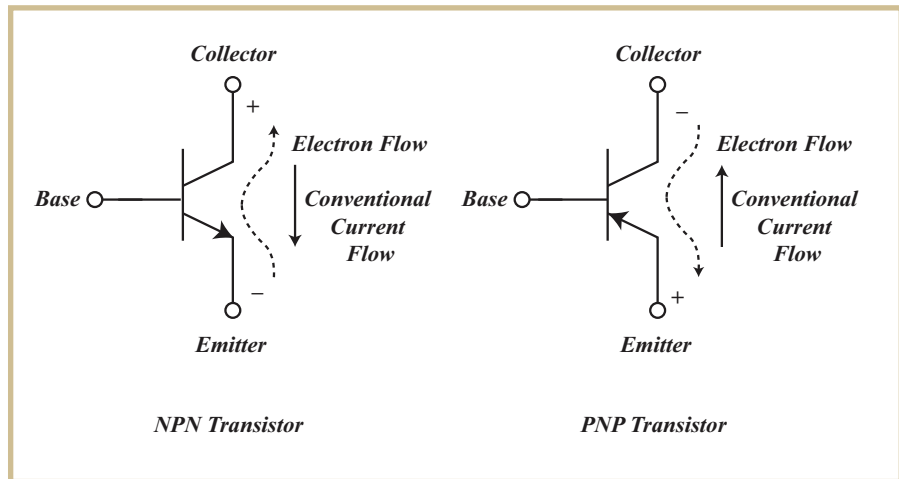
There are many different types of transistors, and Figure 29 shows some of their common symbols. The abbreviation JFET means *junction field-effect transistor*; IGFET means *insulated-gate field-effect transistor*; and MOSFET means *metal oxide semiconductor field-effect transistor*. The three-terminal transistor in the FET family are voltage-operated devices much like vacuum tubes, instead of current-operated devices like bipolar transistors.

These devices have three terminals for connection, and you should be able to identify the leads on the more common devices. In the common *bipolar junction transistor (BJT)*, the emitter is the terminal with the arrowhead. By examining the schematic symbol, you can tell whether the transistor is a PNP or NPN. As you can see in Figure 30, the arrowhead points outward in NPN types, and it points inward in the PNP.



**FIGURE 29—**Transistors are common components in thousands of devices and are available in both discrete packages and in arrays in integrated circuits.

**FIGURE 30—**There are two basic types of bipolar junction transistors, PNP and NPN. It's vital to observe polarities when designing new circuits, and you'll often find both types in circuits, especially when dual polarity power supplies are used.



In a circuit, a properly operating silicon BJT transistor will have a base-to-emitter DC voltage drop of about 0.7 volts. The emitter-to-collector-terminal voltage will be variable depending on the bias of the transistor. Contemporary electronic devices don't usually use individual transistors except where the transistor is providing a large power output, as in the case of a high-power audio amplifier. Another example is when transistors are used as device drivers, where low-power signals drive mechanical or electronic relays controlling high-current devices such as motors. Figure 31 shows an example of a transistor configured as a switch in a circuit that drives a relay. The input signal to the base of the transistor can come from analog or digital logic devices, which allows low-power and low-current sources to control large amounts of



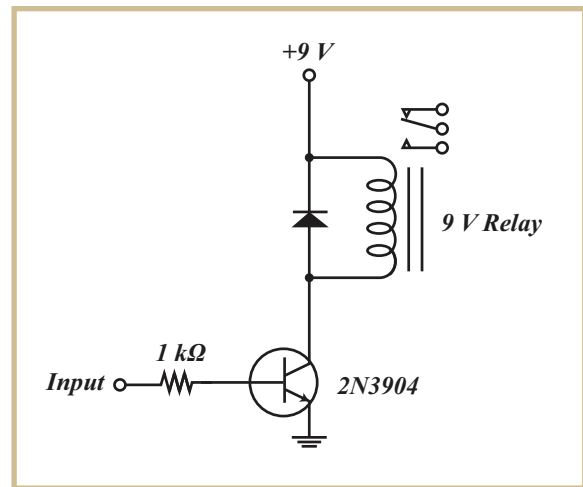
current. A diode is placed in a reverse-biased connection across an inductive load to protect the transistor from induced voltage spikes when the relay is actuated.

## Common Biasing Techniques for Discrete Transistors

Transistors are still used in discrete configurations, that is, they're designed into circuits as individual devices and not as part of integrated circuits. This is sometimes done because transistors can be operated at higher power levels with heat sinks attached. Sometimes individual transistors offer advantages for maintenance and service of equipment. Many times an integrated circuit will function as a pre-amplifier, and the transistor will use the output signal of the IC to drive a high-power output such as a speaker, actuator, or other electromechanical transducer.

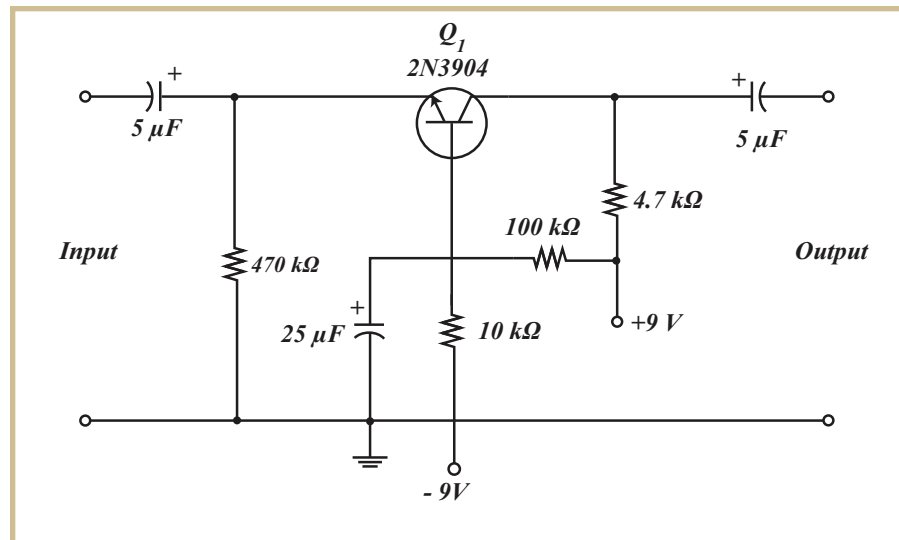
The three types of biasing used for individual transistors are *common emitter*, *common collector*, and *common base*. The name comes from the terminal that's common to both the input and output portions of the circuit, and you'll recognize each type by the way the transistor is biased and positioned in the circuit schematic. The common-base amplifier shown in Figure 32 has the input signal on the emitter, the output on the collector, and the base as the common terminal to the input and output. It's often used as a pre-amplifier for low-impedance transducers, and it has relatively low input impedance.

The common emitter is probably the most common amplifier circuit for discrete transistors. In the example shown in Figure 33, the input signal is on the base, the output signal is taken from the collector, and the emitter is common to both input and output. Many times the emitter has a capacitor called the *emitter-bypass capacitor* attached between the terminal of the transistor and ground. This acts to put the emitter effectively at ground for any AC signals. This is done to raise the gain of the circuit while maintaining the correct DC bias



**FIGURE 31**—Transistors are often used as switches to allow low-level voltage signals from computers and other digital devices to drive high-power devices such as relays or motor controllers.

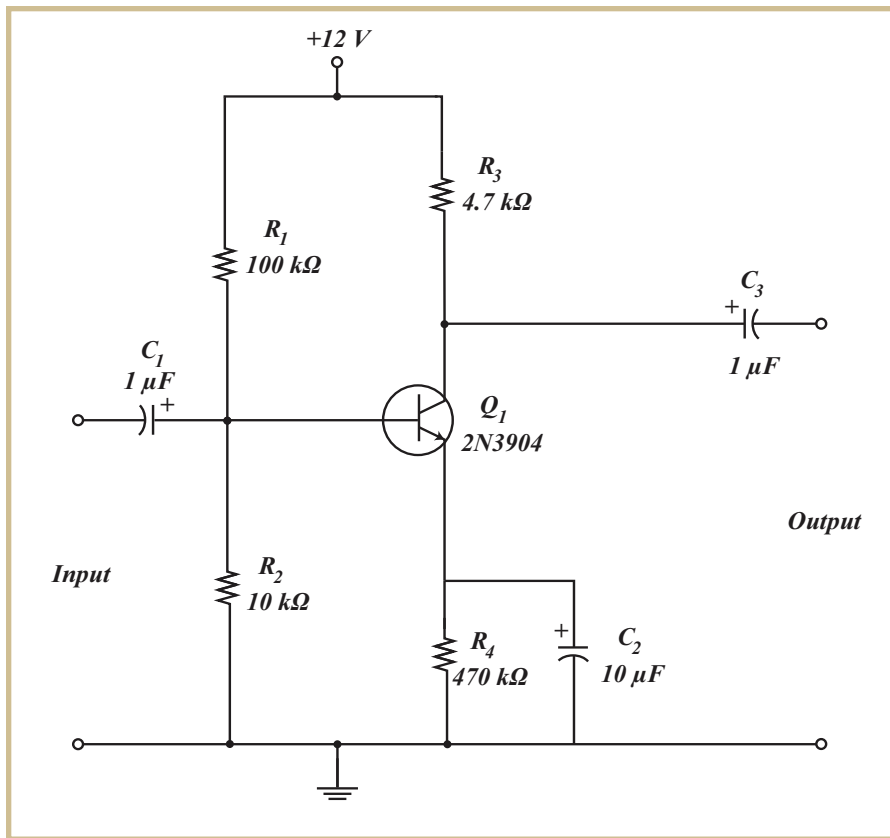
**FIGURE 32—Common-base amplifiers aren't often used because better circuit alternatives are available.**



voltages. Notice that resistors in the form of a voltage divider set the DC voltage at the base. This determines the DC base current and the DC collector voltage, which is often designed to be half of the DC supply voltage. For example, if the transistor amplifier had a +12-volt supply, you might expect to see the DC bias collector voltage at +6.0 volts, so that a Class A amplifier could have a maximum output voltage swing of nearly  $\pm 6.0$  volts above and below the bias voltage of 6.0 volts. Often, the output signal is coupled to a coupling capacitor to move the signal to the next stage of the amplifier, as shown in Figure 33.

Frequent defects in common emitter amplifiers often result from the capacitors connected to the emitter and collector. A bad emitter-bypass capacitor results in lower gain than expected. Because the coupling capacitor connects two stages of an amplifier, one or both stages may have low gain, clipped output signals, or severe distortion because the bias voltages are wrong.

The last type of discrete transistor bias arrangement is the *common-collector amplifier*, shown in Figure 34. The input signal is on the base, the output signal is from the emitter, and the collector is common to both. This type of transistor amp has high input impedance and low output impedance, and is noninverting. This makes it ideal to drive low-impedance loads such as speakers, motors, or actuators. The gain of the common-collector amp is slightly less than 1; you would measure almost the same AC voltage on the base and the

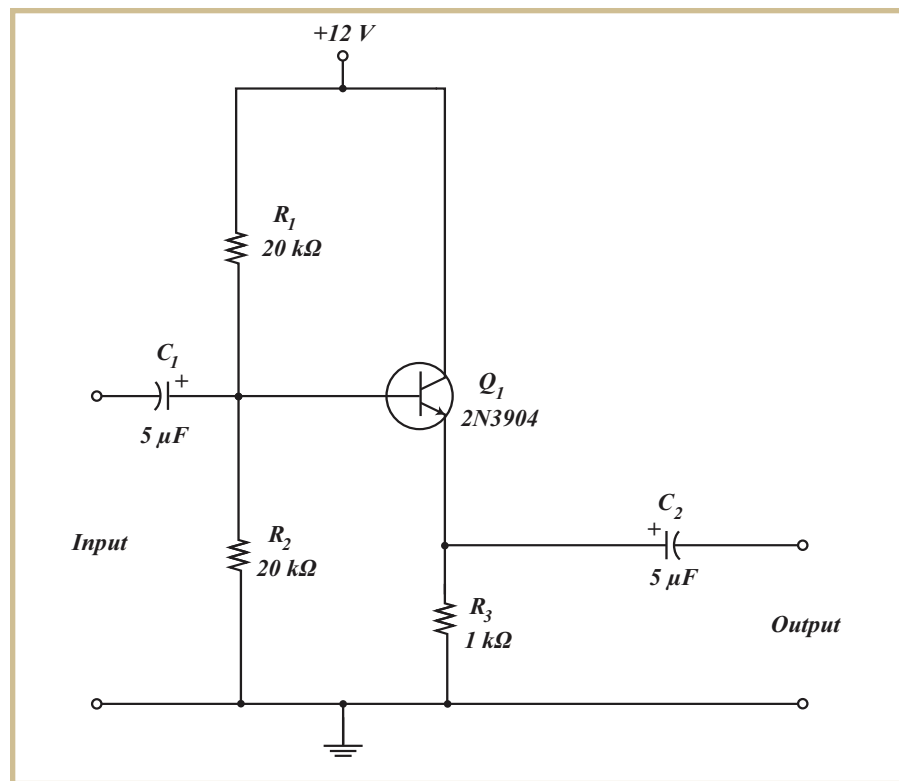


**FIGURE 33—Common-emitter amplifiers are used in hundreds of different types of circuits and are also found in integrated circuits. They have high input impedance and moderately low output impedance, and are used for input and intermediate stages of amplifiers.**

emitter. DC biasing is designed to make the AC output able to swing nearly the full power supply voltage. Often two common-collector transistors are put in parallel with each other using bipolar power supplies, one to handle positive voltage swings, and the other to handle negative voltage swings. In Figure 34, notice that the DC bias voltage on the base would be about 6 volts, making the emitter voltage about 5.3 volts (accounting for the approximate 0.7 volt drop across the base-emitter diode). This would allow an input signal to drive the output signal almost but not quite the entire 12 volts available from the supply.

With the advent of integrated circuits and the availability of a wide variety of reliable and versatile op-amps, you'll see fewer circuits that use discrete transistors for complete circuits. You're more likely to see modern op-amps such as the LM324, that are available packaged as quad op-amps, performing the function of a single or multiple transistor stages. This avoids the problem of troubleshooting bias arrangements and coupling capacitors. As you'll see later, biasing op-amps is very straightforward, using only two or three resistors, and coupling between stages often done directly without the need for capacitors.

**FIGURE 34—Common-collector amplifiers are used as output stages since they're noninverting and have very low output impedance, making them suitable for driving low-impedance devices such as relays or speakers.**



## Transistor Differential Amplifiers

One important configuration for transistors you'll need to recognize is the *differential amplifier*. This is a common circuit for all types of amplifiers and is used extensively in integrated circuits because of its very desirable characteristics. The differential amplifier is used to compare voltages at the two inputs of the transistors and amplify the difference between them. In a common practical application, these devices amplify small signals containing noise, since any noise common to both inputs isn't amplified at all.

Figure 35 shows an example of a typical circuit for a discrete transistor differential amplifier. Notice that the transistors are connected in parallel with each other, with the emitters connected to a resistor. The resistor in this case functions as a constant current source. Sometimes you'll see another small resistor connected between each of the emitters and the current-source resistor. This ensures that each transistor splits the current equally. In integrated circuits, fabricating a transistor is actually easier than making a resistor on a chip. So

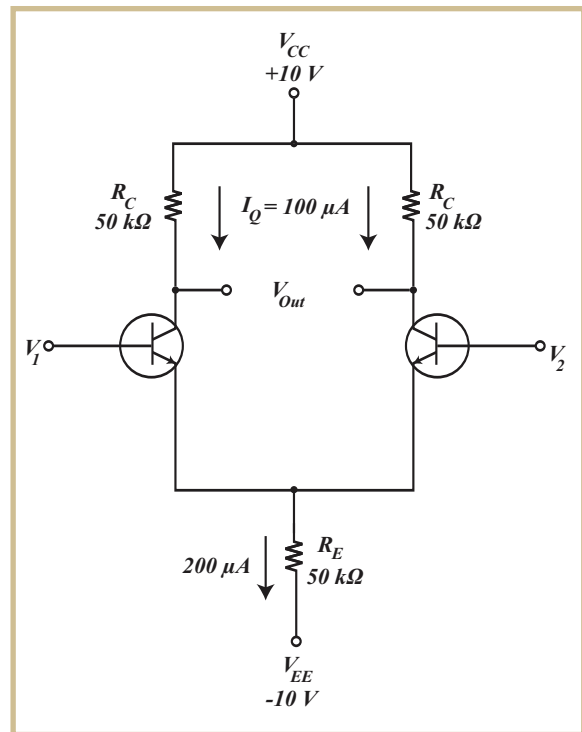
instead of seeing a resistor connected to the transistors, you'll see another transistor biased as a current source or current mirror.

The output of the difference is taken between the two collectors, and this voltage represents the amplified difference between the input voltages. In op-amps or instrumentation amplifiers, this voltage is passed along to a second stage that further amplifies the voltage or power. These differential amplifiers have very high input impedances and high common-mode rejection. This means that any voltage common to both inputs, such as noise, isn't passed through.

