# CHAPTER 1 Introduction

## Learning Outcomes

*This chapter will help you to:*

**1-1** *Identify* some major events in the history of electronics. [1-1]

**1-2** *Classify* circuit operation as digital or analog. [1-2]

**1-3** *Name* major analog circuit functions. [1-3]

**1-4** *Begin* developing a system viewpoint for troubleshooting. [1-3]

**1-5** *Analyze* circuits with both dc and ac sources. [1-4]

**1-6** *List* the current trends in electronics. [1-5]

Electronics is a recent technology that has undergone explosive growth. It is widespread and touches all of our lives in many ways. This chapter will help you to understand how electronics developed over the years and how it is currently divided into specialty areas. It will help you to understand some basic functions that take place in electronic circuits and systems, and will also help you to build upon what you have already learned about circuits and components.

## 1-1 A Brief History

It is hard to place an exact date on the beginning of electronics. The year 1899 is one possibility. During that year, J. J. Thomson, at the University of Cambridge in England, discovered the electron. Two important developments at the beginning of the twentieth century made people interested in electronics. The first was in 1901, when Marconi sent a message across the Atlantic Ocean using *wireless* telegraphy. Today we call wireless communication *radio.* The second development came in 1906, when De Forest invented the audion vacuum tube. The term *audion* related to its first use, to make sounds ("audio") louder. It was not long before the wireless inventors used the *vacuum tube* to improve their equipment.

**Audion**

**Vacuum tube**

Another development in 1906 is worth mentioning. Pickard used the first crystal radio detector. This great improvement helped make radio and electronics more popular. It also suggested the use of *semiconductors* (crystals) as materials with future promise for the new field of radio and electronics.

**Semiconductor**

Commercial radio was born in Pittsburgh, Pennsylvania, at station KDKA in 1920. This development marked the beginning of a new era, with electronic devices appearing in the average home. By 1937 more than half the homes in the United States had a radio. Commercial television began around 1946. In 1947 several hundred thousand home radio receivers were manufactured and sold. Complex television receivers and complicated electronic devices made technicians wish for something better than vacuum tubes.

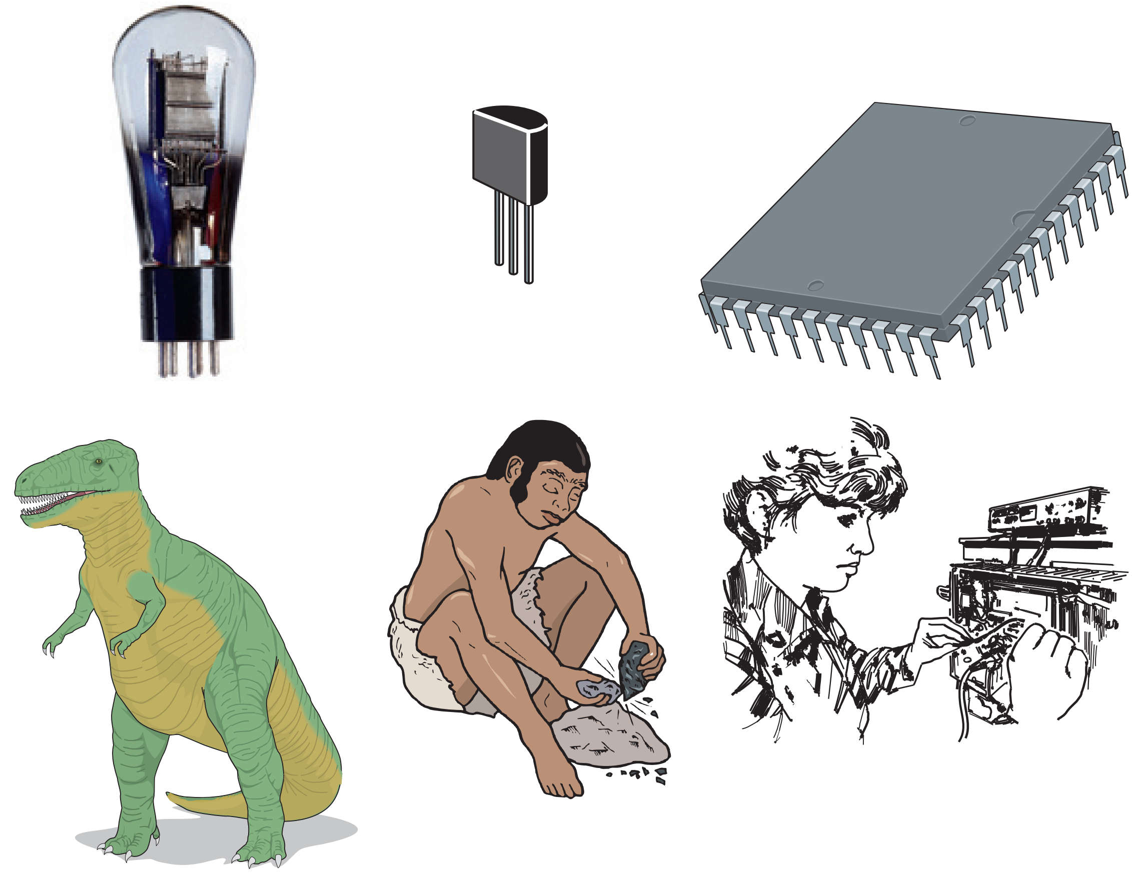
The first vacuum tube computer project was funded by the US government and the research began in 1943. Three years later, the ENIAC was formally dedicated at the Moore School of Electrical Engineering of the University of Pennsylvania on February 15, 1946. It was the world's first electronic digital computer:

- Size: 30 ft × 50 ft
- Weight: 30 tons
- Vacuum tubes: 17,468
- Resistors: 70,000
- Capacitors: 10,000
- Relays: 1500
- Switches: 6000
- Power: 150,000 W
- Cost: $486,000 (about $5 million today)
- Reliability: 7 minutes MTBF (mean time between failures)

A group of students at the Moore School participated in the 50th-year anniversary celebration of the ENIAC by developing an equivalent CMOS (complementary metal oxide semiconductor) chip:

- Size: 7.44 mm × 5.29 mm
- Package: 132 pin PGA (pin grid array)
- Transistors: 174,569
- Cost: several dollars (estimated, per unit, if put into production)
- Power: approximately 1 W
- Reliability: 50 years (estimated)

Scientists had known for a long time that many of the jobs done by vacuum tubes could be done more efficiently by semiconducting



The vacuum tube, the transistor, and then the integrated circuit. The evolution of electronics can be compared with the evolution of life.

crystals, but they could not make crystals pure enough to do the job. The breakthrough came in 1947. Three scientists working with Bell Laboratories made the first working transistor. This was such a major contribution to science and technology that the three men—Bardeen, Brittain, and Shockley—were awarded the Nobel Prize.

Around the same time (1948) Claude Shannon, also then at Bell Laboratories, published a paper on communicating in binary code. His work formed the basis for the digital communications revolution, from cell phones to the Internet. Shannon was also the first to apply Boolean algebra to telephone switching networks when he worked at the Massachusetts Institute of Technology in 1940. Shannon's work forms much of the basis for much of what we now enjoy in both telecommunications and computing.

Improvements in transistors came rapidly, and now they have all but completely replaced the vacuum tube. *Solid state* has become a household term. Many people believe that the transistor is one of the greatest developments ever.

Solid-state circuits were small, efficient, and more reliable. But the scientists and engineers still were not satisfied. Work done by Jack Kilby of Texas Instruments led to the development of the *integrated circuit* in 1958. Robert Noyce, working at Fairchild, developed a similar project. The two men share a Nobel prize in physics for inventing the integrated circuit.

Integrated circuits are complex combinations of several kinds of devices on a common base, called a *substrate,* or in a tiny piece of silicon. They offer low cost, high performance, good efficiency, small size, and better reliability than an equivalent circuit built from separate parts. The complexity of some integrated circuits allows a single chip of silicon only 0.64 centimeter (cm) [0.25 inch (in.)] square to replace huge pieces of equipment. Although the chip can hold thousands of transistors, it still has diodes, resistors, and capacitors too!

