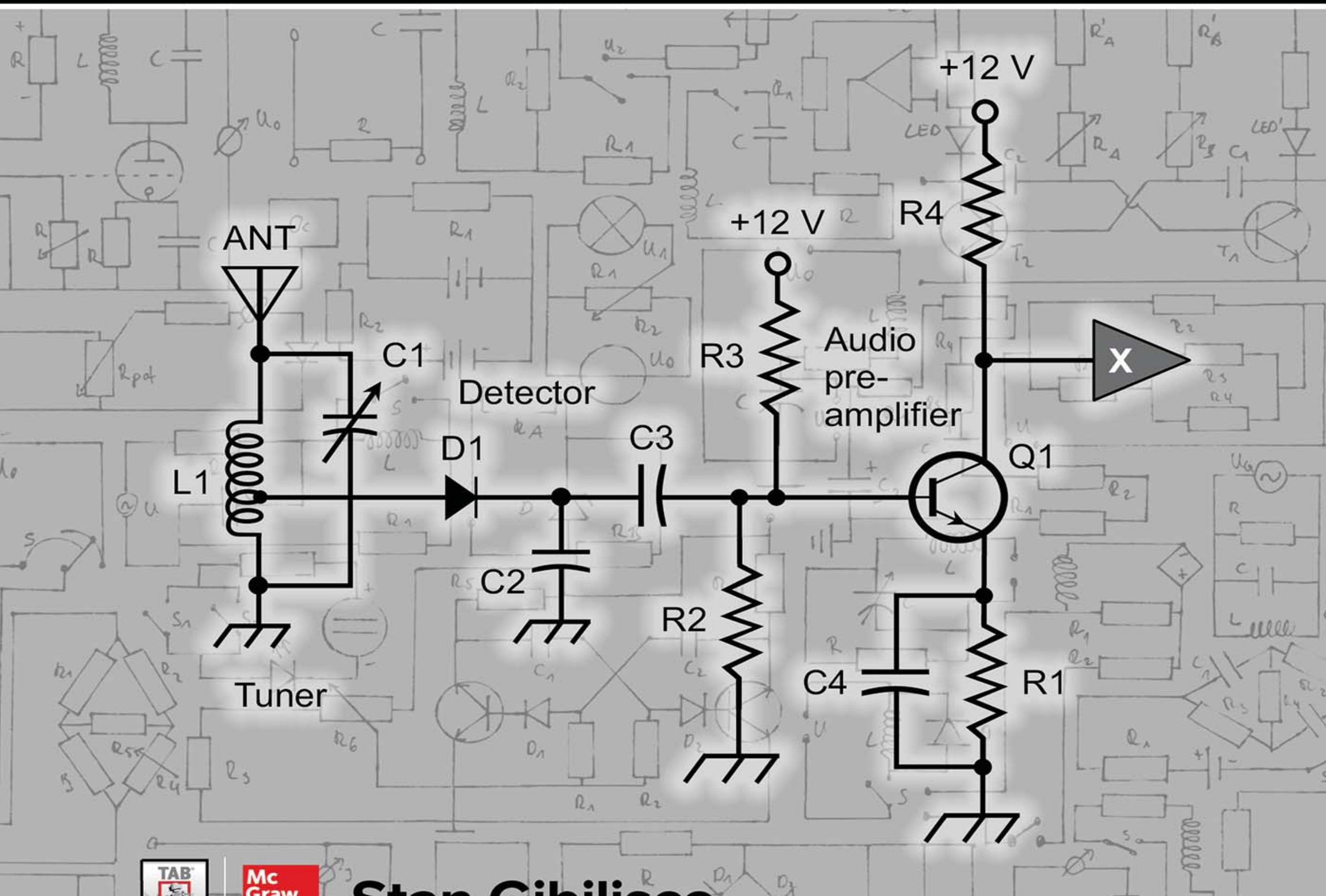
Beginner's Guide to
Reading Schematics

4TH EDITION



TAB Make Great Stuff!

Mc Graw Hill Education

Stan Gibilisco

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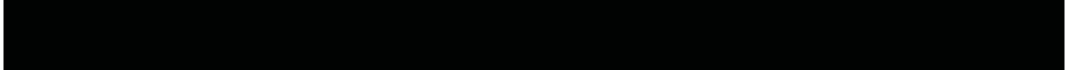