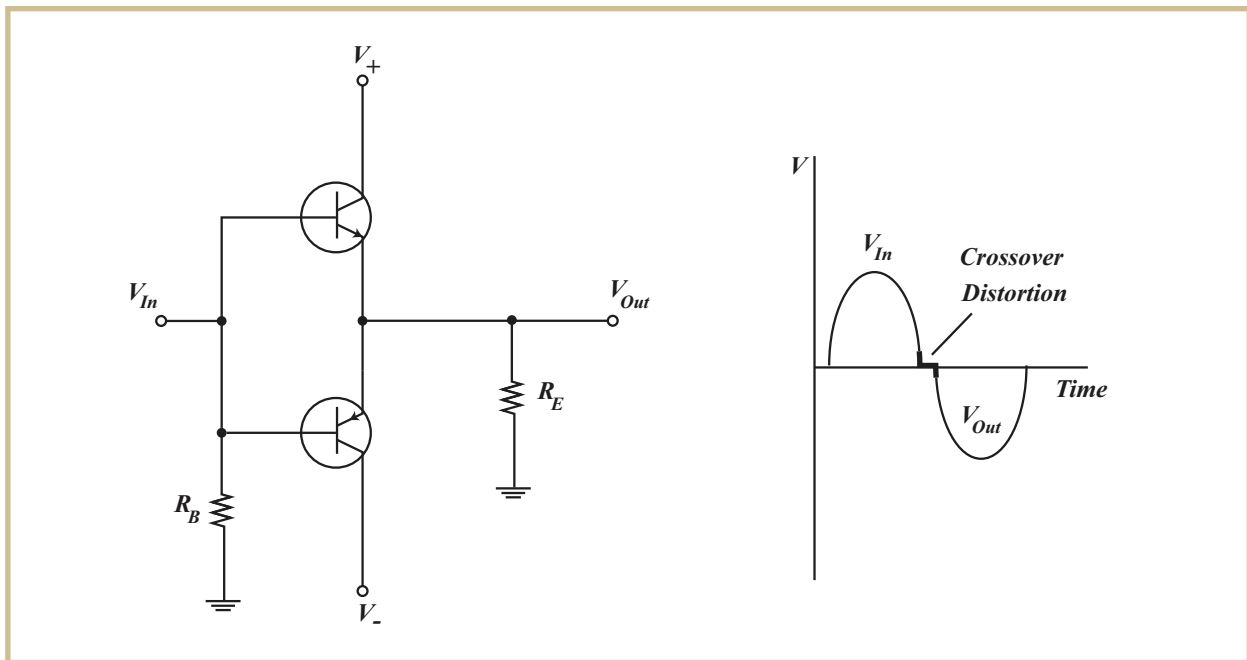
### More Transistor Circuits

Another common transistor configuration is the *complementary-symmetry amplifier* shown in Figure 36. These amplifiers use matched pairs of NPN and PNP transistors that are biased to conserve power. Power use is limited when there's no input signal or voltage because the collector current remains near zero. The NPN transistor amplifies positive-going signals, while the bottom PNP transistor amplifies negative-going signals. Because there's a slight voltage drop across the emitter diodes of each transistor, there's some small amount of distortion, called *crossover distortion*, as the signal voltages go through the zero point.

Transistors that can handle large amounts of power often don't have very high beta values (current gain, or  $I_C$  or  $I_B$ ). That is, they require high base currents to obtain large collector currents. Typical values of beta for a power transistor are 3 to 20, while small-signal transistors can have a beta ranging from 50 to 200. A common way to increase the beta value of an output transistor is to drive a power transistor with a small high-beta signal transformer, as shown in Figure 37. This arrangement is called a *Darlington pair*. Some transistors actually have both transistors in the same case and are fabricated on the same chip. There are disadvantages to using Darlington pairs, including temperature instability, higher emitter voltage drop, and speed limitations.

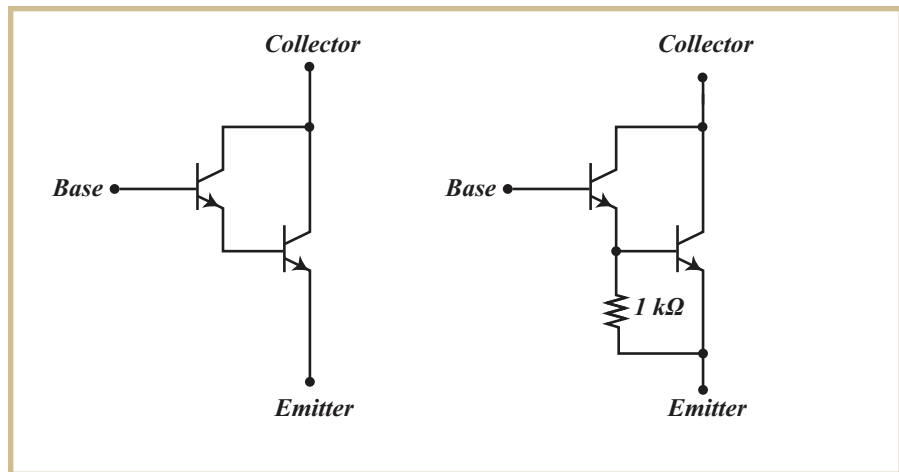


**FIGURE 35**—Differential amplifier circuits are used as the input stage for multistage amplifiers because of their high input impedance.



**FIGURE 36**—Complementary-symmetry amplifiers are used as output stages to drive high-power loads from bipolar power supplies. They introduce a type of crossover distortion because the diodes in the transistors don't conduct when the base input voltages are less than about 0.7 volts.

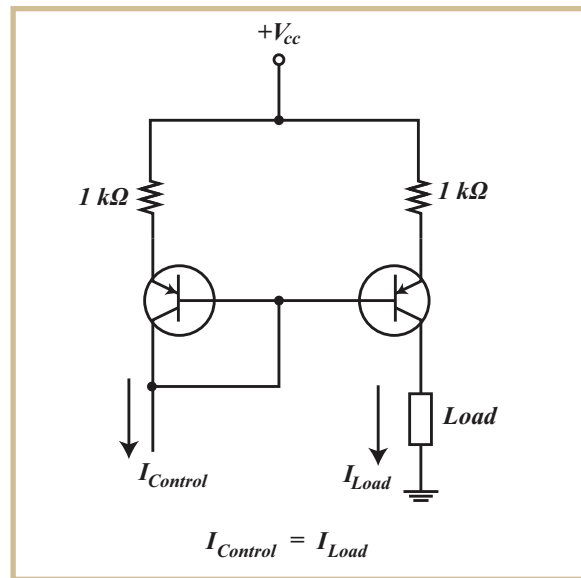
**FIGURE 37**—Darlington pair transistors are often used to allow small input signals to drive high-current loads. But unless the transistors are well matched, temperature instability can be a problem.



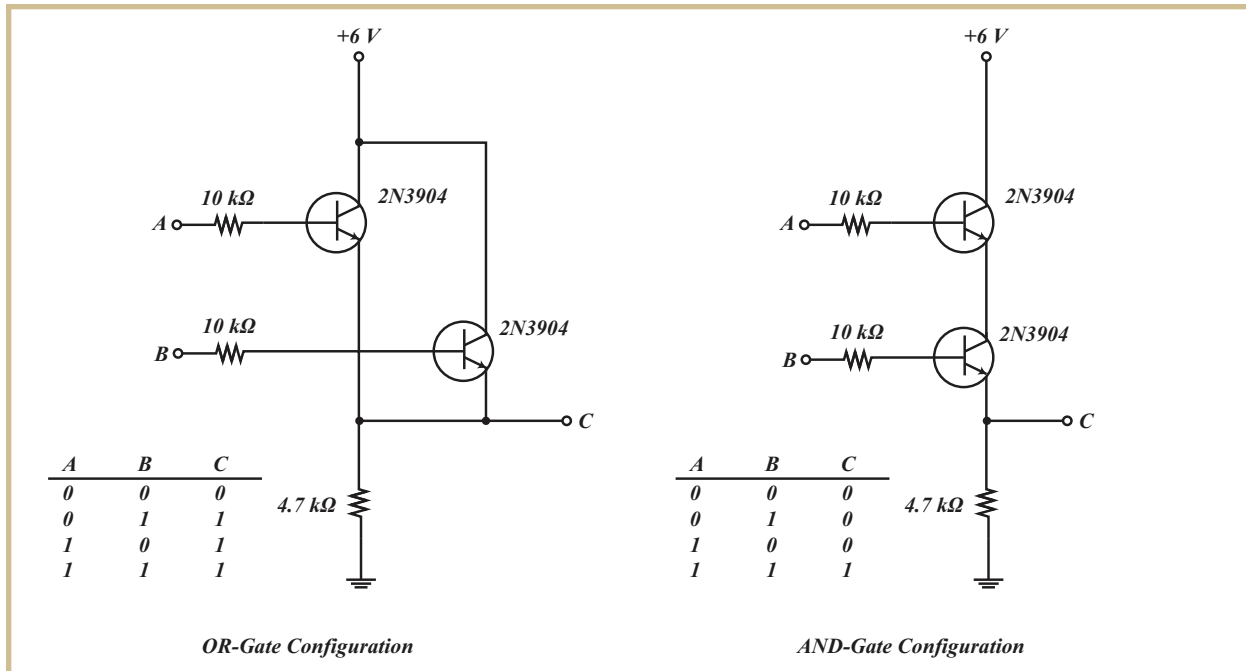
Another common transistor circuit is the *current mirror* shown in Figure 38. This can be found in single and multiple arrangements and is used often as a current source circuit for differential amplifiers. The current in the control or bias side of the circuit is “mirrored” by the transistor connected to the load. The transistor in the bias side is actually connected as a diode (the collector and base are connected together). If the transistors are carefully matched—as they would be in an integrated circuit—the base emitter diodes in each transistor

would split the current equally, thus forcing the collector current in the load to mirror the current in the bias side.

Later in this unit, you'll also learn about *logic gates* in integrated circuits. However, the first logic gates were built with discrete transistor circuits, and you may still encounter them in some applications. Figure 39 shows an OR gate and an AND gate made with simple transistor arrangements. In the OR configuration, you can see that the transistors are in parallel with each other, with a signal at either input causing an output voltage equal to the supply voltage. In the AND gate, the transistors are in series with each other, requiring a signal on both transistors to cause an output voltage. These could be used to drive a relay, for example, without requiring the 5-volt power supply normally used in digital logic, or needing an integrated circuit mounting arrangement for an otherwise simple relay driver.



**FIGURE 38**—Current mirrors are used to make constant current sources, which can be used to bias differential amplifiers. This results in very high input impedances and potentially very high gains in amplifiers.



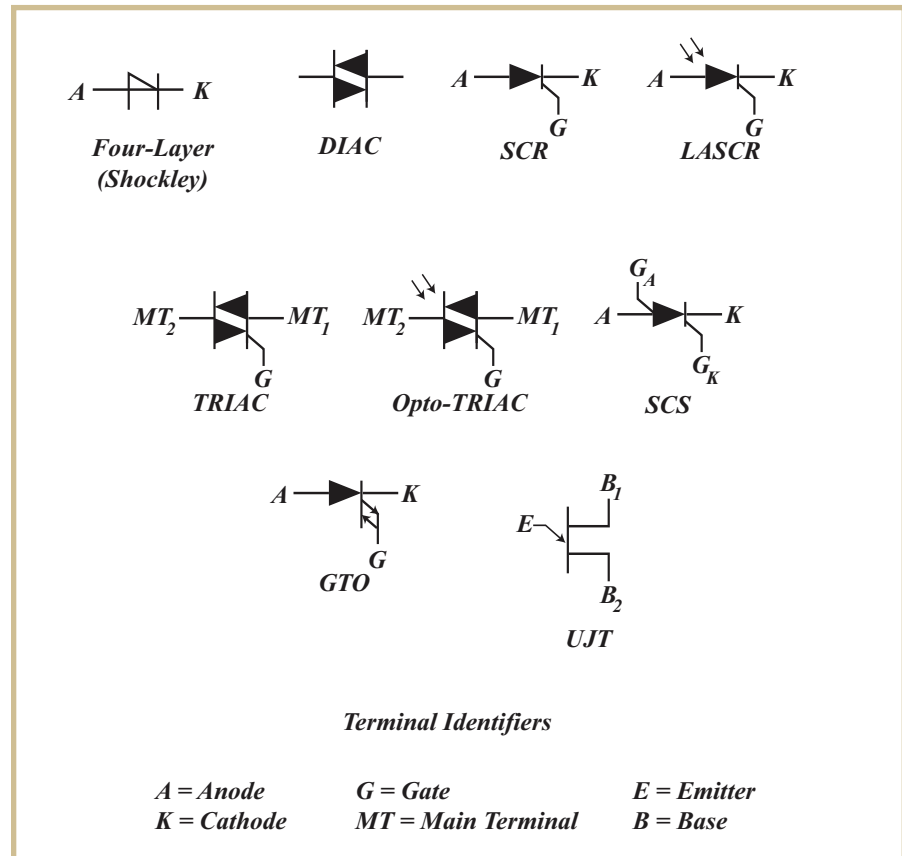
**FIGURE 39**—Although circuits often use integrated circuits for logic functions, many applications can be easily implemented with simple discrete transistors.

We've discussed and illustrated transistors in these examples, but FETs can also be used in many of these circuit arrangements, so you'll need to recognize the general component-arrangement pattern.

## Thyristors

*Thyristors* are a category of electronic devices that act as switches to control current flow. The most common types are *silicon-controlled rectifiers (SCRs)*, *triacs*, and *diacs*. Figure 40 shows the schematic symbols for several of these devices.

**FIGURE 40—Thyristors are active devices, commonly used as switches, that can be digitally controlled.**

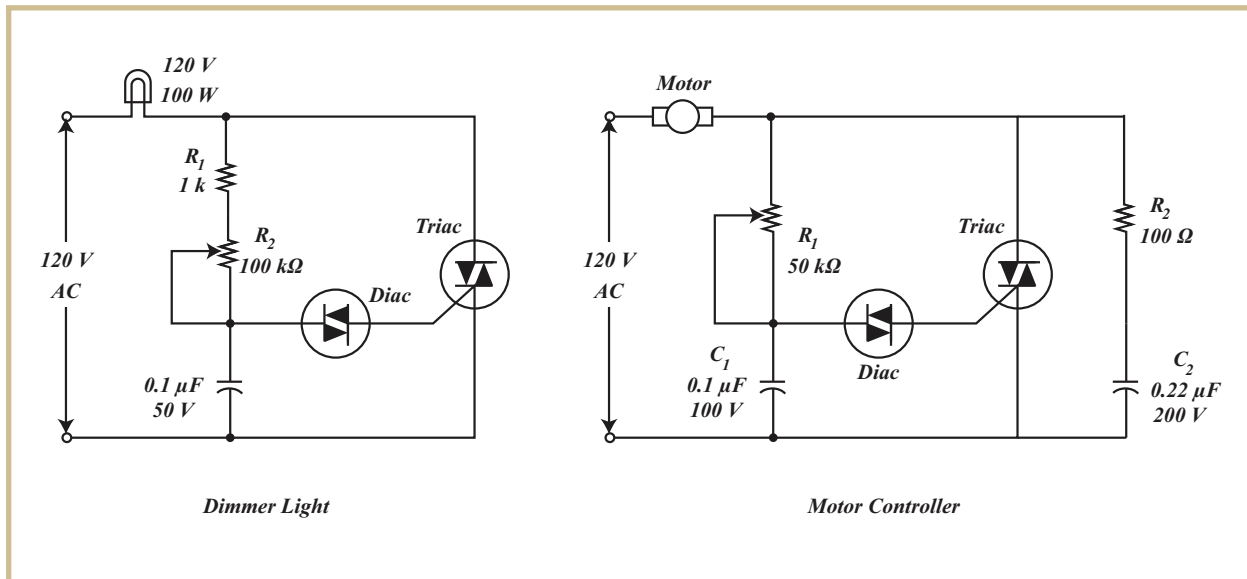


SCRs are diodes whose forward-biased conduction can be controlled with a terminal called a *gate*. When reverse biased, they operate like a normal diode, blocking current. SCR are used mostly in DC circuits or in AC circuits as rectifiers that can be controlled to adjust voltage or current. The arrow in the symbol indicates the forward-biased polarity, with the anode being the more positive terminal. The SCR gate terminal



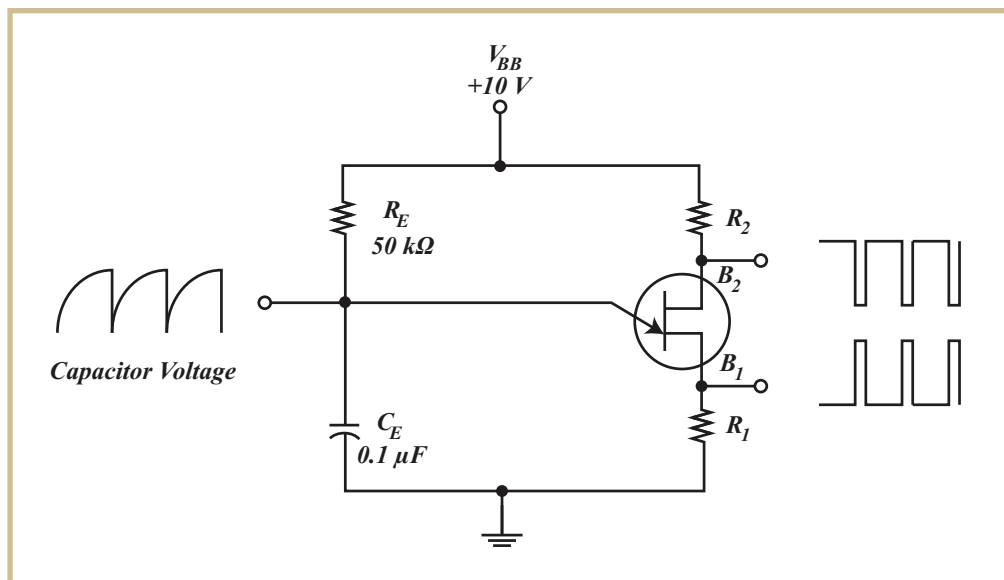
must also be forward biased—more positive than the cathode terminal—in order to be turned on to allow DC current flow. Triacs are used in AC circuits, with the  $MT_1$  and  $MT_2$  terminals connected in series with a load and the gate terminal again being used to turn on current flow when activated.