In 1971 Intel Corporation in California announced one of the most sophisticated of all integrated circuits—the microprocessor. A *microprocessor* is most of the circuitry of a computer reduced to a single integrated circuit. Microprocessors, some containing the equivalent of millions of transistors, have provided billions of dollars worth of growth for the electronics industry and have opened entire new areas of applications.

**Microprocessor**

In 1977 the cellular telephone system entered its testing phase. Since then, the system has experienced immense growth. Its overwhelming success has fostered the development of new technology such as digital communications and linear integrated circuits for communications.

**Solid state**

In 1982, Texas Instruments offered a single chip digital signal processor (DSP). This made it practical to apply DSP to many new product designs. The growth has continued ever since and DSP is now one of the most rapidly expanding segments of the semiconductor industry.

**Integrated circuit**

The integrated circuit is producing an electronics explosion. Now electronics is being applied in more ways than ever before. At one time, radio was almost its only application. Today, electronics makes a major contribution to our society and to every field of human endeavor. It affects us in ways we may not be aware of. We are living in the electronic age.

**Substrate**

## Self-Test

*Determine whether each statement is true or false.*

1. Electronics is a young technology that began in the twentieth century.
2. The early histories of radio and of electronics are closely linked.
3. Transistors were invented before vacuum tubes.
4. A modern integrated circuit can contain thousands of transistors.
5. A microprocessor is a small circuit used to replace radio receivers.

## 1-2 Digital or Analog

Today, electronics is such a huge field that it is often necessary to divide it into smaller subfields. You will hear terms such as medical electronics, instrumentation electronics, automotive electronics, avionics, consumer electronics, industrial electronics, and others. One way that electronics can be divided is into digital or analog.

**Digital electronic device**

A *digital electronic device* or circuit will recognize or produce an output of only several limited states. For example, most digital circuits will respond to only two input conditions: low or high. *Digital circuits* may also be called *binary* since they are based on a number system with only two digits: 0 and 1.

**Digital circuit**

**Linear circuit**

**Analog circuit**

An *analog circuit* can respond to or produce an output for an infinite number of states. An analog input or output might vary between 0 and 10 volts (V). Its actual value could be 1.5, 2.8, or even 7.653 V. In theory, an *infinite* number of voltages are possible. On the other hand, the typical digital circuit recognizes inputs ranging from 0 to 0.4 V as low (binary 0) and those ranging from 2.0 to 5 V as high (binary 1). A digital circuit does not respond any differently for an input of 2 V than it does for one at 4 V. Both of these voltages are in the high range. Input voltages between 0.4 and 2.0 V are not allowed in digital systems because they cause an output that is not predictable.

For a long time, almost all electronic devices and circuits operated in the analog fashion. This seemed to be the most obvious way to do a particular job. After all, most of the things that we measure are analog in nature. Your height, weight, and the speed at which you travel in a car are all analog quantities. Your voice is analog. It contains an infinite number of levels and frequencies. So, if you wanted a circuit to amplify your voice, you would probably think of using an analog circuit.

Telephone switching and computer circuits forced engineers to explore digital electronics. They needed circuits and devices to make logical decisions based on certain input conditions. They needed highly reliable circuits that would always operate the same way. By limiting the number of conditions or states in which the circuits must operate, they could be made more reliable. An infinite number of states—the analog circuit—was not what they needed.

Figure 1-1 gives examples of circuit behavior to help you identify digital or analog operation. The signal going into the circuit is on the left, and the signal coming out is on the right. For now, think of a signal as some electrical quantity, such as voltage, that changes with time. The circuit marked *A* is an example of a digital device. Digital waveforms are rectangular. The output signal is a rectangular wave; the input signal is not exactly a rectangular wave. Rectangular waves have only two voltage levels and are very common in digital devices.

Circuit *B* in Fig. 1-1 is an analog device. The input and the output are sine waves. The output is larger than the input, and it has been shifted above the zero axis. The most important feature is that the output signal is a combination of an infinite number of voltages. In a *linear circuit,* the output is an exact replica of the input. Though circuit *B* is linear, not all analog circuits are linear. For example, a certain audio amplifier could have a distorted sound. This amplifier would still be in the analog category, but would be nonlinear.

Circuits *C* through *F* are all digital. Note that the outputs are all *rectangular* waves (two levels of voltage). Circuit *F* deserves special attention. Its input is a rectangular wave. This could be an analog circuit responding to only two voltage levels except that something has happened to the signal, which did not occur in any of the other examples. The output frequency is different from the input frequency. Digital circuits that accomplish this are called *counters,* or *dividers.*

It is now common to convert analog signals to a digital format, which can be stored in computer memory, on magnetic or optical disks, or on magnetic tape. Digital storage has advantages. Everyone who has heard music played from a digital disk knows that it is usually noise free. Digital recordings do not deteriorate with use as analog recordings do.

**DSP**

Another advantage of converting analog signals to digital is that computers can then be used to enhance the signals. Computers are digital machines. They are powerful, high-speed number crunchers. A computer can do various things to signals such as eliminate noise and distortion, correct for frequency and phase errors, and identify signal patterns. This area of electronics is known as digital signal processing (*DSP*). DSP is used in medical electronics to enhance scanned images of the human body, in audio to remove noise from old

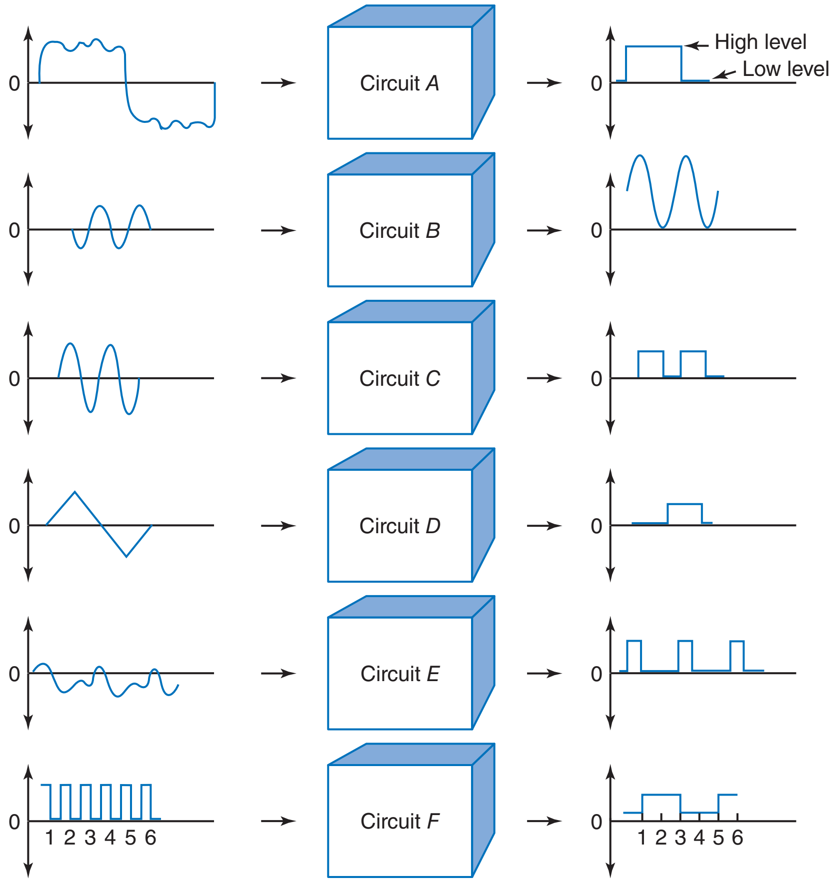



**Fig. 1-1** A comparison of digital and analog circuits.

recordings, and in many other ways. DSP is covered in Chap. 16.

Figure 1-2 shows a system that converts an analog signal to digital and then back to analog. An analog-to-digital *(A/D) converter* is a circuit that produces a binary (only 0s and 1s) output. Note that the numbers stored in memory are binary. A clock (a timing circuit) drives the A/D converter to sample the analog signal on a repetitive basis. Figure 1-3 shows the analog waveform in greater detail. This waveform is sampled by the A/D converter every 20 microseconds (μs). Thus, over a period of 0.8 millisecond (ms), 40 samples are taken. The required sampling rate for any analog signal is a function of the frequency of that signal. The higher the frequency of the signal, the higher the sampling rate.

**A/D converter**

Refer back to Fig. 1-2. The analog signal can be re-created by sending the binary contents of memory to a digital-to-analog *(D/A) converter.* The binary information is clocked out of memory at the same rate as the original signal was sampled. Figure 1-4 shows the output of the D/A converter. It can be seen that the waveform is not exactly the same as the original analog signal. It is a series of discrete steps. However, by using more steps, a much closer representation of the original signal can be achieved. Step size is determined by the number of binary digits (bits) used. The number of steps is found by raising 2 to the power of the number of bits. A 5-bit system provides

**D/A converter**

$$2^5 = 32 \text{ steps}$$

An 8-bit system would provide

$$2^8 = 256 \text{ steps}$$

### EXAMPLE 1-1

An audio compact disk (CD) uses 16 bits to represent each sample of the signal. How many steps or volume levels are possible? Use the appropriate power of 2:

$$2^{16} = 65{,}536$$

This is easy to solve using a calculator with an $x^y$ key. Press 2, then $x^y$, and then 16 followed by the = key.

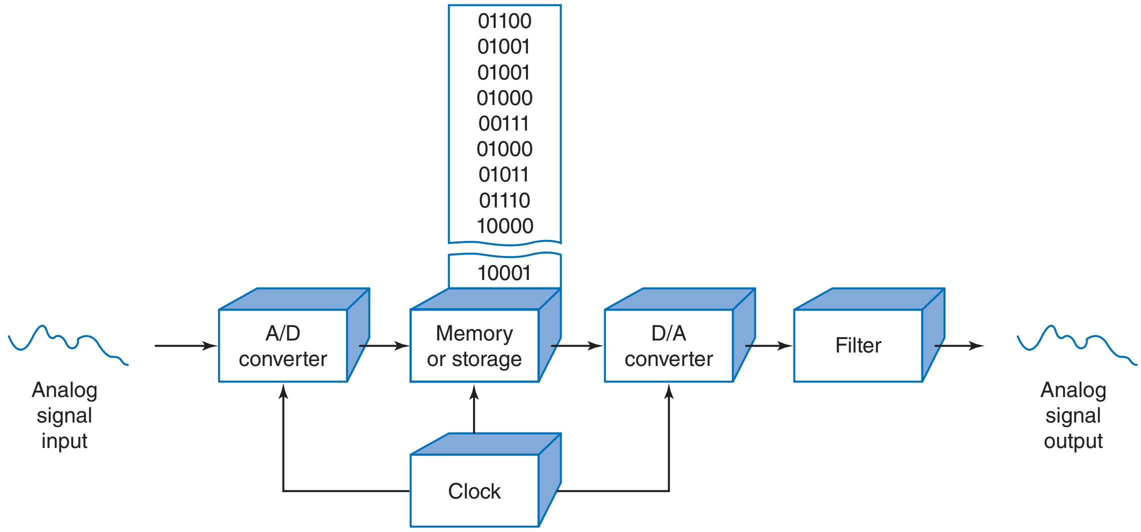



**Fig. 1-2** An analog-to-digital-to-analog system.

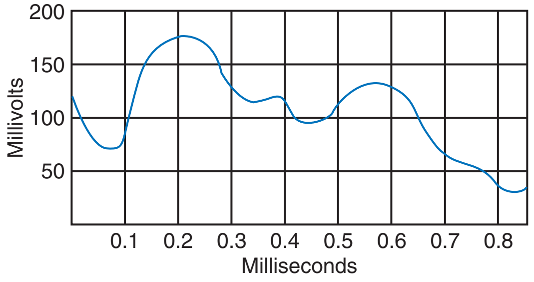



**Fig. 1-3** An analog waveform.

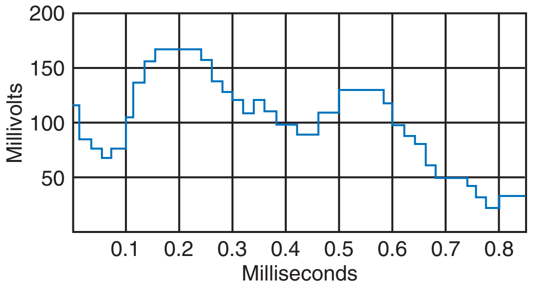



**Fig. 1-4** Output of the D/A converter.

Actually, the filter shown in Fig. 1-2 smooths the steps, and the resulting analog output signal would be quite acceptable for many applications such as speech.

If enough bits and an adequate sampling rate are used, an analog signal can be converted into an accurate digital equivalent. The signal can be converted back into analog form and may not be distinguishable from the original signal. Or it may be noticeably better if DSP were used.

Analog electronics involves techniques and concepts different from those of digital electronics. The rest of this book is devoted mainly to analog electronics. Today most electronic technicians must have skills in both analog and digital circuits and systems.

The term *mixed signal* refers to applications or devices that use both analog and digital techniques. Mixed-signal integrated circuits are covered in Chap. 13.

## Self-Test

*Determine whether each statement is true or false.*

6. Electronic circuits can be divided into two categories, digital or analog.
7. An analog circuit can produce an infinite number of output conditions.
8. An analog circuit recognizes only two possible input conditions.
9. Rectangular waves are common in digital systems.
10. D/A converters are used to convert analog signals to their digital equivalents.
11. The output of a 2-bit D/A converter can produce eight different voltage levels.

## 1-3 Analog Functions

This section presents an overview of some functions that analog electronic circuits can provide. Complex electronic systems can be broken down into a collection of individual functions. An ability to recognize individual functions, how they interact, and how each contributes to system operation will make system analysis and troubleshooting easier.

Analog circuits perform certain operations. These operations are usually performed on *signals*. Signals are electrical quantities, such as voltages or currents, that have some merit or use. For example, a microphone converts a human voice into a small voltage whose frequency and level change with time. This small voltage is called an *audio signal*.

Analog electronic circuits are often named after the function or operation they provide. *Amplification* is the process of making a signal larger or stronger, and circuits that do this are called *amplifiers*. Here is a list of the major types of analog electronic circuits.

1. *Adders:* Circuits that add signals together. Subtracters are also available.
2. *Amplifiers:* Circuits that increase signals.
3. *Attenuators:* Circuits that decrease signals.
4. *Clippers:* These prevent signals from exceeding some set amplitude limit or limits.
5. *Comparators:* Compare a signal against some reference, which is usually a voltage.
6. *Controllers:* Regulate signals and load devices. For example, a controller might be used to set and hold the speed of a motor.
7. *Converters:* Change a signal from one form to another (e.g., voltage-to-frequency and frequency-to-voltage converters).
8. *Detectors:* Remove information from a signal (a radio detector removes voice or music from a radio signal).
9. *Dividers:* Perform arithmetic division of a signal.
10. *Filters:* Remove unwanted frequencies from a signal.
11. *Mixers:* Another name for adders. Also, nonlinear circuits that produce the sum and difference frequencies of two input signals.
12. *Multipliers:* Perform arithmetic multiplication of some signal characteristic (there are frequency and amplitude multipliers).
13. *Oscillators:* Change direct current to alternating current.
14. *Rectifiers:* Change alternating current to direct current.
15. *Regulators:* Circuits that hold some value, such as voltage or current, constant.
16. *Switches:* Turn signals on or off or change their routing in an electronic system.

**Schematic diagram**

**Block diagram**

**Signals**

**Troubleshooting**

A *schematic diagram* shows all of the individual parts of a circuit and how they are interconnected. Schematics use standard symbols to represent circuit components. A *block diagram* shows all of the individual functions of a system and how the signals flow through the system. Schematic diagrams are usually required for what is known as *component-level troubleshooting*. A component is a single part, such as a resistor, capacitor, or an integrated circuit. Component-level repair requires the technician to isolate and replace individual parts that are defective.

System-level repair often requires only a block diagram or a knowledge of the block diagram. The technician observes symptoms and makes measurements to determine which function or functions are improper. Then an entire module, panel, or circuit board is replaced. Component-level troubleshooting usually takes longer than system-level does. Since time is money, it may be economical to replace entire modules or circuit boards.