*Four-layer diodes* and diacs are bidirectional devices that turn on when the voltage across their terminals exceeds their rated voltage. Four-layer diodes conduct in one direction when the voltage exceeds the device rating; diacs conduct in either direction when the voltage rating is exceeded. Diacs and four-layer diodes are often used in the gate circuits of triacs and SCRs to prevent false triggering by noise or circuit transients, as shown in Figure 41, which illustrates some common examples.



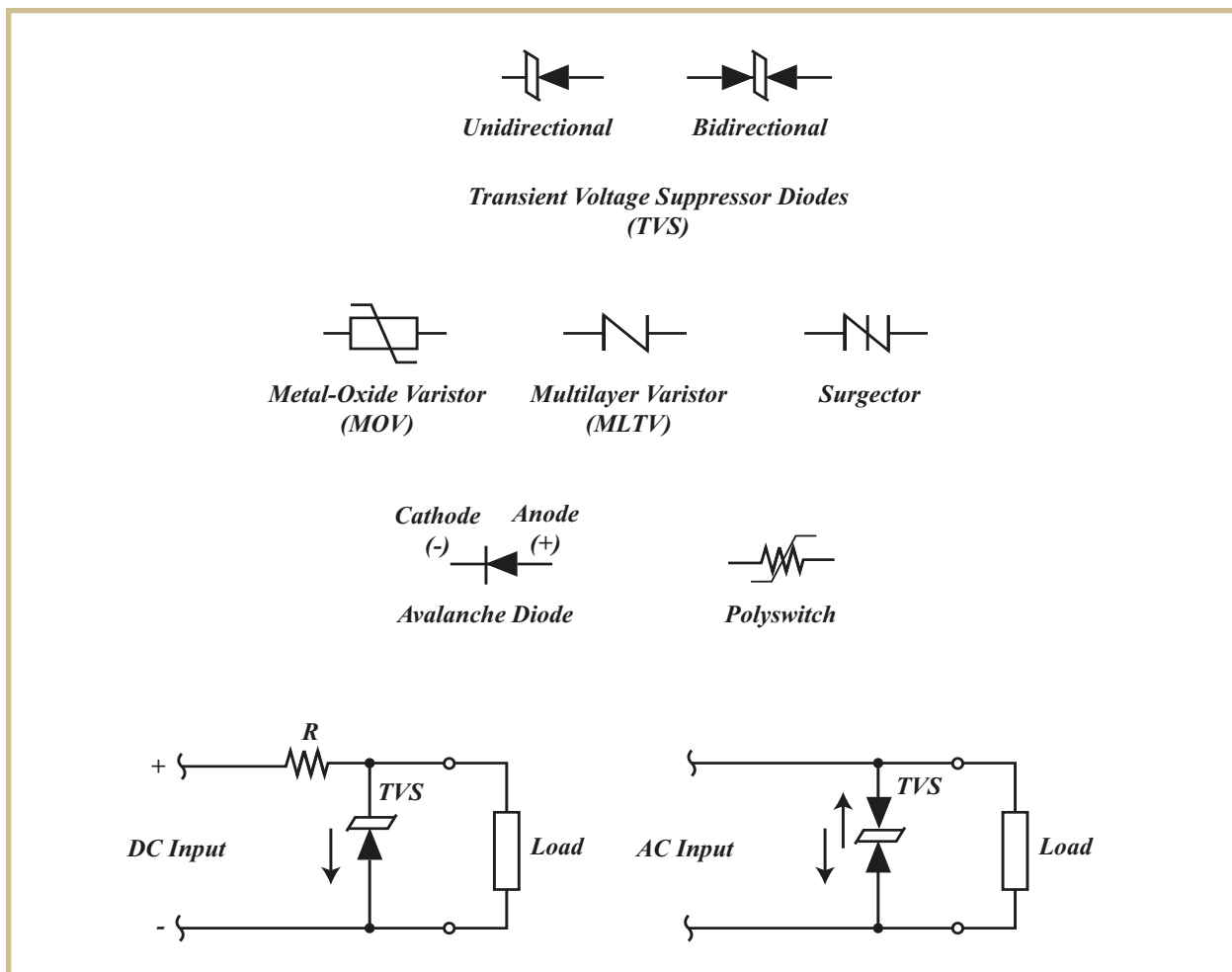
**FIGURE 41—Placing diacs in the trigger circuits of thyristors prevents false triggering from noise or transients.**

A special transistor called a *unijunction transistor (UJT)* is shown in Figure 42. These are more like a voltage-controlled switch than a transistor. When you see these in schematics, you should recognize that they're always associated with timing circuits. They're often used to generate special waveforms such as *triangle waves*. In Figure 42, the capacitor is charged through a resistor, which results in an exponential-shaped capacitor-voltage waveform. If, however, the capacitor was charged through a transistor, a linear ramp—a sawtooth wave—would result at the base of the UJT.



**FIGURE 42—Unijunction transistors are used in timing and waveform circuits.**

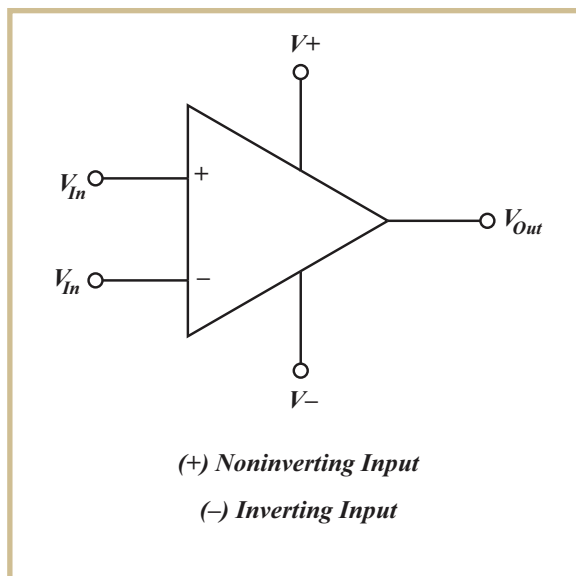
Another category of devices you may encounter in schematic diagrams are *transient-suppressing* devices such as *metal-oxide varistors (MOVs)*, *multilayer MOVs (MTLV)*, *transient voltage suppressor diodes (TVSDs)*, *surge protectors*, and *polyswitches*, as shown in Figure 43. MOVs and similar devices are usually placed in parallel with devices or circuits they're intended to protect. When you encounter these devices in circuits, you should understand they don't amplify or interfere with the signal or current, but only protect other parts of the equipment.



**FIGURE 43**—Special devices such as these diodes, varistors, and polyswitches help protect other electronic components from high-voltage transients. They're usually placed physically close to the component they're designed to protect.

## Operational Amplifiers

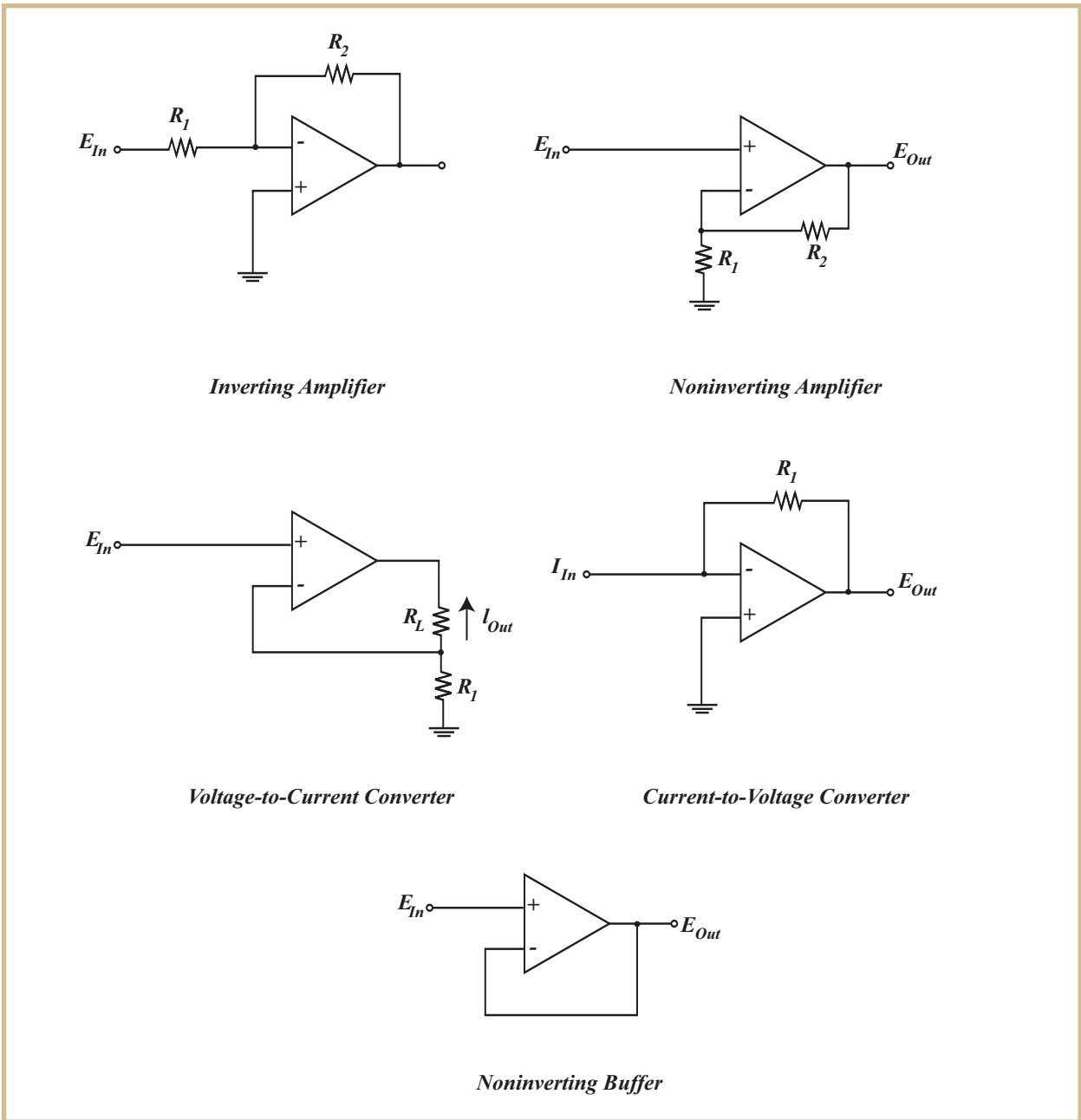
*Operational amplifiers* are solid-state devices containing transistors, diodes, capacitors, and resistors in one package. Op-amps used to consist of discrete devices, but with the advent of circuit miniaturization, they're now constructed from integrated circuits fabricated on wafers of silicon. Common op-amps have standard input, output, power supply, and compensation or bias terminals. Figure 44 shows a basic schematic symbol of an op-amp. The individual symbols show the positive and negative power supply terminals ( $V_+$  and  $V_-$  in Figure 44), but for clarity in larger schematics, they're often *not* shown. So you must understand that they're present and must be connected in the circuit.



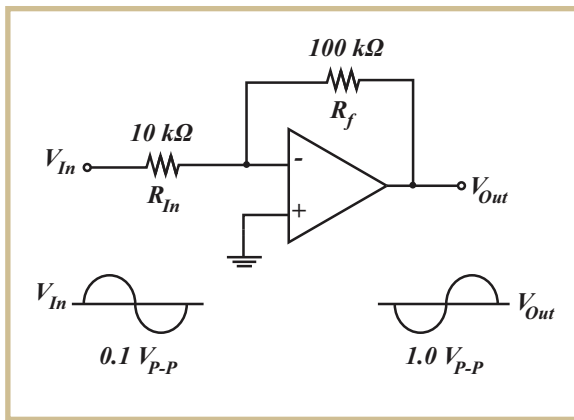
**FIGURE 44—The simple schematic of the op-amp doesn't reflect the power and ease of use they offer to designers of electronic circuits. They have an inverting input, a noninverting input, and an output. Some types have additional connections for bias adjustments or compensation for frequency range.**

Op-amps are commonly used for many applications, including amplifying low-level signals such as audio or video signals. The + and – symbols on the input-voltage side of the triangle don't mean positive and negative. The positive + symbol is next to the noninverting input terminal, and the negative – symbol is next to the inverting terminal. This means that any signals that enter the + terminal maintain the same polarity on the output, while signals applied to the inverting input are reversed in polarity. DC signals are reversed in polarity, too. A 0.25-volt DC input to an inverting op-amp with a gain of 10 will have an output voltage of –2.5 volts. Figure 45 shows some examples of inverting and noninverting amplifiers. You'll see these configurations over and over in all types of electronic circuits.

The function of an op-amp is determined by the biasing resistors connecting its output and input in what's called *closed-loop feedback*. Without any biasing components for feedback, the gain of a common op-amp is on the order of 50,000 to several million, which is usually too high for practical applications. Providing negative feedback—connection of the output back to the inverting input—decreases the gain but increases the bandwidth of the amplifier. Negative feedback is usually done with two resistors, as shown in Figure 46. The value of the resistors sets the amount of feedback and the gain of the amplifier. In the figure, the amplifier would have a gain of 10, and the signal would be inverted, for example. Understanding the operation of the biasing resistors will help you troubleshoot amplifiers by checking to make sure each amp has the correct gain.



**FIGURE 45—Op-amps are very versatile and are used in many different types of circuits. You'll need to recognize the basic arrangements of connections that tell you what the circuit function is. These circuits are common, but represent only a few of the possible applications for op-amps.**

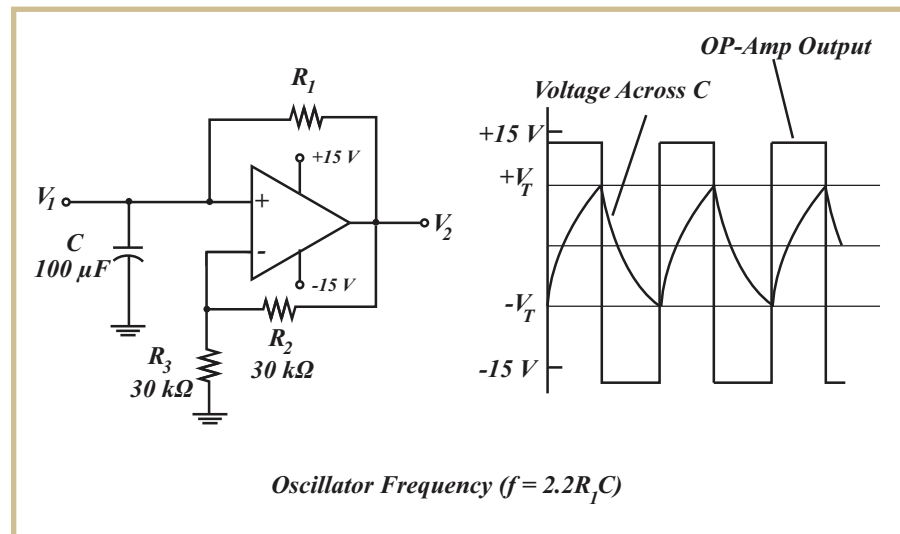


**FIGURE 46—The inverting amplifier is probably the most common type of op-amp configuration and is easily adaptable to many different setups, from audio to television applications.**