*Troubleshooting* begins at the system level. Using knowledge of circuit functions, the block diagram, observation of symptoms, and measurements, the technician isolates the

Technician inspecting a circuit board.

difficulty to one or more circuit functions. If replacement boards or modules are on hand, one or more functions can be replaced. However, if component-level troubleshooting is required, the technician continues the isolation process to the component level, often by using a voltmeter and an oscilloscope.

Figure 1-5 shows one block of a block diagram for you to see the process. Troubleshooting is often a series of simple yes or no decisions. For example, is the output signal shown in Fig. 1-5 normal? If so, there is no need to troubleshoot that circuit function. If it is not normal, four possibilities exist: (1) a power supply problem, (2) an input signal problem, (3) the block (function) is defective, or (4) some combination of these three items. Voltmeters and/or oscilloscopes are generally used to verify the power supply and the input signal to a block. If the supply and input signals are normal, then the block can be replaced or component-level troubleshooting on that circuit function can begin. The following chapters in this book detail how electronic circuits work and cover component-level troubleshooting.

Figure 1-6 shows a block with only one input (power) and one output. Assuming the output signal is missing or incorrect, the possibilities are: (1) the power supply is defective, (2) the oscillator is defective, (3) or both are defective.

Figure 1-7 shows an amplifier that is controlled by a separate input. If its output signal is not correct, the possible causes are: (1) the power supply is defective, (2) the input signal is defective, (3) the control input is faulty, (4) the amplifier has malfunctioned, or (5) some combination of these four items.

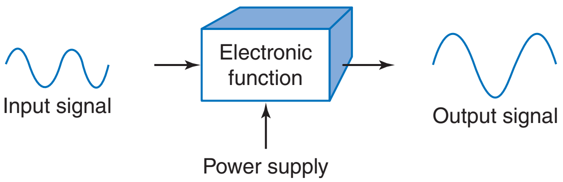



**Fig. 1-5** One block of a block diagram.

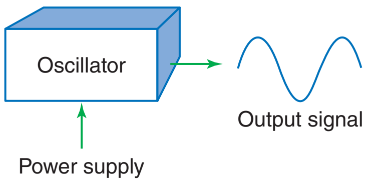



**Fig. 1-6** A block with only a power supply input.

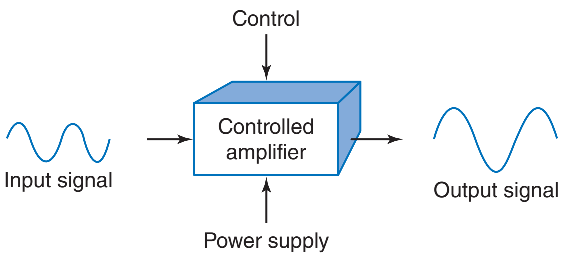



**Fig. 1-7** Amplifier with a control input.

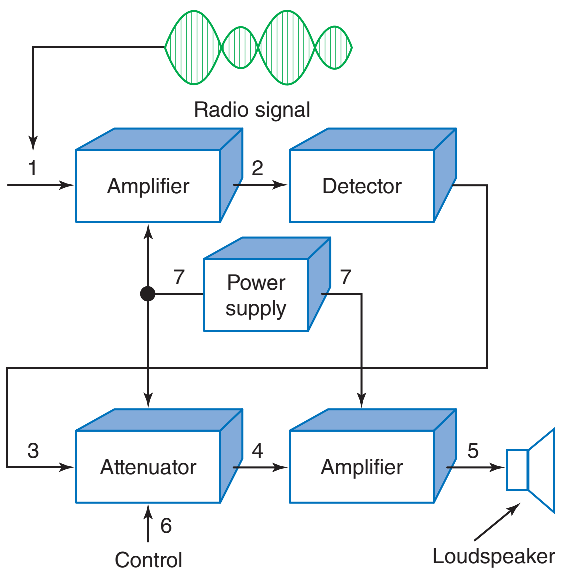



**Fig. 1-8** Partial block diagram of a radio receiver.

Figure 1-8 illustrates a partial block diagram for a radio receiver. It shows how signals flow through the system. A radio signal is amplified, detected, attenuated, amplified again, and then sent to a loudspeaker to produce sound. Knowing how the signal moves from block to block enables a technician to work efficiently. For example, if the signal is missing or weak at point 5, the problem could be caused by a bad signal at point 1, or any of the blocks shown might be defective. The power supply should be checked first, since it affects most of the circuit functions shown. If it checks good, then the signal can be verified at point 1, then point 2, and so on. A defective stage will be quickly located by this orderly process. If the signal is normal at point 3 but not at point 4, then the attenuator block and/or its control input is bad.

Much of this book is devoted to the circuit details needed for component-level troubleshooting. However, you should remember that troubleshooting begins at the system level. Always keep a clear picture in your mind of what the individual circuit function is and how that function can be combined with other functions to accomplish system operation.

## Self-Test

*Determine whether each statement is true or false.*

12. Amplifiers make signals larger.
13. If a signal into an amplifier is normal but the output is not, then the amplifier has to be defective.
14. Component-level troubleshooting requires only a block diagram.
15. A schematic diagram shows how individual parts of a circuit are connected.
16. The first step in troubleshooting is to check individual components for shorts.

## 1-4 Circuits with Both DC and AC

The transition from the first electricity course to an electronics course can cause some initial confusion. One reason for this is that dc and ac circuit concepts are often treated separately in the first course. Later, students are exposed to electronic circuits that have both dc and ac components. This section will make the transition easier.

Figure 1-9 shows examples of circuits containing both dc and ac components. A battery, a dc source, is connected in series with an ac source. The waveform across the resistor shows that both direct current and alternating current are present. The waveform at the top in Fig. 1-9 shows a sine wave with an average value that is positive. The waveform below this shows a sine wave with a negative average value. The average value in both waveforms is called the *dc component of the waveform,* and it is equal to the battery voltage. Without the batteries, the waveforms would have an average value of 0 V.

**DC component**

Figure 1-10 shows an *RC* (resistor-capacitor) circuit that has both ac and dc sources. This circuit is similar to many linear electronic circuits, which are energized by dc power supplies, such as batteries, and which often process ac signals. Thus, the waveforms in linear electronic circuits often show both ac and dc components.

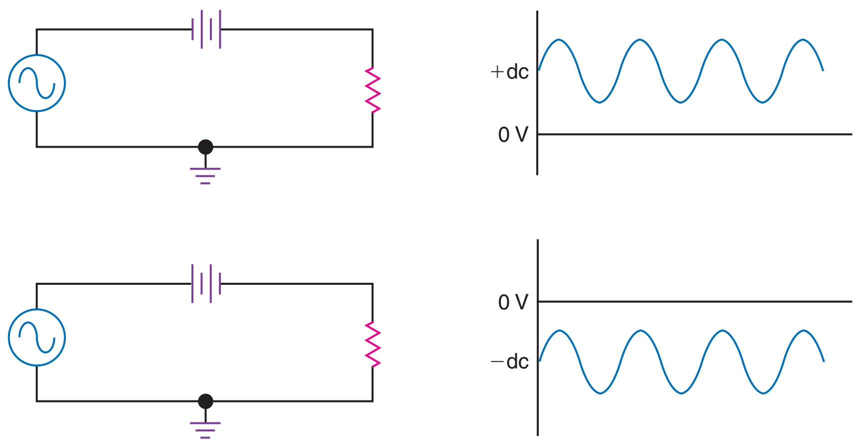



**Fig. 1-9** Circuits with dc and ac sources.

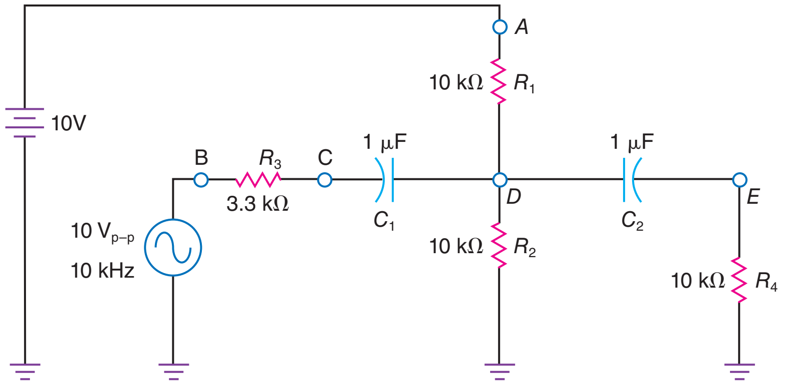



**Fig. 1-10** An *RC* circuit with two sources.

Figure 1-11 shows the waveforms that occur at the various nodes in Fig. 1-10. A node is a point at which two or more circuit elements (resistors, inductors, etc.) are connected. These two figures will help you understand some important ideas that you will need in your study of linear electronics.