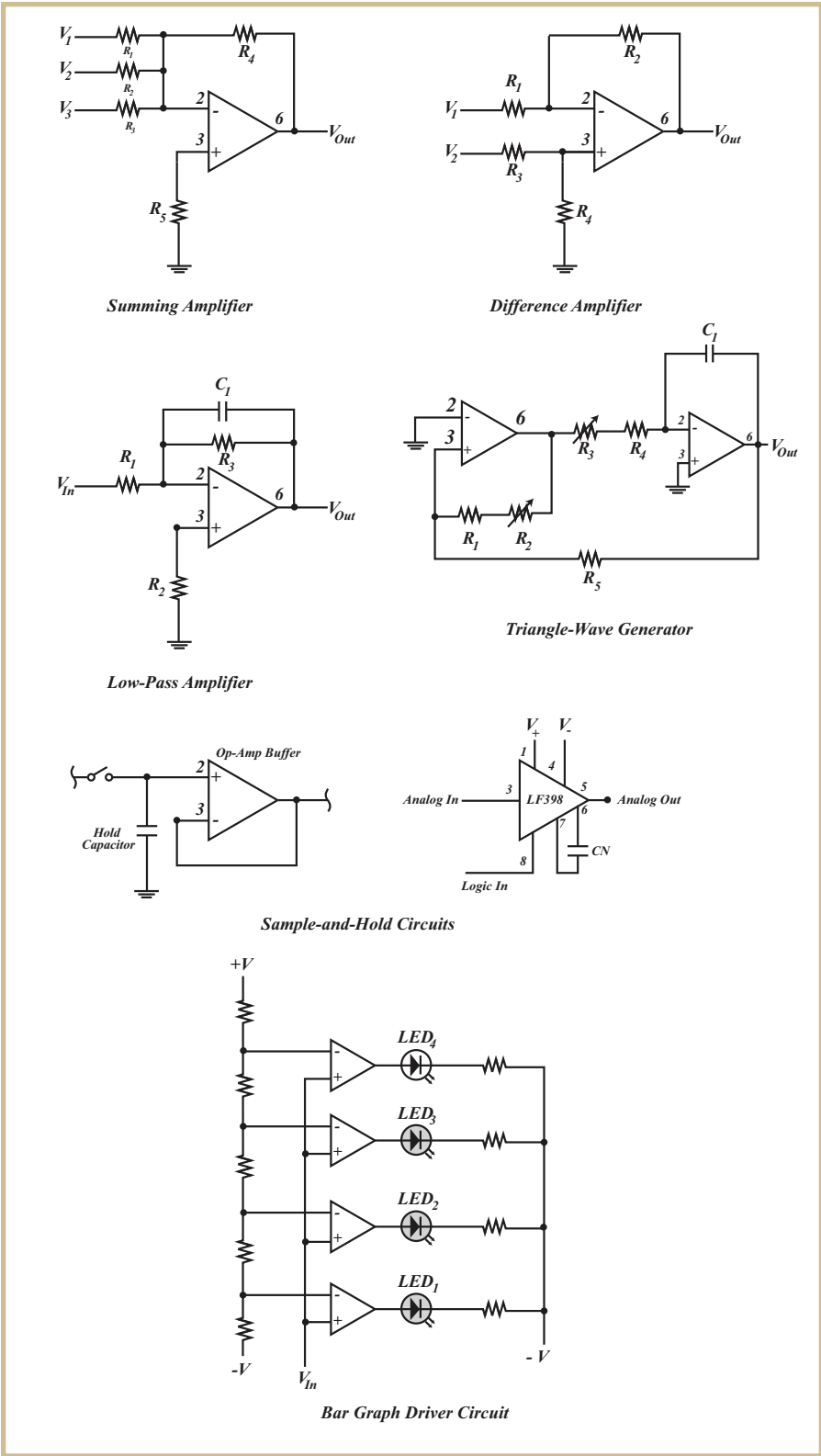
Positive feedback is also used with op-amps to make special-function circuits such as oscillators and comparators. *Oscillators* are found in many types of electronic devices. Figure 47 shows an example of a simple *relaxation square-wave oscillator* that might be used as a test circuit or electronic clock. The op-amp amplifies the voltage difference between the inputs, so the output varies between the positive and negative supply voltages. It's said to be *saturated*, since even a small difference in the input voltages is amplified much more than the power supply can deliver. When the output switches from one polarity to the other, the capacitor

begins charging in the opposite direction until the voltage difference at the input of the amplifier switches polarity, repeating the cycle at a rate determined by the values of the resistor and capacitor.

**FIGURE 47—Positive feedback is used to make oscillators, which are easy to design with op-amps. The value of the capacitor and feedback resistor determines the frequency of the output.**



Op-amps can be configured to perform all the functions of a transistor, plus many additional circuit functions. The key to understanding how a circuit operates is to recognize the biasing arrangement of the components connected to the terminals. You'll often encounter the common circuit configurations for op-amps shown in Figure 48.



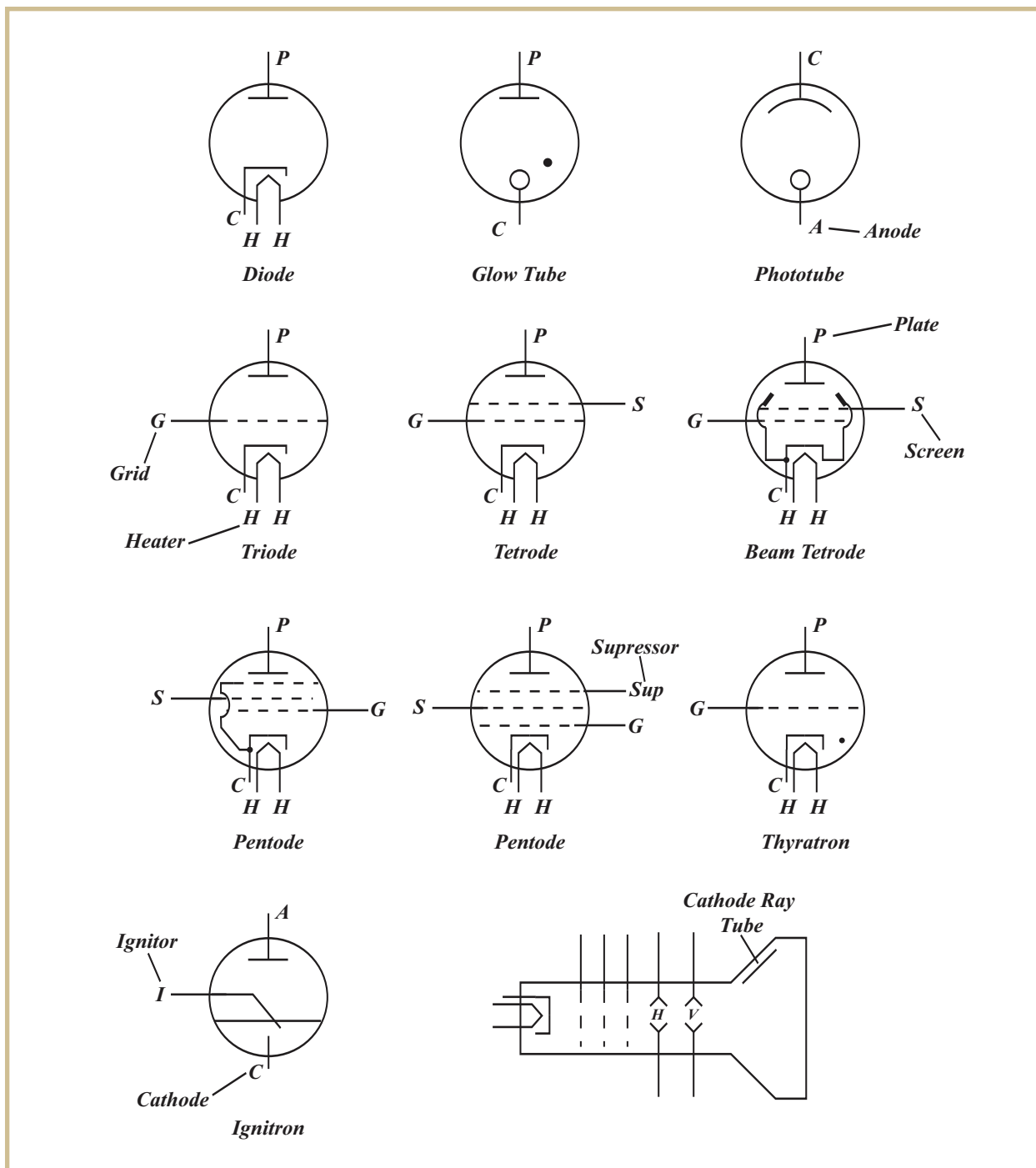
**FIGURE 48—Op-amps can be easily configured to perform many important circuit functions simply by connecting the right passive components to the inputs and outputs. These circuits are common, and you'll see them often in schematics.**

## Vacuum Tubes

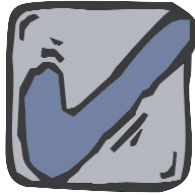
Although no longer common, *vacuum tubes* are still found in many electronic devices, especially in audio applications. Vacuum tubes excel at very high-power applications because some are able to dissipate heat better than solid-state devices, but they suffer from crossover distortion when used as output amplifiers. Since they're active devices, vacuum tubes require bias voltages to function, but they have several extra requirements. Vacuum tubes usually operate at much higher voltages, so you're likely to see power supplies with voltage outputs as high as several hundred volts or more connected to the plate of the tube. Vacuum tubes also require a *filament voltage*: a common value for audio tubes is 6.3 or 12.6 volts. The first number of the tube usually tells you the filament voltage; for example, a 12AY7 has a filament voltage between 12 and 12.9 volts. The remaining letters and numbers are codes to identify the tube, and in this case the AY identifies the tube type, and 7 means it has seven elements, which include heater, cathode, grids, and plates.

Although not strictly vacuum tubes, some tubes are partially evacuated and filled with a gas that aids current conduction when the gas is ionized. They typically operate at high voltages and can conduct large amounts of current. For example, an *ignitron* is an older design for a rectifier tube that's still used today because it can handle thousands of amperes at voltages up to 50 kV. These are mainly used in heavy manufacturing applications. Figure 49 shows some common schematic symbols for vacuum tubes.





**FIGURE 49—Vacuum tubes are still used for new designs but are most commonly found in older equipment. They require more electrical connections and higher voltages.**



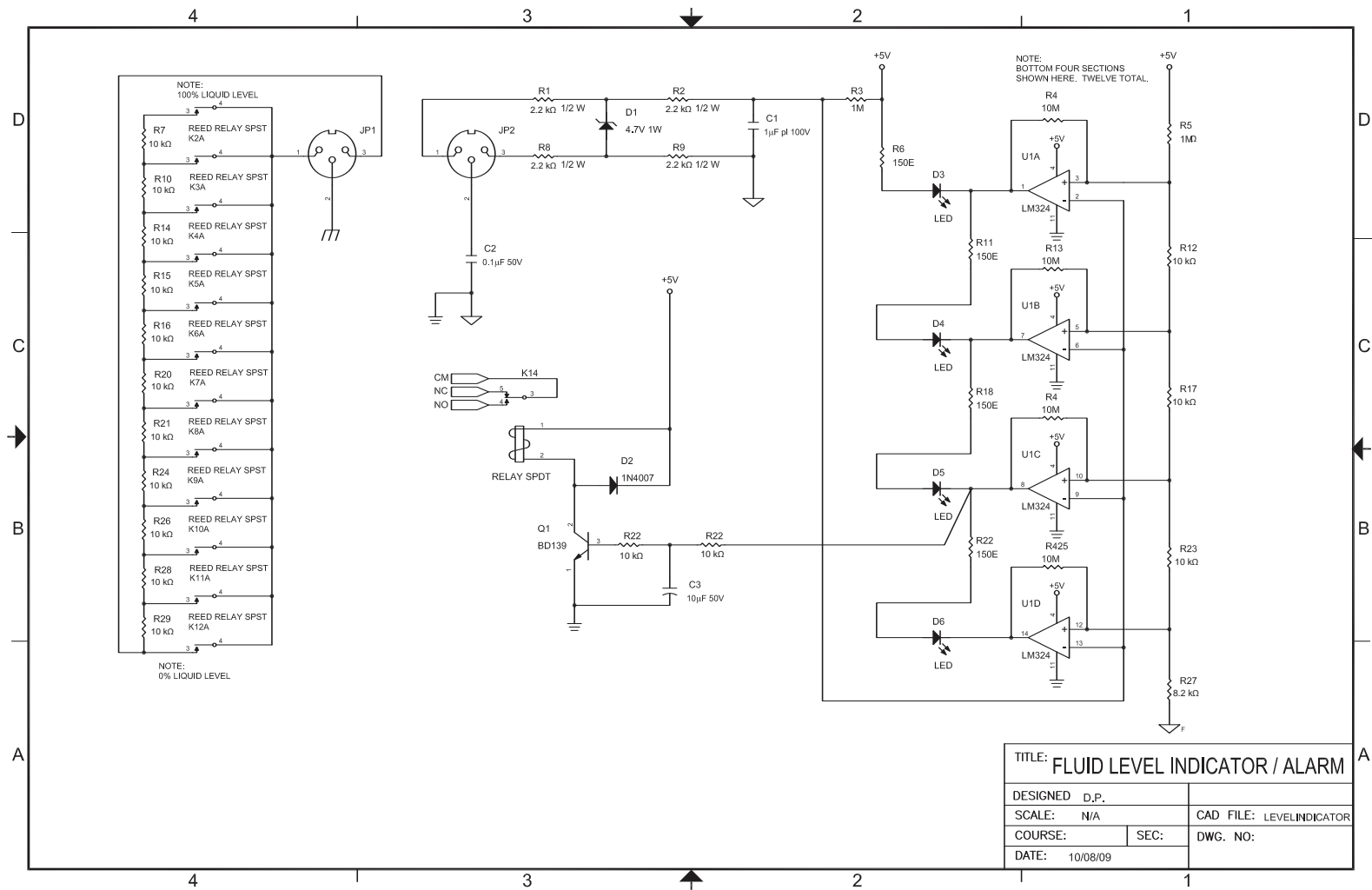
## Self-Check 2

Refer to the schematic on the following page to answer these questions.

1. Pin 2 on JP1 is \_\_\_\_\_.
2. The indicator lights showing the fluid levels are \_\_\_\_\_.
3. The power supply voltage that provides power to this circuit is \_\_\_\_\_.
4. Which op-amp must have a high output to activate K14?
5. The relay driver is a (NPN/PNP) \_\_\_\_\_, with a type number of \_\_\_\_\_.
6. The relay driver is protected by a \_\_\_\_\_ diode.
7. The inputs to the op-amps from the reed relay sensors are on pins \_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_ of the op-amps.
8. How many integrated circuits will be on this circuit board?
9. The power supply and ground pins on the op-amp are \_\_\_\_\_ and \_\_\_\_\_, respectively.
10. D1 is a \_\_\_\_\_ with a maximum power dissipation of \_\_\_\_\_ watts.
11. The voltage divider that provides the reference voltages to the op-amps is made from resistors \_\_\_\_\_.
12. The normally closed connection of relay K14 is from pins \_\_\_\_\_ to \_\_\_\_\_.

*(Continued)*

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Check your answers with those on page 79.

# INTERPRETING DIGITAL-CIRCUIT SCHEMATICS

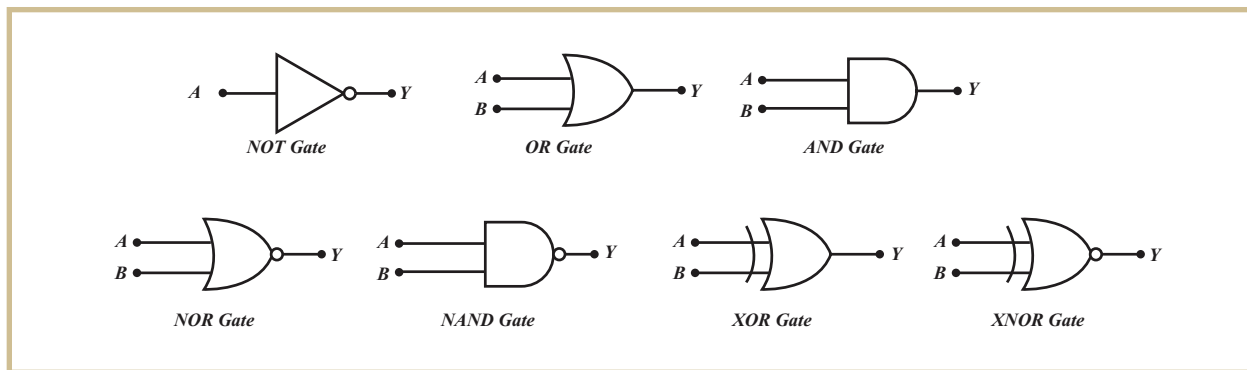
*Analog circuits* are ones that deal with an infinitely variable range of voltages or currents. *Digital circuits* refer to circuits in which the voltage at any point in the circuit will be a fixed value, such as +5 or 0 volts. In real circuitry some minor variation is possible of course, but in general there will be a high voltage that represents the “on” condition and a low voltage that represents the “off” condition. A high voltage is sometimes called a *logic high* or *logic 1*, and the low voltage is called a *logic low* or *logic 0*. Because they have only two states, digital circuits are easy to control and can be easily made to count using binary arithmetic. Digital counters count with numbers that have more digits than our decimal system, but because digital “real estate” on a circuit board is relatively cheap compared to analog devices, digital computing has taken over the computer world. When we need to see an actual number, the binary numbers are simply changed into the more common decimal form.

Digital circuitry began to appear in electronic devices in the 1960s and '70s and quickly took over many aspects of consumer and industrial electronic devices. Part of this market penetration was due to the increasing density of the devices: thousands of transistors could fit in a very small space. Also, digital circuits are easy to control, less susceptible to electrical noise, and lend themselves to easy control by computers, thus offering many more options in their applications.

There are several basic digital gates you'll need to recognize and know how they're used in circuits. Combinations of these gates occur so often they've been incorporated into special integrated circuits. These include *flip-flops*, *latches*, and *multivibrators*. Many electronic devices are designed and constructed by integrating subcircuits that use combinations of digital gates, special devices, and even analog components. You'll begin to recognize the function of these subcircuits and how they function within the overall purpose of the equipment.