The waveform for Node A, in Fig. 1-11, shows *pure direct current*. The word "pure" is used because there is no ac component. This is the waveform expected from a dc source such as a battery. Since Node A in Fig. 1-10 is the positive terminal of the battery, the dc waveform is no surprise.

Node B, in Fig. 1-11, shows *pure alternating current* (there is no dc component). Node B is the ac source terminal in Fig. 1-10, so this waveform is what one would expect it to be.

The other waveforms in Fig. 1-11 require more thought. Starting with Node C, we see a pure ac waveform with about half the amplitude of the ac source. The loss in amplitude is caused by the voltage drop across $R_3$, discussed later. Node D shows an ac waveform with a 5 V dc component. This dc component is established by $R_1$ and $R_2$ in Fig. 1-10, which act as a voltage divider for the 10 V dc battery. Finally, Node E in Fig. 1-11 shows a pure ac waveform. The dc component has been removed by $C_2$ in Fig. 1-10. A dc component is present at Node D but is missing at Node E because *capacitors block or remove the dc component of signals or waveforms.*

**Capacitors block dc component**

**You May Recall**

. . . that capacitors have infinite reactance (opposition) for direct current and act as open circuits.

The formula for capacitive reactance is

$$X_C = \frac{1}{2\pi fC}$$

As the frequency ($f$) approaches direct current (0 Hz), the reactance approaches infinity. In capacitors, the relationship between frequency and reactance is *inverse*. As one goes down, the other goes up.

#### EXAMPLE 1-2

Determine the reactance of the capacitors in Fig. 1-10 at a frequency of 10 kHz and compare this reactance with the size of the resistors:

$$X_C = \frac{1}{2\pi fC}$$

$$= \frac{1}{6.28 \times 10 \times 10^3 \times 1 \times 10^{-6}}$$

$$= 15.9\ \Omega$$

The reactance 15.9 Ω is low. In fact, we can consider the capacitors to be short circuits at 10 kHz because the resistors in Fig. 1-10 are 10 kΩ, which is much larger.

Let's summarize two points: (1) the capacitors are open circuits for direct current, and (2) the capacitors are short circuits for ac signals when the signal frequency is relatively high. These two concepts are applied over and over again in analog electronic circuits. Please try to remember them.

What happens at other frequencies? At higher frequencies, the capacitive reactance is even lower, so the capacitors can still be viewed

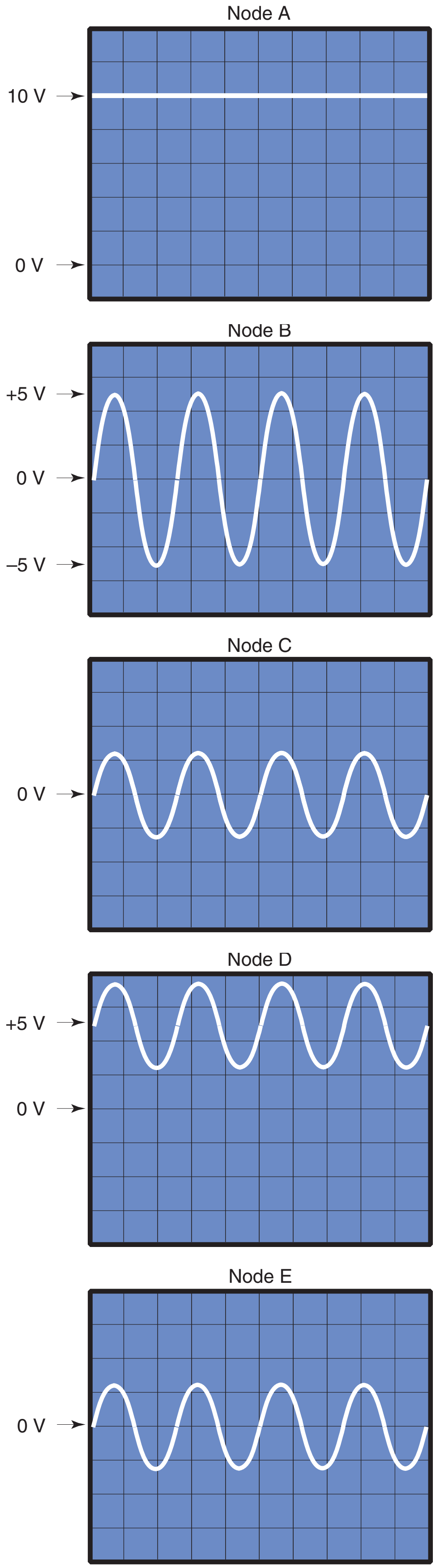



**Fig. 1-11** Waveforms for Fig. 1-10.

as shorts. At lower frequencies, the capacitors show more reactance and the short-circuit viewpoint may no longer be correct. As long as the reactance is less than one-tenth of the effective resistance, the short-circuit viewpoint is generally good enough.

### EXAMPLE 1-3

Determine the reactance of the capacitors in Fig. 1-10 at a frequency of 100 Hz. Will the short-circuit viewpoint be appropriate at this frequency?

$$X_C = \frac{1}{2\pi fC}$$

$$= \frac{1}{6.28 \times 100 \times 1 \times 10^{-6}}$$

$$= 1.59\ \text{k}\Omega$$

This reactance is in the 1000-Ω range, so the capacitors *cannot* be viewed as short circuits at this frequency.

Figure 1-12 illustrates the equivalent circuits for Fig. 1-10. The dc equivalent circuit shows the battery, $R_1$, and $R_2$. Where did the other resistors and the ac source go? They are "disconnected" by the capacitors, which are open circuits for direct current. Since $R_1$ and $R_2$ are equal in value, the dc voltage at Node D is half the battery voltage, or 5 V. The ac equivalent circuit is more complicated. Note that resistors $R_1$, $R_2$, and $R_4$ are in

## ABOUT ELECTRONICS

**Surface-Mount Technology and the Technician** Although SMT has reduced the amount of time spent on component-level troubleshooting, technicians with these troubleshooting skills are still in demand.

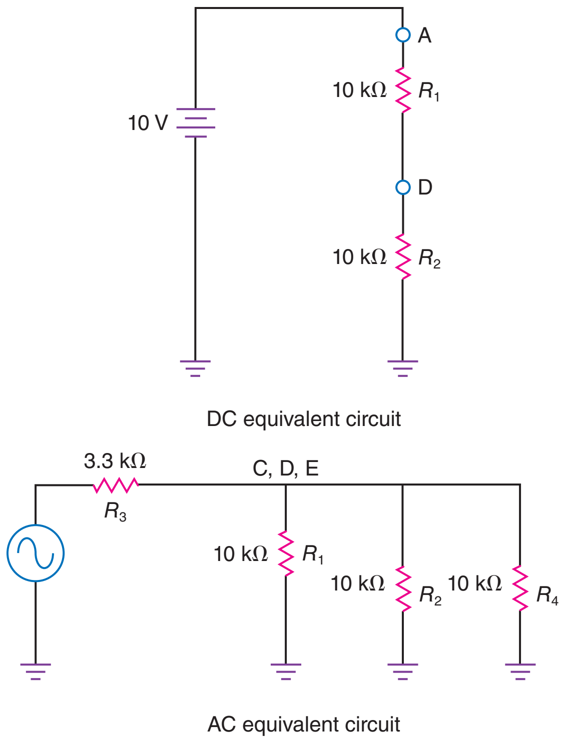



**Fig. 1-12** Equivalent circuits for Fig. 1-10.

**Superposition theorem**

**Bypassing**

**Coupling capacitor**

**Blocking capacitor**

**Bypass capacitor**

parallel. Since $R_2$ and $R_4$ are connected by $C_2$ in Fig. 1-10, they can be joined by a short circuit in the ac equivalent circuit. Remember that the capacitors can be viewed as short circuits for signals at 10 kHz. An equivalent short at $C_2$ puts $R_2$ and $R_4$ in parallel. Resistor $R_1$ is also in parallel because the internal ac resistance of a dc voltage source is taken to be 0 Ω. Thus, $R_1$ in the ac equivalent circuit is effectively grounded at one end and connected to Node D at the other. The equivalent resistance of three 10-kΩ resistors in parallel is one-third of 10 kΩ or 3.33 kΩ—almost equal to the value of $R_3$. Resistor $R_3$ and the equivalent resistance of 3.33 kΩ form a voltage divider. So, the ac voltage at Nodes C, D, and E will be about half the value of the ac source, or 5 $V_{p\text{–}p}$.

When the dc and ac equivalent circuits are taken together, the result at Node D is 5 V dc and 5 $V_{p\text{–}p}$ alternating current. This explains the waveform at Node D shown in Fig. 1-11. The *superposition theorem,* which you may have studied, provides the explanation for the combining effect.

There is another very important concept used in electronic circuits, called *bypassing.* Look at Fig. 1-13 and note the $C_2$ is grounded at its right end. This effectively shorts Node D as far as the ac signal is concerned. The waveform shows that Node D has only 5 V dc, since the ac signal has been *bypassed.* Bypassing is used at nodes in circuits in which the ac signal must be eliminated.

Capacitors are used in many ways. Capacitor $C_2$ in Fig. 1-10 is often called a *coupling capacitor.* This name serves well since its function is to couple the ac signal from Node D to Node E. However, while it couples the ac signal it *blocks* the dc component. So, it may also be called a *blocking capacitor.* Capacitor $C_2$ in Fig. 1-13 serves a different function. It eliminates the ac signal at node D and is called a *bypass capacitor.*

Figure 1-14 shows a clever application of the ideas presented here. Suppose there is a problem with weak signals from a television station. An amplifier can be used to boost a weak signal. The best place for one is at the antenna, but the antenna is often on the roof. The amplifier needs power, so one solution would be to run power wires to the roof along with a separate cable for the television signal. The one coaxial cable can serve both needs (power and signal).

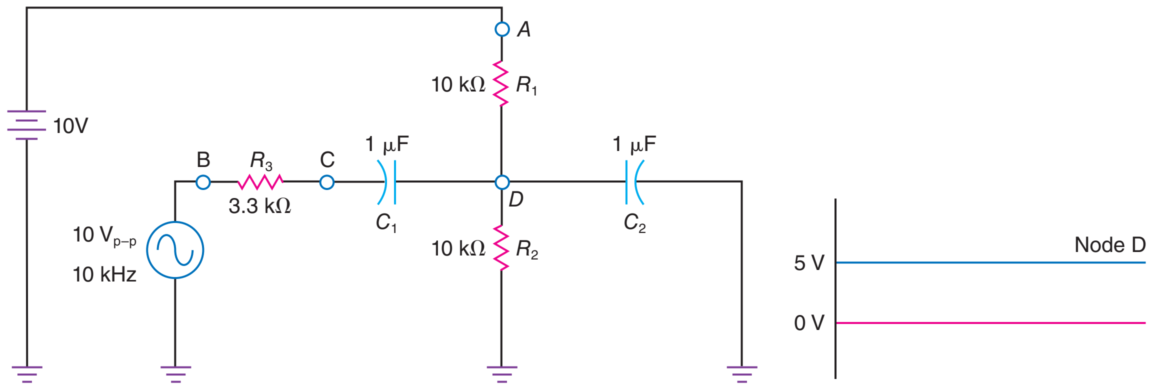



**Fig. 1-13** The concept of bypassing.

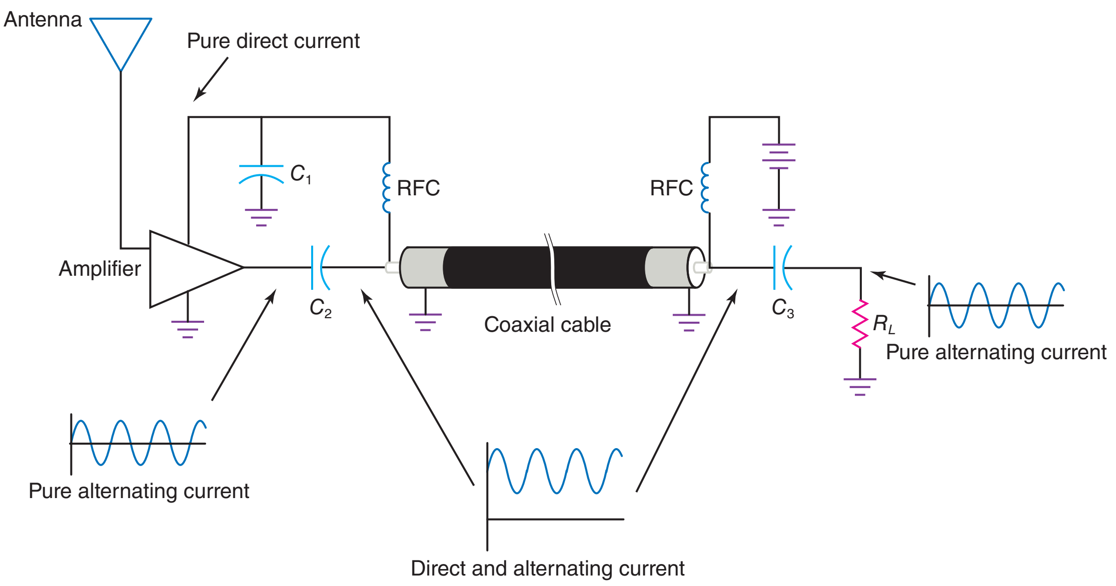



**Fig. 1-14** Sending power and signal on the same cable.

The battery in Fig. 1-14 powers an amplifier located at the opposite end of the coaxial cable. The outer conductor of the coaxial cable serves as the ground for both the battery and the remote amplifier. The inner conductor of the coaxial cable serves as the positive connection point for both the battery and the amplifier. Radio-frequency chokes (*RFCs*) are used to isolate the signal from the power circuit. *RFCs* are coils wound with copper wire. They are inductors and have more reactance for higher frequencies.

**You May Recall**

. . . that inductive reactance increases with frequency:

$$X_L = 2\pi fL$$

Frequency and reactance are *directly* related in an inductor. As one increases, so does the other.

At direct current ($f$ = 0 Hz) the inductive reactance is zero. The dc power passes through the chokes with no loss. As frequency increases, so does the inductive reactance. In Fig. 1-14 the inductive reactance of the choke on the right side of the figure prevents the battery from shorting the high-frequency signal to ground. The inductive reactance of the choke on the left side of Fig. 1-14 keeps the ac signal out of the power wiring to the amplifier.

**You May Recall**

Chokes are so named because they "choke off" high-frequency current flow.

### EXAMPLE 1-4

Assume that the RFCs in Fig. 1-14 are 10 $\mu$H. The lowest-frequency television channel starts at 54 MHz. Determine the minimum inductive reactance for television signals. Compare the minimum choke reactance with the impedance of the coaxial cable, which is 72 V.

$$X_L = 2\pi fL = 6.28 \times 54 \times 10^6 \times 10 \times 10^{-6}$$
$$= 3.39 \text{ k}\Omega$$

The reactance of the chokes is almost 50 times the cable impedance. This means that the chokes effectively isolate the cable signal from the battery and from the power circuit of the amplifier.

Capacitors $C_2$ and $C_3$ in Fig. 1-14 are coupling capacitors. They couple the ac signal into and out of the coaxial cable. These capacitors act as short circuits at the signal frequency, and they are open circuits for the dc signal from the battery. Capacitor $C_1$ is a bypass capacitor. It ensures that the amplifier is powered by pure direct current. Resistor $R_L$ in Fig. 1-14 is the load for the ac signal. It represents the television receiver.