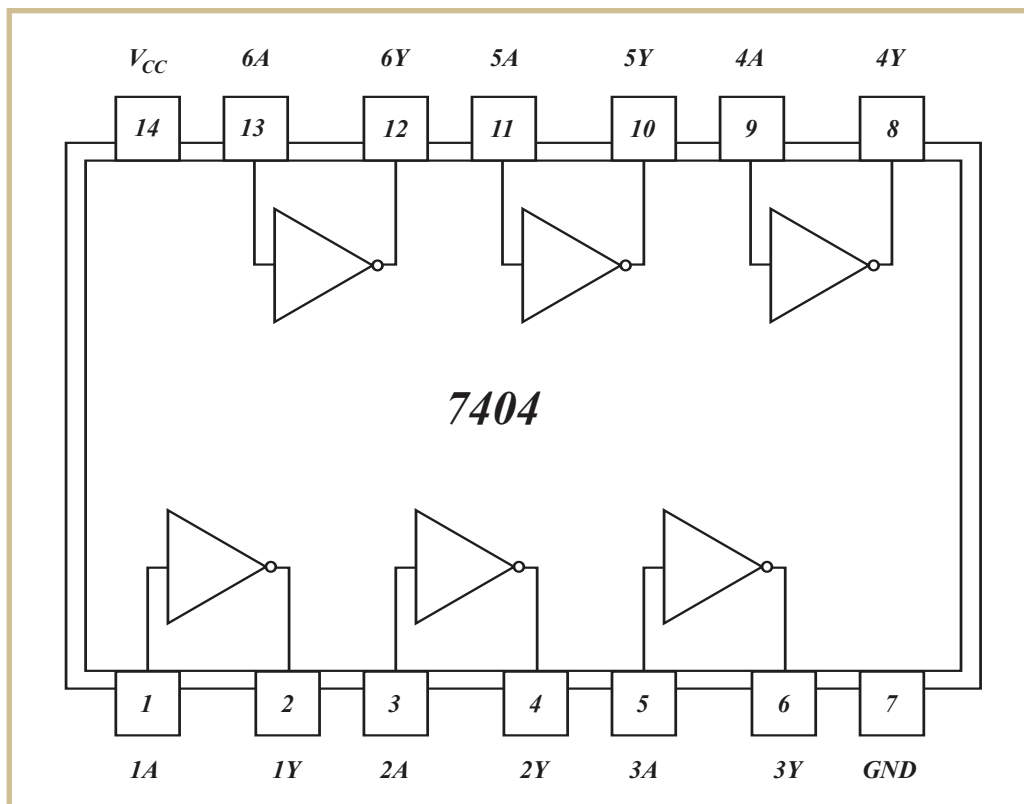
## Basic Digital Gates

Gates are fundamental building blocks of digital circuits: AND gates, OR gates, NOT gates (which are a type of voltage inverter), and XOR, or exclusive-or gates. When a NOT gate is put on the output of an OR or an AND gate, it becomes a NOR or a NAND gate, respectively. The same applies to adding a NOT to an XOR gate, where it becomes an XNOR. Figure 50 shows the schematic symbols of these common digital logic gates. Many logic gates use the NOT symbol on input terminal, meaning that an input signal is inverted before it enters the device. You'll often see this in other types of digital devices such as flip-flops and clock circuits.



**FIGURE 50**—Digital logic symbols are most commonly drawn using the traditional symbols shown above.

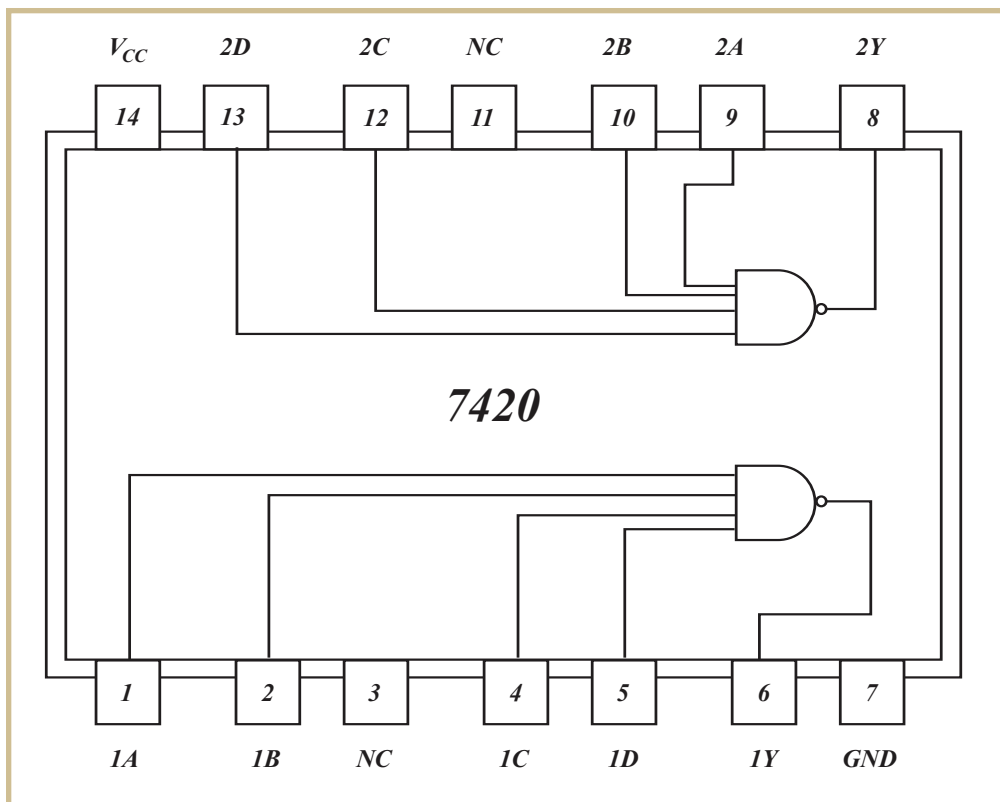
Digital devices are numbered to indicate the type of device, and often the number is printed on the schematic next to the symbol; however, many digital integrated circuits contain multiple gates, such as the 7404 shown in Figure 51. Power is supplied to the  $V_{CC}$  terminal and the circuit is grounded at pin 7. In the 7400 series of circuits with 14 pins, the  $V_{CC}$  terminal is pin 14 and the ground is pin 7. The power connections serve all the gates within the integrated circuit.



**FIGURE 51**—Logic gates are often packaged with multiple gates in one circuit, sharing common source and ground connections, as in this 7404.

The simple AND, OR, and XOR gates we’ve talked about so far have only two terminals. Digital gates can have more than one input, but they usually have only one output. Figure 52 shows a 7420 integrated circuit that has two four-input OR gates, with the corresponding pinout diagrams.

Digital devices are classified by their *family*, a term that refers to the method of construction and the voltages at which they typically operate. There are two major families of logic devices: the *bipolar* and the *metal oxide semiconductor (MOS)* families, with several subfamilies within each. Table 2 shows the classification and divisions of these families. Each family has advantages and disadvantages for specific applications, and you’ll need to understand when you can substitute devices if you’re repairing digital equipment. In general, bipolar circuits are faster but consume more power and physical space, while MOS types are smaller, slower, and consume less power.



**FIGURE 52**—Logic gates can have multiple inputs, such as this dual quad-input NAND gate.

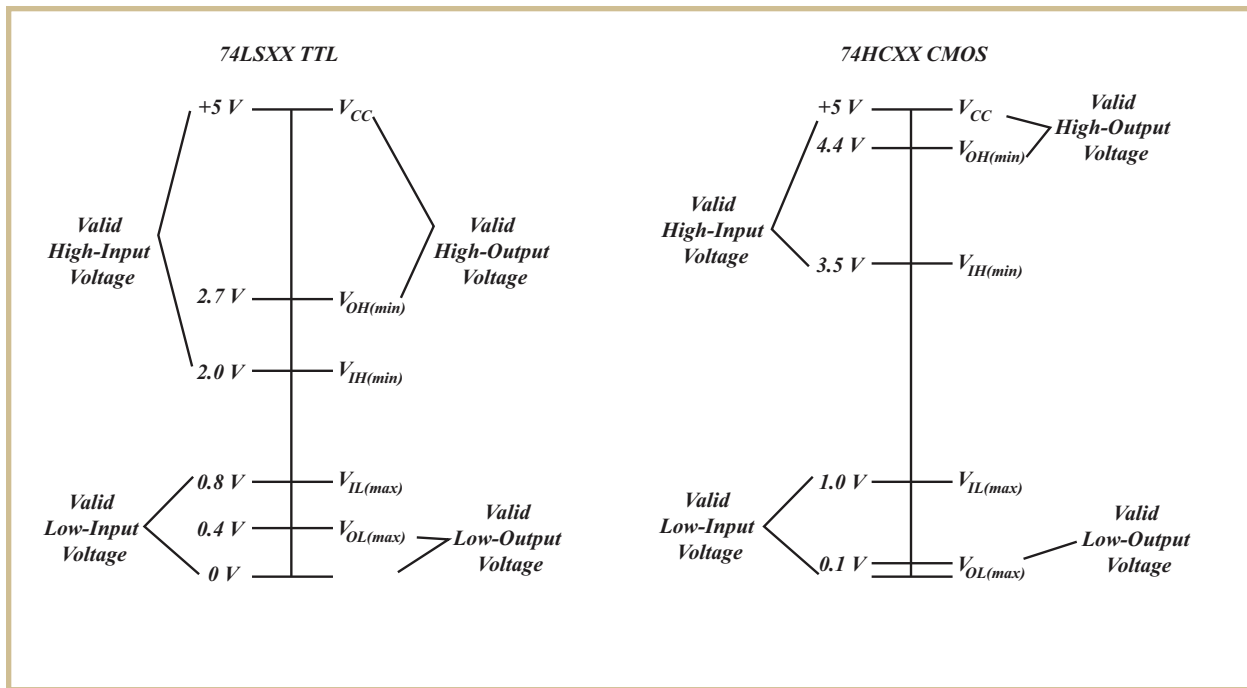
| <b>BIPOLAR AND MOS LOGIC FAMILIES COMPARED</b> |                                |
|--|--------------------------------|
| <b>Bipolar Logic Family</b>                    | <b>MOS Logic Family</b>        |
| TTL (Transistor-Transistor Logic)              | PMOS (P-Channel MOSFET)        |
| Standard TTL                                   | NMOS (N-Channel MOSFET)        |
| Low-Power TTL                                  | CMOS (Complimentary MOSFET)    |
| High-Speed TTL                                 | High-Speed CMOS                |
| Schottky TTL                                   | High-Speed CMOS TTL-Compatible |
| Low-Power Schottky TTL                         | Advanced CMOS Logic            |
| Advanced Low-Power Schottky TTL                | Advanced CMOS TTL-Compatible   |
| ECL (Emitter-Coupled Logic)                    |                                |
| IIL (Integrated Injection Logic)               |                                |

The *transistor-transistor-logic (TTL)* family, shown in Table 3, is a very common family of digital devices. These integrated circuits have device numbers beginning with 74 and additional digits to identify the device, such as 7400, which is a quad NAND gate: four NAND gates in one package that share a power supply and ground. Although this family has been around since the 1960s, newer versions such as the 74LS—low-power Schottky—series allow higher speeds and lower power consumption. When you see these newer devices they'll be labeled with special letter designations within the number, such as 74LS08 for a quad two-input AND gate.

| <b>Table 3</b>         |  |
|------------------------|--|
| <b>TTL SUBFAMILIES</b> |  |
| <b>Designator</b>      | <b>Family</b>                          |
| No letters             | Standard TTL                           |
| 74LSXX                 | Low-power Schottky                     |
| 74SXX                  | Schottky                               |
| 74LXX                  | Low-power                              |
| 74ALSXX                | Advanced low-power Schottky            |
| 74ASXX                 | Advanced Schottky                      |
| 74FXX                  | Fairchild advanced Schottky TTL (FAST) |

These circuits are fabricated using transistors formed on a silicon substrate, and operate between 0 and 5 volts. There are common standards that define the low and high voltages with which digital devices will operate. While we say that a low is 0 volts, it may in fact range from 0.0 volts to 0.8 volts; a high value can range from 2.0 to 5.0 volts. Figure 53 shows a comparison between the LS and HC types of digital logic chips for valid high and low voltages.





**FIGURE 53—Digital logic families are tolerant of changes in voltages representing high and low logic levels, but not all families have the same ranges.**

Another common family of digital integrated circuits is the *complementary MOSFET (CMOS)* family. These circuits will work at a higher range of voltages, up to 18 volts (Table 4). The advantage of CMOS is that they operate with less current flow and are better suited for low-power circuits, as in battery-operated devices. However, these higher-voltage type circuits are usually slower in responding to logic-level changes, which limits the speed of operation. The first CMOS devices were labeled with device numbers such as 4001, a quad two-input NOR gate. The CMOS series is now obsolete, however, and new equipment will have either 74CXX or similar numbers, as shown in Table 4. Device numbers with 54XX numbers are intended for extended temperature-range operation—in military applications, for example.

| Table 4          |                                |
|------------------|--------------------------------|
| CMOS SUBFAMILIES |                                |
| Designator       | Family                         |
| 74CXX or 54CXX   | Standard CMOS                  |
| 74HCXX           | High-speed CMOS                |
| 74SHCTXX         | High-speed CMOS—TTL compatible |
| 74ACXX           | Advanced CMOS                  |
| 74ACTXX          | Advanced CMOS—TTL compatible   |

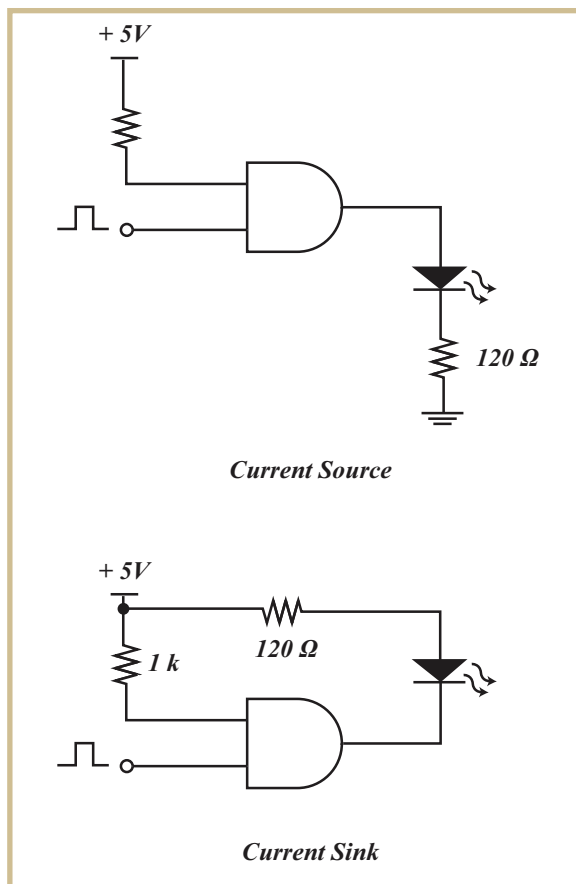
These CMOS devices have the same pin configurations on the physical integrated circuits as the TTL counterparts.

Digital-circuit devices are used for control functions and must be able to both *source* and *sink* current. That means that a logic gate can provide the source voltage when at a

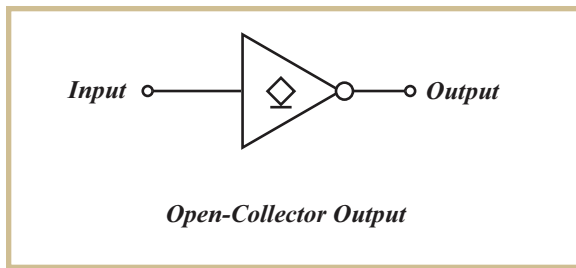
logic high level to light an LED, or it can ground the cathode side of the LED to cause it to light up when the cathode is connected to a high voltage. Figure 54 illustrates both possibilities. In addition, since the output of a gate can be used as the input for many other gates, digital circuits must be able to fan out and drive a minimum number of inputs to other gates.

Figure 55 shows the symbol for an open collector NOT gate. These are used in applications where the gate must sink larger amounts of current, as in some display drivers. These gates must have a pull-up resistor connected to the gate output.

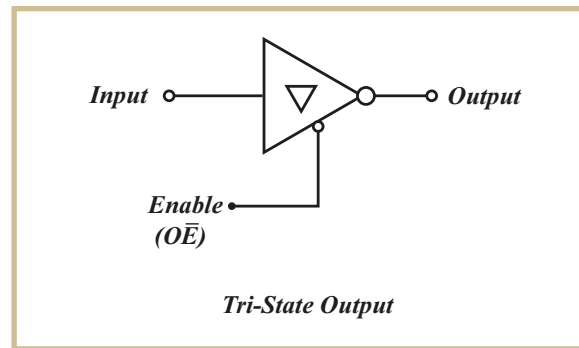
Another important type of TTL gate is the *three-state*, or *tri-state*, *output gate*. Figure 56 shows how the schematic symbol appears on a schematic, with an *enable* terminal on the side of the gate. You'll see these gates in computer circuits because the gate outputs can be disconnected internally from the physically wired output on the circuit board. This allows multiple circuits to share common



**FIGURE 54**—Digital circuits can either source or sink currents by supplying logic high or low, depending on the applications and other gates in the circuits.



**FIGURE 55**—Open collector gates are used when the gate must sink large amounts of current.



**FIGURE 56**—The tri-state output gate is used extensively when the gates drive data buses in computers or controllers that must share the physical wires. The output is disconnected from the bus unless the enable pin is activated.