## Self-Test

*Solve problems 17 to 21.*

17. Determine the average value of the bottom waveform shown in Fig. 1-9 if the battery develops 7.5 V.
18. Find the average value of the waveform for Node D and for Node E in Fig. 1-10 if the battery provides 25 V.
19. Which components are used in electronics to block direct current, to couple ac signals, and for bypassing?
20. What is the function of $C_1$ in Fig. 1-14?
21. What is the function of $C_2$ in Fig. 1-14?

## 1-5 Trends in Electronics

**Learning curve**

Trends in electronics are characterized by enormous growth and sophistication. The growth is the result of the *learning curve* and competition. The learning curve simply means that as more experience is gained, more efficiency results. Electronics is maturing as a technology. The yield of integrated circuits is a good example of this. A new integrated circuit (IC), especially a sophisticated one, may yield less than 10 percent. Nine out of ten do not pass the test and are thrown away, making the price of a new device very high. Later, after much is learned about making that part, the yield goes up to 90 percent. The price drops drastically, and many new applications are found for it because of the lower price. Although the new parts are complex and sophisticated, the usual result is a product that is easier to use. In fact, "user friendly" is a term used to describe sophisticated products.

**Microminiaturization**

The IC is the key to most electronic trends. These marvels of *microminiaturization* keep expanding in performance and usually decrease the cost of products. They also require less energy and offer high reliability. One of the most popular ICs, the microprocessor, has created many new products. DSP chips are now fast and inexpensive, encouraging rapid growth.

**Surface-mount technology (SMT)**

Along with ICs, *surface-mount technology (SMT)* also helps to expand electronics applications. *SMT* is an alternative to insertion technology for the fabrication of circuit boards. With insertion technology, device leads pass through holes in the circuit board. The insides of the holes are usually plated with metal to electrically connect the various board layers. Circuit boards designed for insertion technology have more plated-through holes, are larger, and cost more.

The devices intended for *SMT* have a different appearance. As Fig. 1-15 shows, the

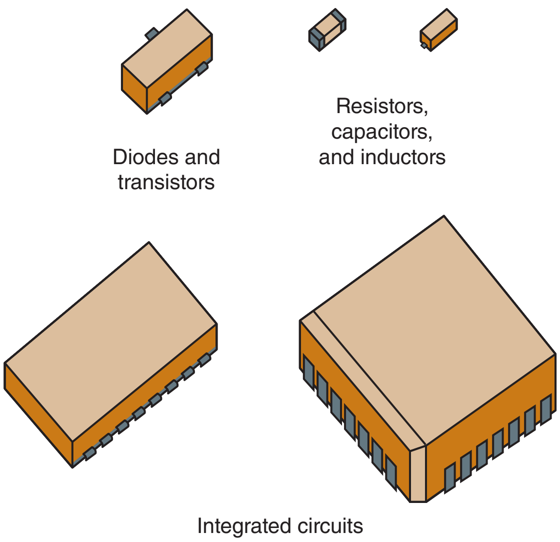
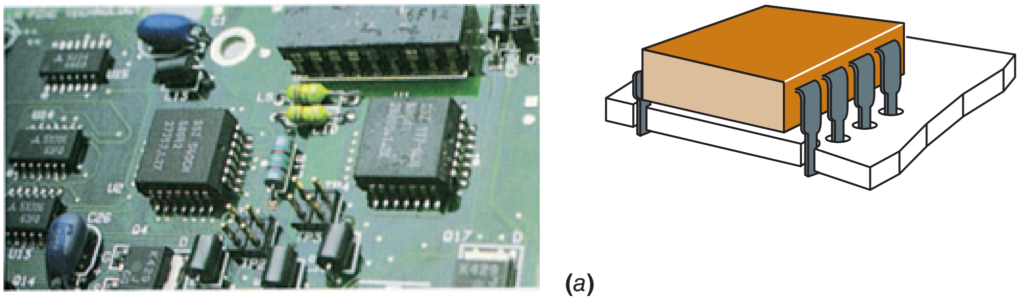
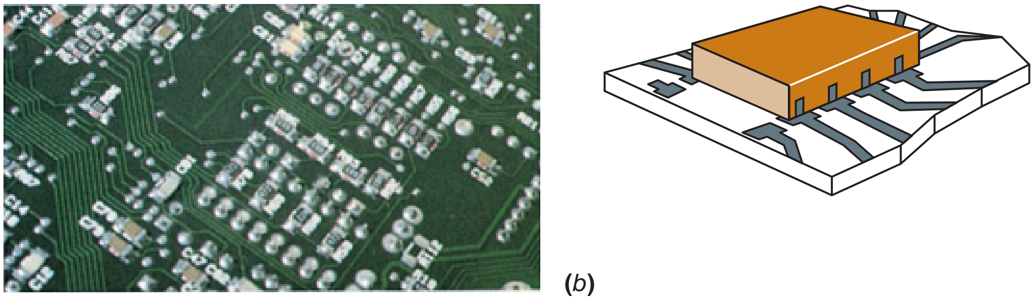



**Fig. 1-15** Device packaging for surface-mount technology.



(*a*)



(*b*)

A comparison of conventional-mount and surface-mount technologies. (a) The photo shows both methods, and the drawing shows the conventional method. (b) Photo and drawing of a surface-mount technology (*SMT*) circuit board.

device packages have very short leads or just end terminals. These packages are designed to be soldered onto the surface of printed circuit boards. The short leads save material and reduce the stray effects associated with the longer leads used in insertion technology. *SMT* provides better electrical performance, especially in high-frequency applications.

Two other advantages of *SMT* are lower circuit assembly cost, since they are easier to automate, and a lower profile. Since more boards can be packed into a given volume, smaller, less expensive products will become available.

A disadvantage of *SMT* technology is the close spacing of IC leads. Troubleshooting and repair are difficult. Figure 1-16 shows some tools that should be on hand to make measurements on modern circuit boards. The probe allows momentary contact to be safely made at one IC pin. An ordinary probe is uninsulated and will likely slip between two *SMT* device leads. When this happens, the two leads will be shorted together and damage could result. The single contact test clip in Fig. 1-16 is preferred for making connections that will be used for more than one measurement. The IC test clip in Fig. 1-16 is the best tool for *SMT* IC measurements. It clips onto an *SMT* IC and provides larger and widely-spaced test contacts for safe probing or test-clip connections. Different models are available for the various *SMT* IC packages.

The uses for electronic devices, products, and systems are expanding. Computer technology finds new applications almost on a daily basis. Electronic communications is expanding rapidly. Thanks to compression and processing breakthroughs, the growth is brisk. Three-dimensional image processing is providing

## ABOUT ELECTRONICS

Yes, it is possible to safely probe surface-mount integrated circuits.