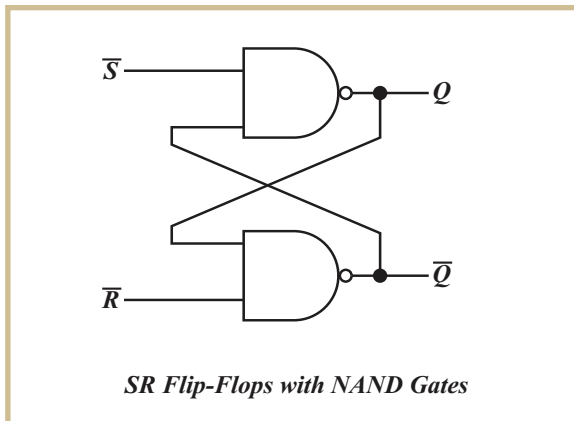
wiring. For example, in computers there are address buses and input and output buses that have as many as 32 wires that must be connected to memory, CPU, and display devices. Tri-state devices allow different circuits to access the buses at different times for efficient use of the circuit board space.

## Common Digital Integrated Circuits

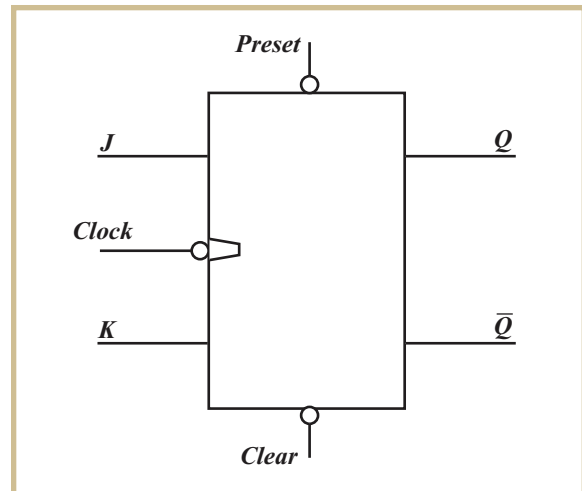
*Flip-flops* are digital circuits that have stable output states of both high and low—depending on the input condition—that are maintained even after the inputs have been removed. They're very common in digital devices because they can be used as memory or as control circuits. They can be constructed from individual gates, or they can be obtained as packages with one or more flip-flops on one package. Flip-flops have two outputs, labeled  $Q$  and  $\bar{Q}$  (NOT  $Q$ , which can also be represented with  $!Q$ ), and each may have functions in the circuit.

You'll encounter several different kinds of flip-flops and can recognize them from the typical arrangements of the gates on the schematic. The *SR* (or *RS*) *flip-flop* is the *SET-RESET flip-flop* and is made from two NAND gates, as shown in Figure 57. These are often used as simple latches, memory or switch debouncers. *D flip-flops* have one input for data, and a clock input. The value of the input signal on  $D$  is transferred to the

Q output when the clock input cycles. Another type is the *J-K flip-flop*, which can be wired to perform the functions of several different kinds of flip-flops; you'll often see them in the schematics of digital circuits. Figure 58 shows the J-K flip-flop symbol. Notice that it has pins on the top and bottom labeled "Preset" and "Clear." When the Clear terminal is made low, the Q output is made to go low; when the Preset goes low, the Q output is set to a logic high value. Also notice that these flip-flops have clock inputs. The state of the output changes with a negative-going clock signal—changing from a high to low value—that's said to be *negative-edge triggered*. They can also be designed to trigger on a positive-going clock edge. Flip-flops are often used in memory circuits and circuits that handle serial and parallel data transmission.



**FIGURE 57**—The SR (or RS) flip-flop can be made with a pair of NAND gates. The bar over the inputs means that a low logic level is the condition that sets or resets the outputs.



**FIGURE 58**—The JK flip-flop is one of the most common types of digital storage devices, and is often used with groups of other flip-flops to function as memory or shift registers. The circles on the input terminals mean that the signal is inverted before entering the chip, similar to the inverting symbol on op-amps and logic chips.

## Common Digital-Circuit Applications

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While digital devices are used in digital circuits such as computers, they're also often used with analog circuits to perform functions too difficult to achieve with analog or passive components. In the same way, analog devices are often used in digital equipment to convert digital signals and outputs to higher power values. In this section we'll cover common examples of digital circuits, as well as those mixed digital and analog circuits that often appear in schematics.

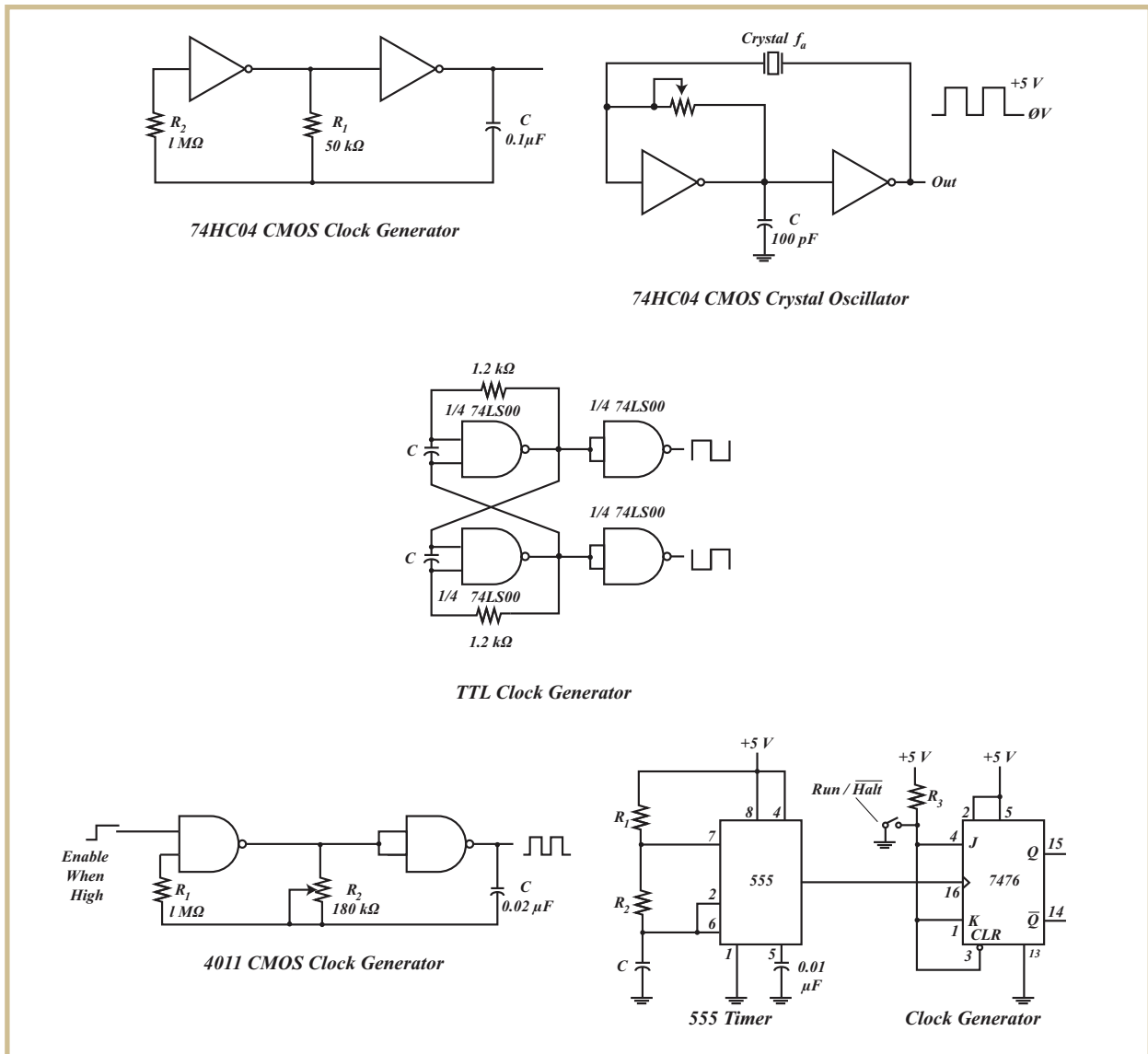
Many digital circuits are driven by *clocks*, which are square-wave oscillators that provide timing signals to other parts of the circuitry. These clocks and their square-wave outputs cause other circuits to move data, store data in memory, count real time, synchronize displays, and perform many other functions. You'll need to recognize the various configurations of these clock circuits in different forms of electronic circuits. A common term for a digital circuit that changes output states is *multivibrator*. There are three types of multivibrators:

- *Astable multivibrators* have no stable output states, that is, they continuously change between high and low outputs at a rate determined by external components such as RC networks.
- *Bistable multivibrators* have two stable states. They can be put in a high or low output condition and remain that way until changed by other parts of the circuit. These are also called *flip-flops*, or *latches*.
- *Monostable multivibrators* have one stable state, high or low depending on the circuit design. They can be forced to assume the unstable state by an external trigger, and will remain in that state for a length of time determined by external components—RC networks—and then return to their one stable state. These are used as analog timers and also as inputs to digital circuits, preventing false triggering from occurring.

*Clock circuits* are a type of astable multivibrator used in a wide variety of devices. Because gates are essentially op-amps, they can be used with positive feedback loops to generate simple

square-wave circuits for timing or controls. Gates are typically used in pairs, with the output of one feeding back to the input of the other, and vice versa. Capacitors and resistors control the rate of feedback, thus adjusting the frequency of the clock. Figure 59 shows examples of simple clock circuits using resistors and capacitors connected to logic gates to control the frequency. For greater accuracy, a crystal can be used to control the output frequency.

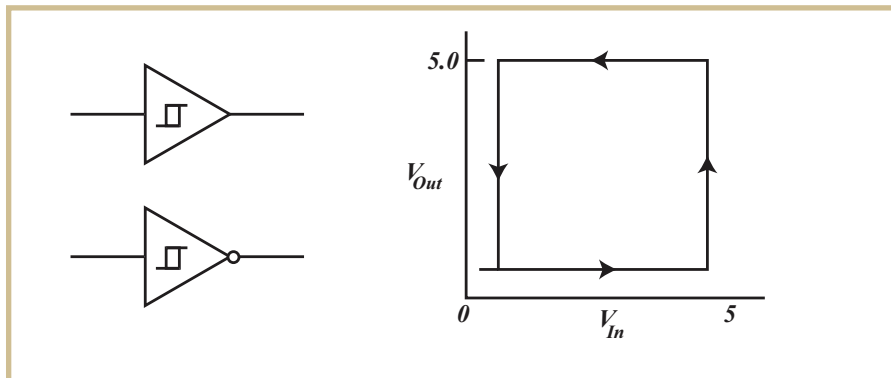
The *Schmitt trigger* is a unique and important device used in electronic circuits, and you should learn to recognize it. Figure 60 shows its schematic symbol and a graph of input



**FIGURE 59**—Clock circuits are used to control the sequence of operations in computers and controllers, and are easily made with logic gates and passive components. Including precision crystals makes them more accurate.

voltage versus output voltage. As you can see, the Schmitt trigger has only two output states, logic high and logic low. It's used to convert analog waveforms into square waves and to clean up signals that may have various types of noise. Notice that once the output level has changed, the input voltage must change to another threshold value before the output again changes, ensuring that the output won't change for slowly varying signals that are close to one of the thresholds.

Because of this ability to change output states only when the upper or lower threshold voltages have been exceeded, the Schmitt trigger is often used as a simple clock generator for



**FIGURE 60—The Schmitt trigger is used to prevent false or erratic triggering of logic gates, or to convert analog waveforms to digital square waves.**

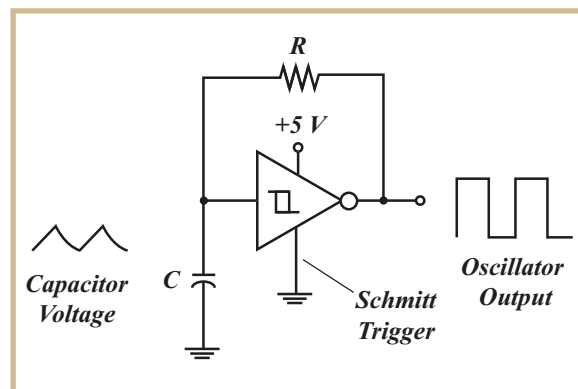
digital circuits. You can recognize these circuits as clock circuits because the output is fed back to the input through an RC network, as shown in Figure 61. In TTL circuits, the resistor will never be more than about 1000 ohms and the frequency will be approximately

$$F = (6.69 \times 10^{-4}) / C$$

If the device is a CMOS device there are no restrictions on the value of R, and the frequency can be calculated by

$$F = (5.88 \times 10^{-4}) / (R \times C)$$

As you may suspect, the ability to make the resistor different values gives circuit designers more flexibility in making variable-frequency clocks. You'll sometimes

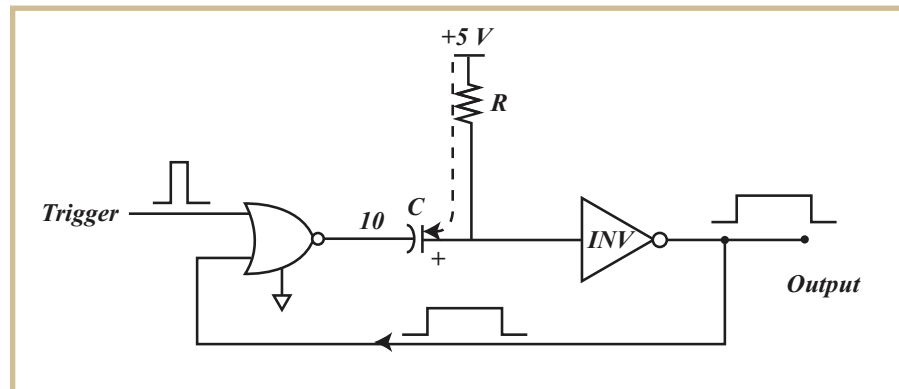


**FIGURE 61—This is another example of an easily configured clock oscillator using minimal components.**

see transistors replace the resistor in the circuit, with transistors controlled by other electronic circuits to vary the frequency as desired.

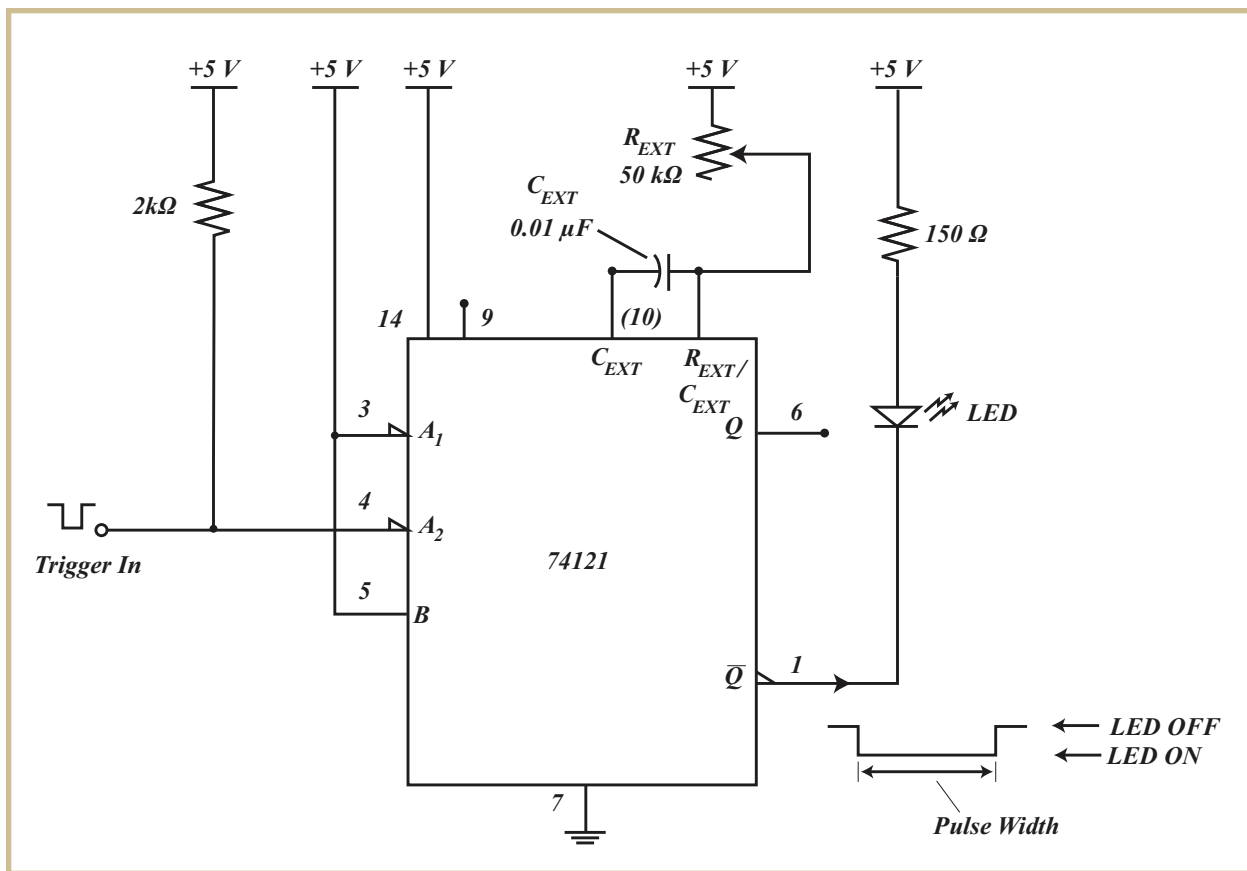
Monostable multivibrators are also called *one-shots*, and are used in many application as analog timers, as noted before. Figure 62 shows an example of how a one-shot can be designed from a NOR gate and an inverter. You can see that the time the output of the inverter is high depends on the values of the RC network connected between the two gates.

**FIGURE 62—A simple one-shot multivibrator can be made from two NOR gates and an RC network.**



A much more common one-shot circuit uses the 74121 integrated circuit, which is a precision timer available in single and dual packages. This circuit has both Q and NOT Q ( $\bar{Q}$ ) outputs and pins specifically for connecting external RC components. This circuit is very versatile and is commonly used for timing devices such as turning lights or relays on or off for specific amounts of time. Figure 63 shows an example of a 74121 connected as a one-shot multivibrator. It can also be used for sequencing equipment on and off times, and as well as giving a time delay after a switch is turned on or off. These chips can be cascaded to achieve time delays from hours to days. Whenever you see these in schematics, look for the RC components that cause the time to be set and how each of the outputs is used.





**FIGURE 63**—The 74121 is a versatile timing chip that’s available in dual packages. They’re useful in timing and sequencing circuits.

In industrial applications, the output of digital circuits is often used to control high-power devices such as relays, motors, pumps, or heaters. Since the output of a gate is relatively low power, it must be amplified to give the necessary control voltage or current to operate the device. You’ll often see the output of a digital gate used to drive a transistor, SCR, or triac as a switch. The gate gives a low-level current that’s used to turn the transistor on or off, as shown in Figure 31.

Another common application of a simple digital gate circuit is the *switch debouncer*. Mechanical switches often bounce when the contacts are opened or closed, causing several rapid switch closures instead of a clean make-or-break action. This can cause false activation of circuits. A simple circuit made of two NAND gates and resistors can clean noisy switches so that the power signal doesn’t have any voltage spikes or noise.

**FIGURE 64—Noise in electronic circuits can be generated by the mechanical bounce of switch contacts as they're opened or closed. This circuit is an example of how gates can be made to smooth the interface between the mechanical and electrical components.**

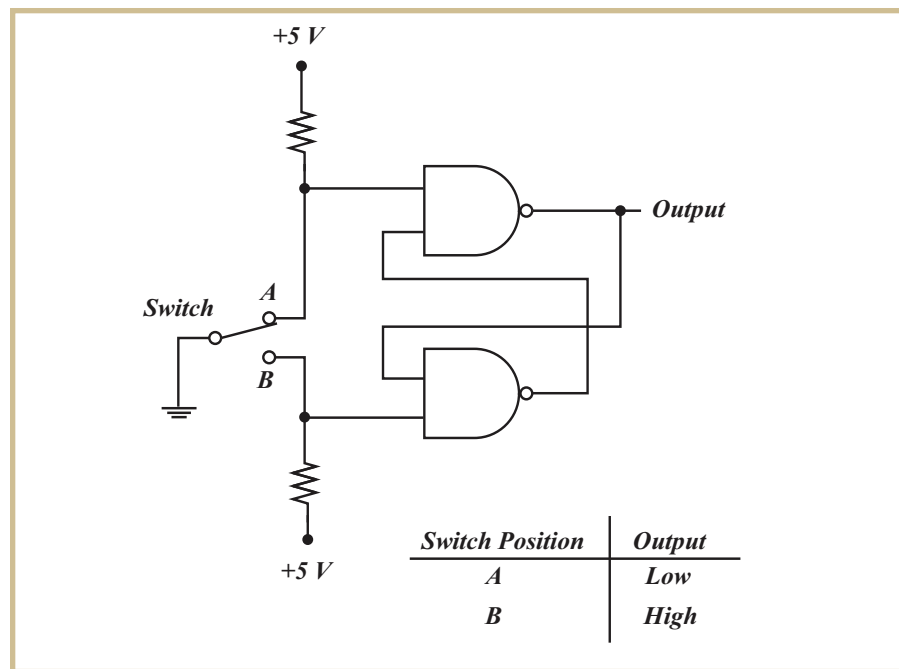
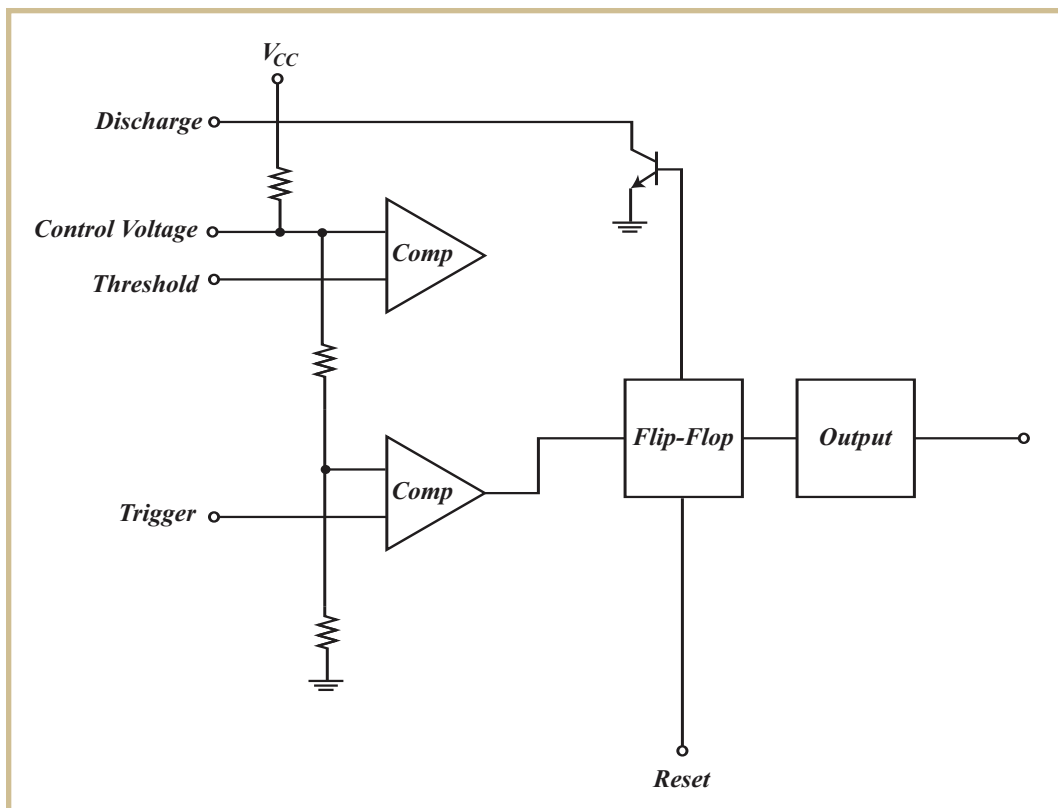


Figure 64 shows an example of the type of configuration you'll see in schematics when gates are used as switch debouncers. This is the same configuration as the basic flip-flop circuit discussed earlier in this unit.

## Common 555 Timer Circuits

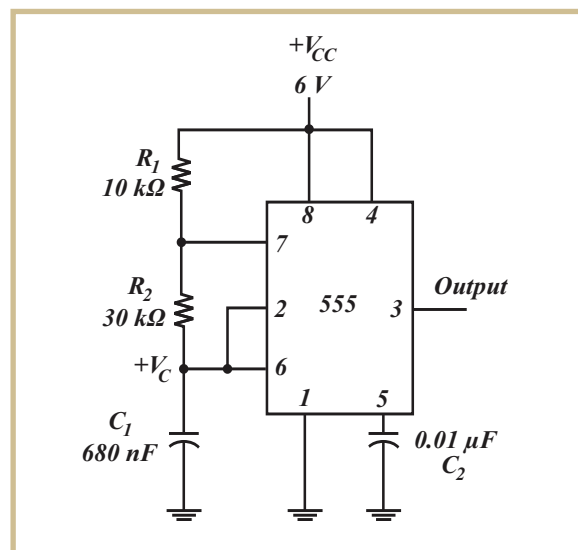
One of the most common integrated circuits found in commercial and industrial equipment is the *555 timer*. The chip itself is a combination of digital and analog circuitry and is available in single- and dual-timer packages. Figure 65 shows the internal configuration of the timer, which consists of a voltage divider, a transistor, two voltage comparators, and an RS flip-flop. The timer is a versatile circuit found in many applications, and is often used as both astable and monostable multivibrators. Because the operation of the timer is controlled by the external RC components, its output can be made to vary in time and width, thus varying frequency and duty cycle.



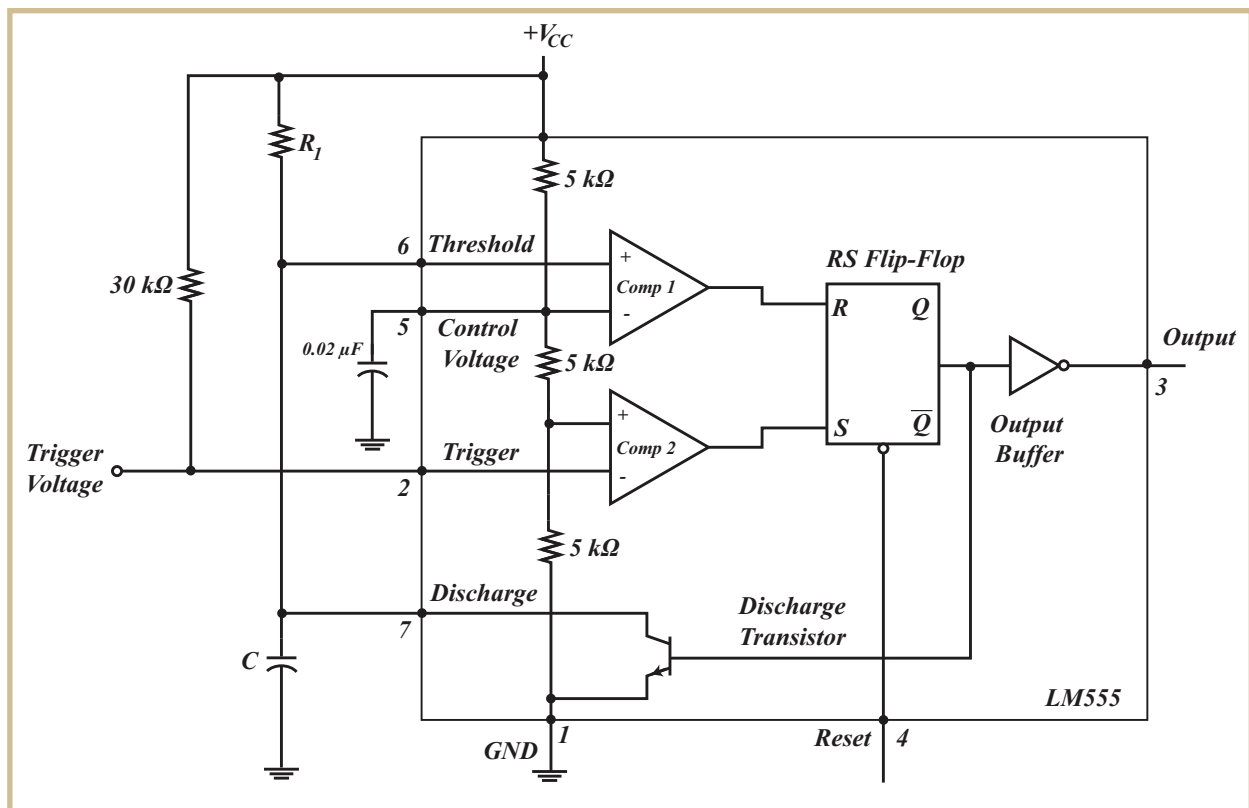
**FIGURE 65**—The 555 timer consists of a single integrated circuit that’s made from components you’ve already studied, such as op-amps, voltage dividers, flip-flops, and transistors. The 556 timer is two separate 555 timers in a single integrated-circuit package.

Figure 66 shows a typical configuration for a 555 astable multivibrator. Note that the on time and off time are set by the value of  $R_1$ ,  $R_2$ , and  $C_1$ . The values of  $R_1$  and  $R_2$  should be between  $10\text{ k}\Omega$  and  $14\text{ M}\Omega$  and  $C_1$  should be between  $100\text{ pF}$  and  $1000\text{ microfarads}$ .

Figure 67 shows the 555 timer configured as a monostable. Notice the similarity in the way the components are connected. When you see a 555 timer in a circuit, look carefully to determine the timer’s configuration and function.



**FIGURE 66**—You’ll see the 555 configured as an astable multivibrator or oscillator in many circuits that require a clock or timing circuit. The frequency or duty cycle can be varied by making the resistors variable.



**FIGURE 67**—The 555 can also be made into a monostable multivibrator for timing applications. Since the 555 can run on higher voltages than digital logic gates, it's a better choice for interfacing with other analog circuits than a 74121.

## Reading Datasheets

As you learn to read schematics, you'll start to recognize patterns of circuits that are used over and over again. But even when you recognize the circuit's function, you often won't know about the individual component characteristics of the devices used. Especially in digital circuits, you may not even recognize the device or circuit without knowing the device number. Manufacturers publish product specification datasheets for all electronic devices, and they show such important data as pin configurations; description of the pin, or terminal function; maximum voltage and current ratings as well as the testing conditions for reporting the data; temperature and thermal characteristics; minimum and maximum performance characteristics, with test circuits and performance graphs and charts; and finally, the physical dimensions of all the case styles available.

In the past, manufacturers published catalogs of product specifications that ran to many volumes of hundreds of pages each. Technicians had difficulty accessing this information simply because of the size and availability of the catalogs and the number of manufacturers involved.

Today, you can find datasheets for almost any device on the Internet, even if it's manufactured abroad. One such site is found at **<http://www.datasheetcatalog.com>**. This site, one of many on the Internet, has many manufacturing datasheets available that are indexed according to manufacturer and device number. Manufacturers will also have their own Web sites, where datasheets are available.

As an exercise, go to **<http://www.datasheetcatalog.com>** and find the datasheet from Fairchild Semiconductor for the 2N3904 transistor. (*Note:* Web sites often change, so if you find the site above isn't available, find any site that offers the 2N3904 datasheet and follow the discussion below, as all datasheets should be similar.) You'll see that the home page shows many manufacturer logos and over 4,000 catalog pages. If you scroll down the leftmost column, you'll see many part numbers you can click on to investigate, but for now, find the 2N3904, which is a common transistor. Notice that there's no indication of what any of these numbers mean as far as what type of devices they are; you have to know what number you're looking for.

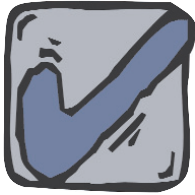
Click on 2N3904, and you'll see a page listing all the manufacturers that make this device, and a link to download a datasheet for the device. Choose the Fairchild Semiconductor device and click on the link to download the PDF file for the 2N3904. The first thing you'll notice is that there are three physical configurations available, each with a different number. However, notice they all share the 3904 part of the number.

The first part of the datasheet is a brief description of what the device is and how it's typically used. Next is a table of absolute maximum ratings. These are the ratings of the device that can't be exceeded without damage. For example, it states that the maximum collector-to-emitter voltage,  $V_{CEO}$ , is 40 V. The O means the base terminal is open, or unconnected, which is a standard test connection. The maximum continuous collector current for this device is 200 mA, and the operating temperature range is from  $-55$  to  $+150$  degrees Celsius. Next, there's

a table of general operating electrical characteristics and the test conditions under which they're measured. There are also graphs showing typical characteristics. Finally, there are the physical dimensions of the different package styles available, as well as the packaging dimensions for automated assembly line purposes.

Not all devices or datasheets provide this much information, but you should be able to find important information about almost any device you'll encounter in schematic diagrams. A useful feature often included in datasheets is typical applications for the device. These circuits are often typical configurations or unique ways in which the product can be used, and they'll have important information about how the devices will perform for certain applications.

In general, it's very easy to find data about components you aren't familiar with simply by typing the device number in an Internet search engine such as Google. For example, if you saw an IC on a schematic marked ICL8038, you could type the number in the search engine text box, and you'll almost always see a reference to a device datasheet in the returned search results. The catalogs that device manufacturers used to produce are almost always found online, usually in a PDF file, which is a very common and easily viewed file type. This makes the reference books technicians used to keep almost obsolete.