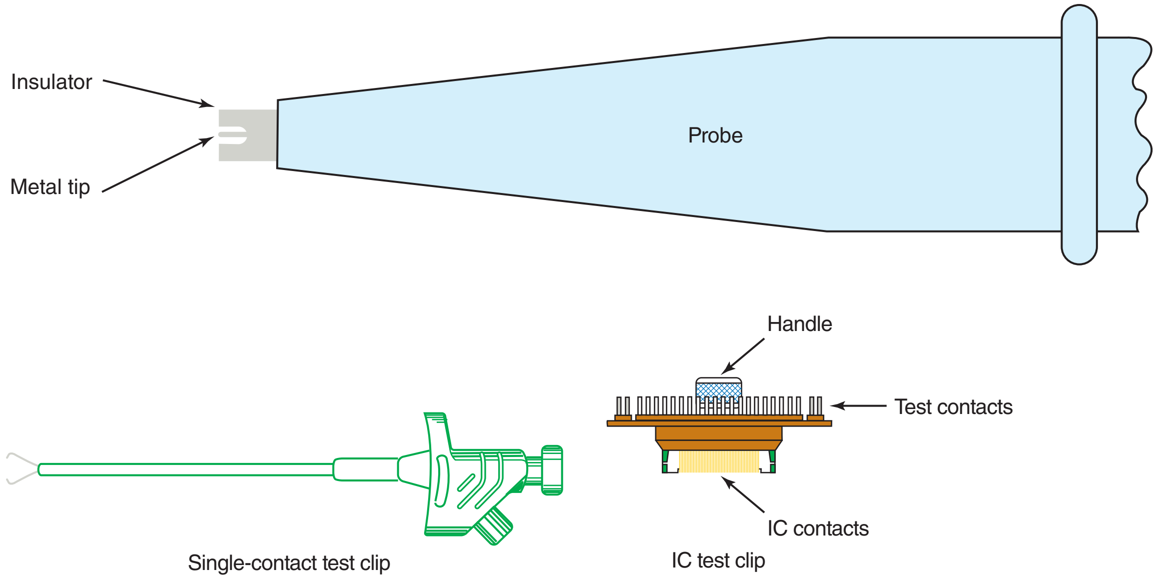



**Fig. 1-16** Tools for *SMT* measurements.

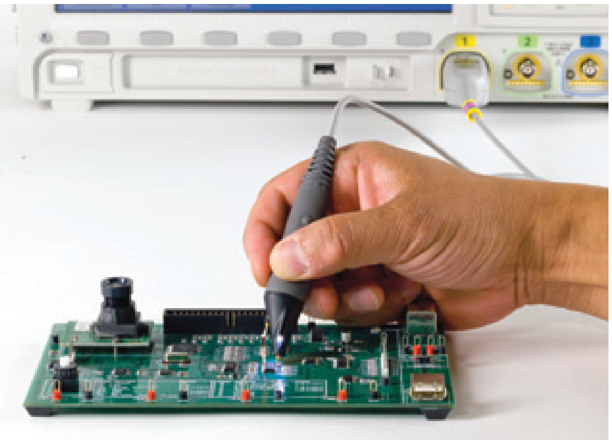
systems for product inspection, automated security monitoring, and even virtual reality for education and entertainment. Computer technology is merging with telecommunications to provide new methods of information transfer, education, entertainment, and shopping. New sensors are being developed to make systems energy-efficient and less damaging to the environment. As an example, heating, ventilating, and air-conditioning systems will use oxygen sensors to direct airflow in buildings on an as-needed basis. Consider these features that have affected the automotive industry:

- A DSP system that makes the sound in a convertible as good with the top down as with it up.
- A radar-assisted cruise control for improved safety.
- No more camshaft. Electronic valves open and close precisely when they should.
- A "tuned" suspension system that provides a soft ride or a snappy sports car feel, depending on the driver's mood.
- Blind spot and lane departure warning systems.
- Bluetooth and voice command for hands-free cell phone operation.
- Voice command for hands-free operation of the GPS navigation system and other vehicle features.
- USB port for playing MP3 music files.

Product features continue to expand. Digital cameras might have a built-in GPS receiver to identify the locations where shots were taken and perhaps a built-in projector to share images without relying on an external device or a tiny on-board LCD screen. More accessories such as pointing devices, scanners, keyboards, and printers offer wireless connectivity. Television receivers have built-in Ethernet, WiFi, HDMI, and USB ports for Internet access and easy integration with other devices, and some receivers offer vivid three-dimensional viewing. Mobile devices with WiFi or 3G replace computers for e-mail, Internet browsing, social networking, and so on. Smart phones integrate functions once dependent on computers.

The information age is merging databases to reduce errors and improve safety and efficiency. A patient is more likely to get the tests she or he needs, the correct medications, the correct procedures, and all in a timely fashion. Health care professionals have instant access to medical history, test results, notes, and comments from other professionals. And the patient wrist tag might have an embedded RF chip. Medical imaging continues to improve to hasten the diagnostic procedure, increase accuracy, and eliminate the need for some invasive procedures or more costly or dangerous tests.

Homes and other structures are becoming more energy efficient thanks to sophisticated but affordable control systems and improved

Agilent 1145A probe for surface-mount devices.


Imagine: a color projector built into a portable camera!

appliances and lighting. Renewable sources such as photovoltaic arrays can feed surplus energy into the grid; this would not be safe or practical without electronic devices such as inverters, controllers, and smart converters.

The outlook is bright for those with careers in electronics. The new products, the new applications, and the tremendous growth mean good jobs for the future. The jobs will be challenging and marked by constant change.

## Self-Test

*Determine whether each statement is true or false.*

22. Integrated circuits will be used less in the future.
23. The learning curve makes electronic devices less expensive as time goes on.
24. In the future, more circuits will be fabricated using insertion technology and fewer will be fabricated with *SMT*.

# Chapter 1 Summary and Review

## Summary

1. Electronics is a relatively young field. Its history began in the twentieth century.
2. Electronic circuits can be classified as digital or analog.
3. The number of states or voltage levels is limited in a digital circuit (usually to two).
4. An analog circuit has an infinite number of voltage levels.
5. In a linear circuit, the output signal is a replica of the input.
6. All linear circuits are analog, but not all analog circuits are linear. Some analog circuits distort signals.
7. Analog signals can be converted to a digital format with an A/D converter.
8. Digital-to-analog converters are used to produce a simulated analog output from a digital system.
9. The quality of a digital representation of an analog signal is determined by the sampling rate and the number of bits used.
10. The number of output levels from a D/A converter is equal to 2 raised to the power of the number of bits used.
11. Digital signal processing uses computers to enhance signals.
12. Block diagrams give an overview of electronic system operation.
13. Schematic diagrams show individual part wiring and are usually required for component-level troubleshooting.
14. Troubleshooting begins at the system level.
15. Ac and dc signals are often combined in electronic circuits.
16. Capacitors can be used to couple ac signals, to block direct current, or to bypass alternating current.
17. *SMT* is replacing insertion technology.

## Related Formulas

Number of levels in a binary system: levels $= 2^n$

Capacitive reactance: $X_C = \dfrac{1}{2\pi fC}$

Inductive reactance: $X_L = 2\pi fL$

## Chapter Review Questions

*Determine whether each statement is true or false.*

1-1. Most digital circuits can output only two states, high and low. (1-2)

1-2. Digital circuit outputs are usually sine waves. (1-2)

1-3. The output of a linear circuit is an exact replica of the input. (1-2)

1-4. Linear circuits are classified as analog. (1-2)

1-5. All analog circuits are linear. (1-2)

1-6. The output of a 4-bit D/A converter can produce 128 different voltage levels. (1-2)

1-7. An attenuator is an electronic circuit used to make signals stronger. (1-3)

1-8. Block diagrams are best for component-level troubleshooting. (1-3)

1-9. In Fig. 1-8, if the signal at point 4 is faulty, then the signal at point 3 must also be faulty. (1-3)

1-10. Refer to Fig. 1-8. The power supply should be checked first. (1-3)

## Chapter Review Questions...continued

1-11. Refer to Fig. 1-10. Capacitor $C_2$ would be called a bypass capacitor. (1-4)

1-12. Node C in Fig. 1-10 has no dc component since $C_1$ blocks direct current. (1-4)

1-13. In Fig. 1-11, Node D is the only waveform with dc and ac components. (1-4)

1-14. Refer to Fig. 1-14. The reactance of the coils is high for dc signals. (1-4)

## Critical Thinking Questions

1-1. Functions now accomplished by using electronics may be accomplished in different ways in the future. Can you think of any examples?

1-2. Can you describe a simple system that uses only two wires but will selectively signal two different people?

1-3. What could go wrong with capacitor $C_2$ in Fig. 1-10, and how would the fault affect the waveform at Node D?

1-4. What could go wrong with capacitor $C_2$ in Fig. 1-13, and how would the fault affect the waveform at Node D?

## Answers to Self-Tests

1. T
2. T
3. F
4. T
5. F
6. T
7. T
8. F
9. T
10. F
11. F
12. T
13. F
14. F
15. T
16. F
17. −7.5 V
18. 12.5 V, 0 V
19. capacitors
20. bypass
21. coupling (dc block)
22. F
23. T
24. F

Contrast between an LED light source and incandescent lamps. The LEDs are much more efficient and will be replacing the older incandescent types.