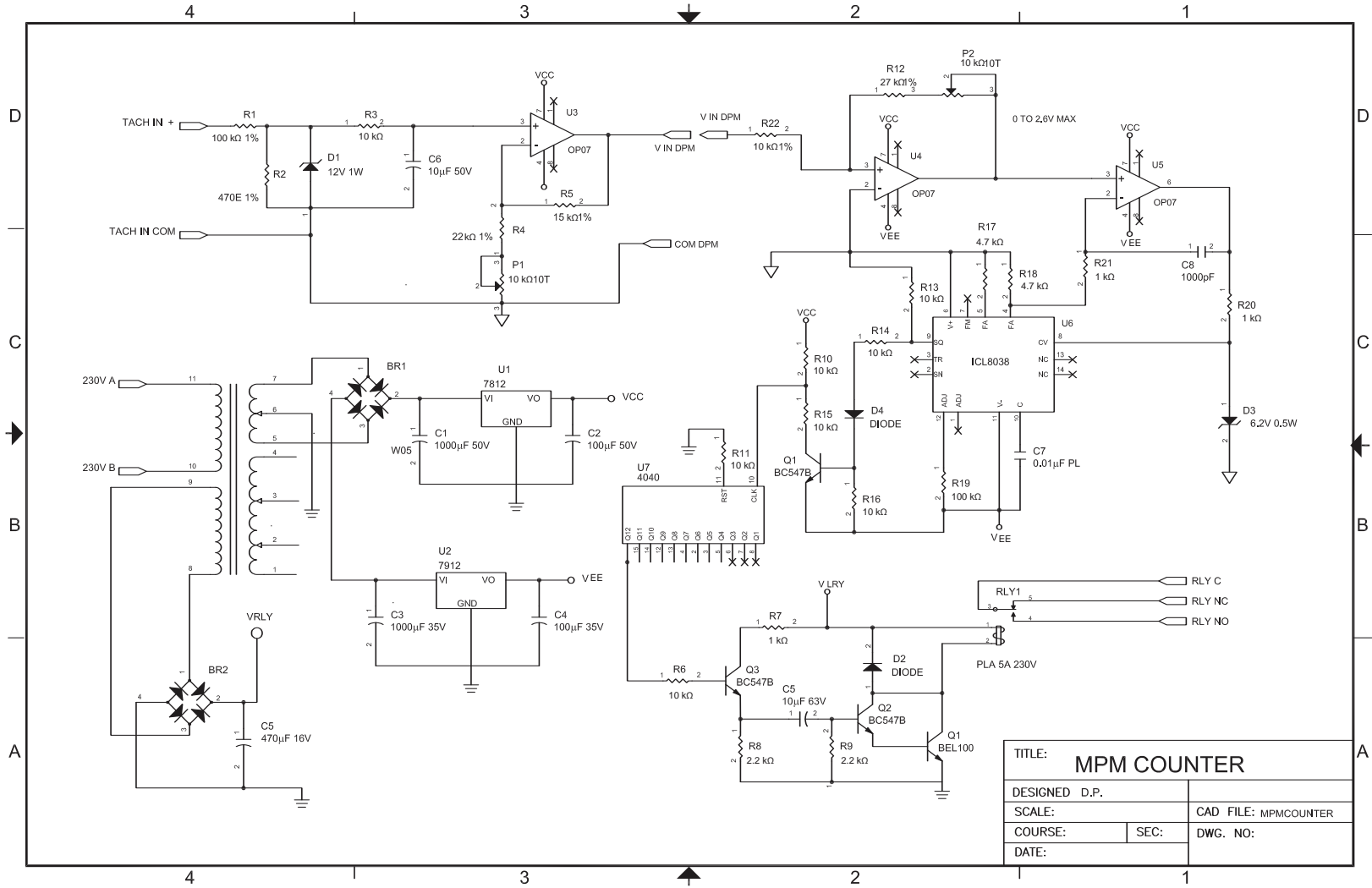
## Self-Check 3

Refer to the schematic drawing on the following page to answer these questions.

1. The AC power needed for this circuit is \_\_\_\_\_ V.
2. The TACH IN signal will be limited to \_\_\_\_\_ V by (component number) \_\_\_\_\_.
3. The transistor combination  $Q_1$  and  $Q_2$  form a \_\_\_\_\_.
4. TACH COM IN is connected to \_\_\_\_\_ ground.
5. U3 is configured as a(n) \_\_\_\_\_ amplifier whose gain is adjustable by \_\_\_\_\_.
6. The component that drives the clock input to the 4040 is \_\_\_\_\_.
7. The negative supply is regulated by \_\_\_\_\_ and has a value of \_\_\_\_\_ V.
8.  $BR_2$  supplies power to \_\_\_\_\_.
9. Capacitors \_\_\_\_\_ and \_\_\_\_\_ are shown on the print with the wrong polarity.
10. U4 is configured as a(n) \_\_\_\_\_ amp and has a gain of about \_\_\_\_\_.

*(Continued)*

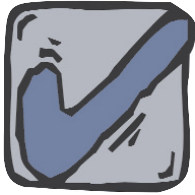
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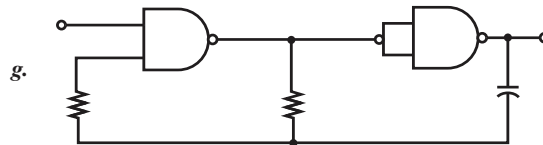
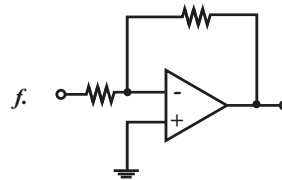
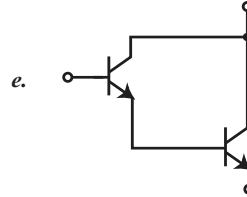
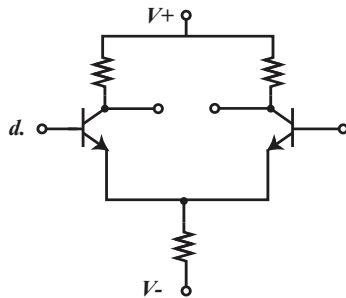
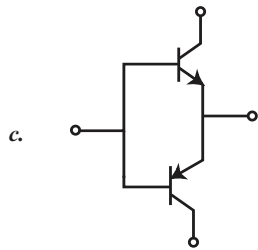
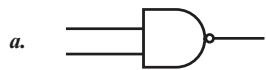
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| TITLE: MPM COUNTER |                      |
| DESIGNED: D.P.     |                      |
| SCALE:             | CAD FILE: MPMCOUNTER |
| COURSE:            | SEC: DWG. NO:        |
| DATE:              |                      |

(Continued)





## Self-Check 3



Write the letter for the correct schematic symbol next to the description below. (Note: Not all of the letters will be used.)

11. An inverting op amp \_\_\_\_\_
12. A digital clock \_\_\_\_\_
13. Darlington pair \_\_\_\_\_
14. Differential amplifier \_\_\_\_\_
15. Exclusive NOR gate \_\_\_\_\_

Check your answers with those on page 80.

## NOTES

## ***Self-Check 1***

1. block diagram
2. integrated circuit
3. wiring diagram
4. right
5. 1000
6. 115 V
7. unenergized
8. p
9. j
10. f
11. o
12. d
13. e
14. n
15. l

## ***Self-Check 2***

1. chassis ground
2. LED diodes, D3, D4, D5, D6
3. +5 V
4. U1C
5. NPN, BD139
6. 1N4007
7. 2, 6, 9, 13
8. One
9. 4, 11
10. 4.7 V zener diode, 1.0
11. R5, R12, R17, R23, R27
12. 3, 5

**A  
n  
s  
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e  
r  
s**

## Self-Check 3

1. 230
2. 12,  $D_1$
3. Darlington pair
4. circuit
5. noninverting,  $P_1$
6. Q1 BC547 transistor
7.  $U_2$ , 12 (or -12)
8. VRLY
9.  $C_3$ ,  $C_4$
10. inverting, 2.7 to 3.7
11. f
12. g
13. e
14. d
15. b

## Understanding and Using Electronic Diagrams

EXAMINATION NUMBER

**08609500**

Whichever method you use in submitting your exam answers to the school, you must use the number above.

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**Questions 1–20: Select the one best answer to each question.**

1. A capacitor labeled C2 220 $\mu$ F 50V
  - A. can be replaced by a capacitor with the same value with a rating of 100 V.
  - B. must have a matching capacitor C1 220 $\mu$ F 50V.
  - C. is a polarized capacitor.
  - D. can be used in circuits with voltages up to 100 V.
2. A voltage regulator labeled U2 7915 has an output voltage of
  - A. +30.
  - B. +12.
  - C. -12.
  - D. -15.
3. A transformer with the primary and secondary labeled 1:4 on the schematic has an input voltage of 30 V on the primary. The secondary voltage is
  - A. 7.5 V.
  - B. 15 V.
  - C. 60 V.
  - D. 120 V.

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4. A \_\_\_\_\_ shows the physical arrangement of wires and components.
- A.** functional diagram
  - B.** schematic
  - C.** wiring diagram
  - D.** block diagram
5. Timer circuits such as a 555 timer use \_\_\_\_\_ to control time delays and frequencies.
- A.** RC networks
  - B.** low-pass filters
  - C.** transistors
  - D.** multivibrators
6. Switches in schematics of electronic equipment are shown in
- A.** their normally operating condition.
  - B.** the de-energized condition.
  - C.** the state of first activation.
  - D.** a convenient position.
7. In a schematic diagram, the symbol for a polarized capacitor is sometimes indicated by
- A.** heavier lines on one side of the symbol.
  - B.** a "Polarized" notation.
  - C.** the larger capacitance values.
  - D.** a curved line on the negative side.
8. A capacitor marked with an EIA code of C4 473 100V has a capacitance value of
- A.** 0.047  $\mu\text{F}$ .
  - B.** 4.4  $\mu\text{F}$ .
  - C.** 100  $\mu\text{F}$ .
  - D.** 473  $\mu\text{F}$ .
9. An inductor symbol on a schematic with a dotted line next to the coil symbol indicates
- A.** the coil has a ferrite core.
  - B.** the coil has a metal core.
  - C.** the coil has a polarity.
  - D.** it's part of a transformer.
10. Bipolar-junction transistors have arrows that indicate junctions. A transistor is a PNP type when the
- A.** arrowhead points toward the center of the device.
  - B.** arrowhead points toward the positive supply.
  - C.** arrowhead points in the same direction as electron flow.
  - D.** junction voltage exceeds 0.7 volts.
11. Digital logic devices that need to actuate large power devices
- A.** use open collector outputs.
  - B.** have multiple gates in a parallel bus structure.
  - C.** are configured as multivibrators.
  - D.** use the output voltage to drive a transistor switch.
12. Digital logic devices marked 74LSXX such as the 74LS02
- A.** require higher voltages than older TTL devices.
  - B.** consume less power than older TTL devices.
  - C.** have lower fanout capabilities than CMOS devices.
  - D.** have narrower logic-level voltages than TTL devices.



13. In Figure A-1, U4 is configured as a(n)
- A.** negative voltage regulator.
  - B.** monostable multivibrator.
  - C.** astable multivibrator.
  - D.** differential amplifier.
14. Assuming EIA identification codes are used in Figure A-1, the capacitor C6 has a value of
- A.** 103 nF.
  - B.** 103  $\mu$ F.
  - C.** 0.01  $\mu$ F.
  - D.** 470 nF
15. In Figure A-1, C8, D2, D3, and C9 are showing
- A.** a source of negative DC voltage.
  - B.** a filtering circuit for the 79L05.
  - C.** a regulator for the 555 timer circuit.
  - D.** blocking diodes and capacitors for U2.
16. In Figure A-1, technical information about Q1
- A.** will be identical to the technical data for Q2.
  - B.** is usually available on other pages of a complete schematic.
  - C.** can be obtained *only* from the designer of the circuit.
  - D.** can be found on datasheets from Internet sources.



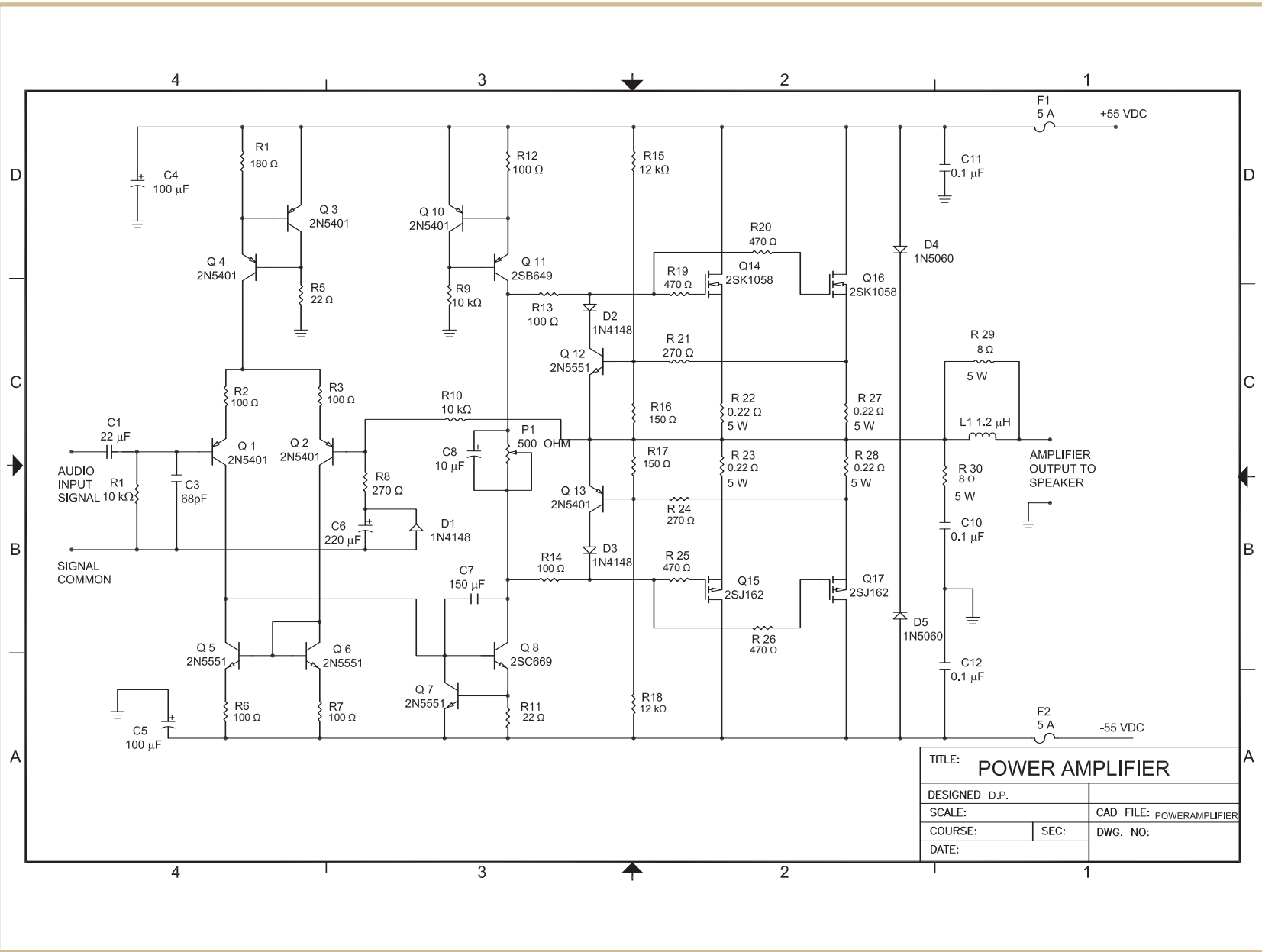


FIGURE A-2—Use this figure to answer questions 17–19.

17. In Figure A-2, Q1 and Q2 are arranged as a
- current mirror.
  - differential amp.
  - complementary-symmetry amplifier.
  - current source.
18. In Figure A-2, Q5 and Q6 are arranged as a
- current mirror.
  - differential amp.
  - complementary-symmetry amplifier.
  - current source.
19. In Figure A-2, the maximum output current of the amplifier must be less than
- 2 amps.
  - 4 amps.
  - 5 amps.
  - 10 amps.

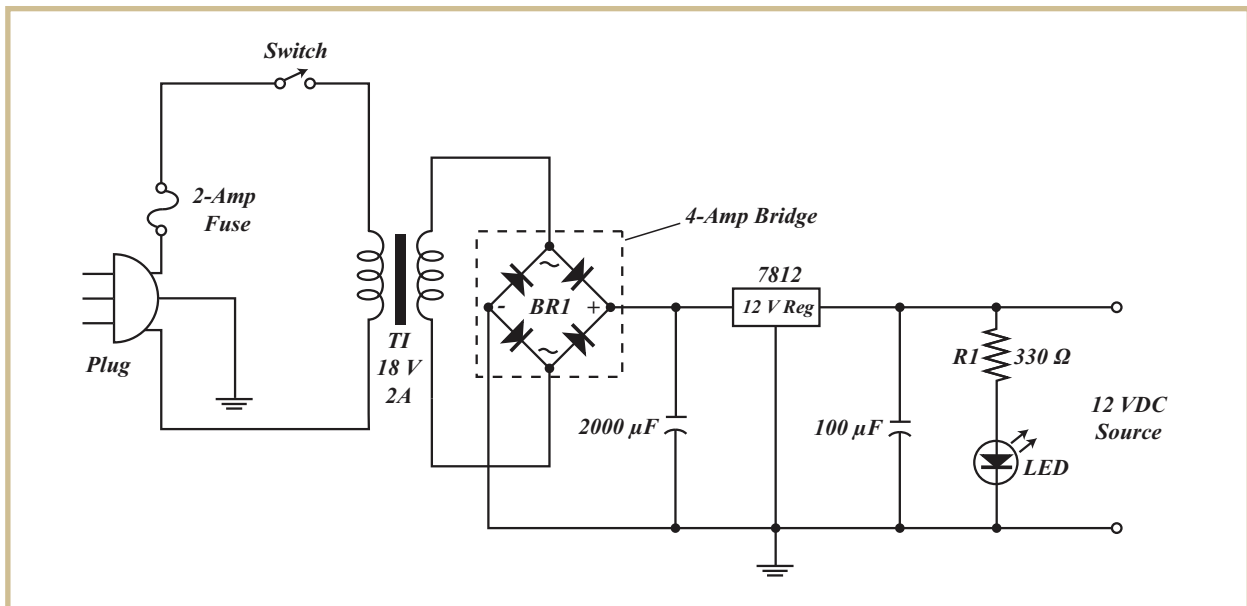


FIGURE A-3—Use this figure to answer question 20.

20. In Figure A-3, R1 is used as a
- current-limiting resistor for the LED.
  - voltage divider.
  - load for the power supply.
  - low-pass filter in conjunction with C2.