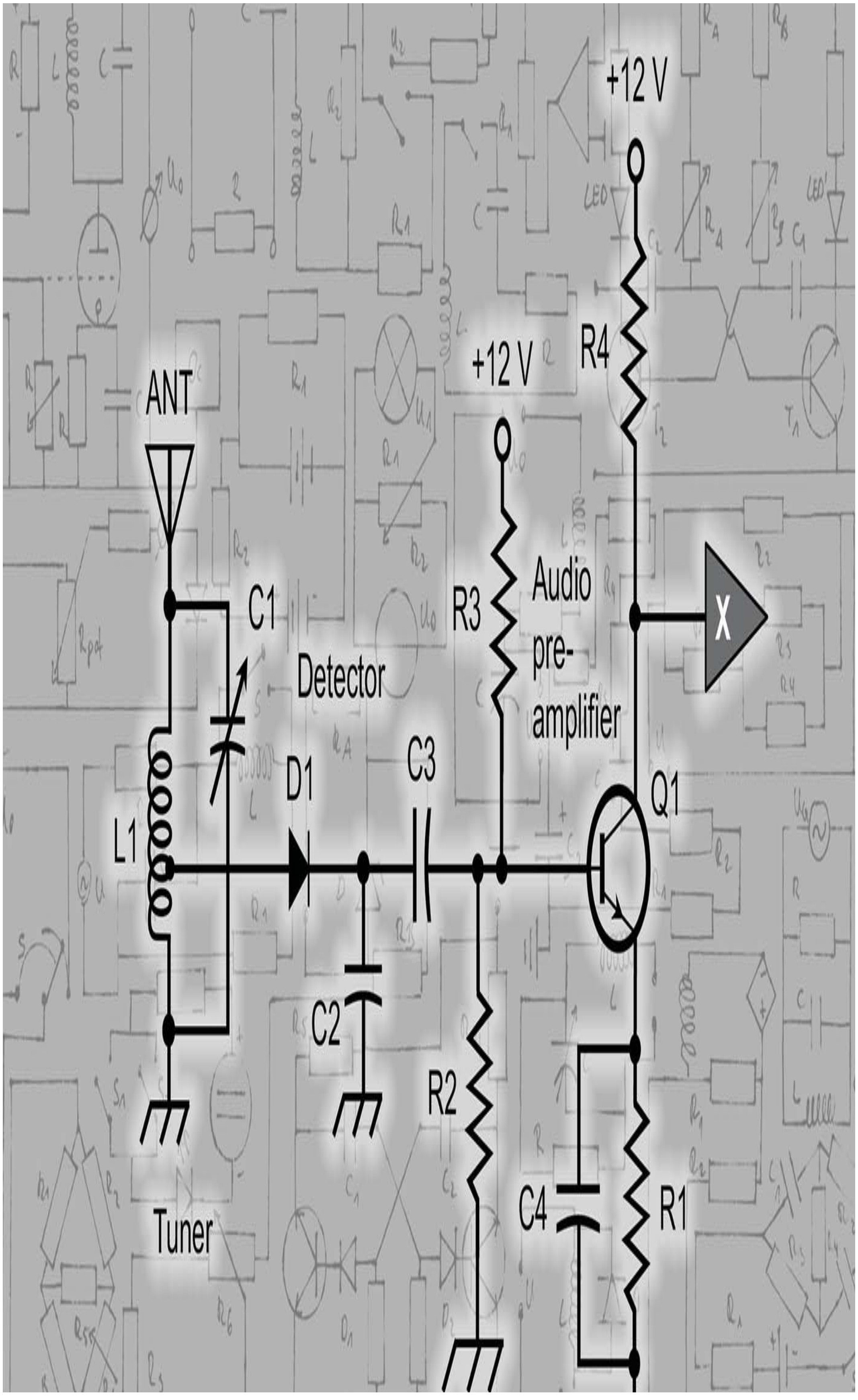
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About the Author

Stan Gibilisco, an electronics engineer, mathematician, and radio hobbyist, has authored numerous titles for the McGraw-Hill *Demystified* and *Know-It-All* series, along with dozens of other technical books and magazine articles. His work appears in several languages in countries throughout the world. Stan has been an active amateur radio operator since 1966. His currently holds the call sign W1GV.

In Memory of Jack

Contents

Introduction

Have you "caught the electronics bug" and then balked at the sight of diagrams with arcane symbols when you decided to build, troubleshoot, or repair something? If so, you have the solution in your hands.

Don't give up on electronics when you encounter strange-looking circuit diagrams. You don't quit your favorite sport because you fear the rigors of training, do you? No! You get into condition with practice. Schematic diagrams (or "schematics"), sensibly drawn and neatly arranged, can help you design, build, maintain, and repair electronic equipment. But you must do some work to gain skill at reading and interpreting schematics.

As you plan a trip by car, road maps show you how to navigate the countryside. As you work with electronic equipment, schematics show you the way through simple circuits, complex devices, and massive systems. Once you know what the symbols represent, you'll find schematics no more difficult than road maps.

While you read this book, you'll learn the rationale of schematics, how to draw or interpret each symbol, and how the symbols interconnect to form functional circuits. You'll also get a chance to do a few simple experiments. Then you can continue your quest in any field of electronics from amateur radio to space communications, from surround sound to virtual reality.

You'll find my website at **www.sciencewriter.net**. I also create videos; simply search YouTube for my name. Have fun!

Stan Gibilisco

1

The Master Plan

You'll encounter three types of diagrams in electricity and electronics literature. Each style serves a unique purpose. When you buy an electric or electronic device or system, it should (in the ideal case) come with an operating and maintenance manual that includes all three types of diagrams.

- A *block diagram* gives you an overview of how the individual circuits in a system work together. You'll see each circuit represented as a "block" (rectangle or other shape, depending on the application). Interconnecting lines, sometimes with arrows on one or both ends, show how the circuits combine to form the whole system, and how currents and signals flow among those circuits. Figure 1-1 is a simple example.

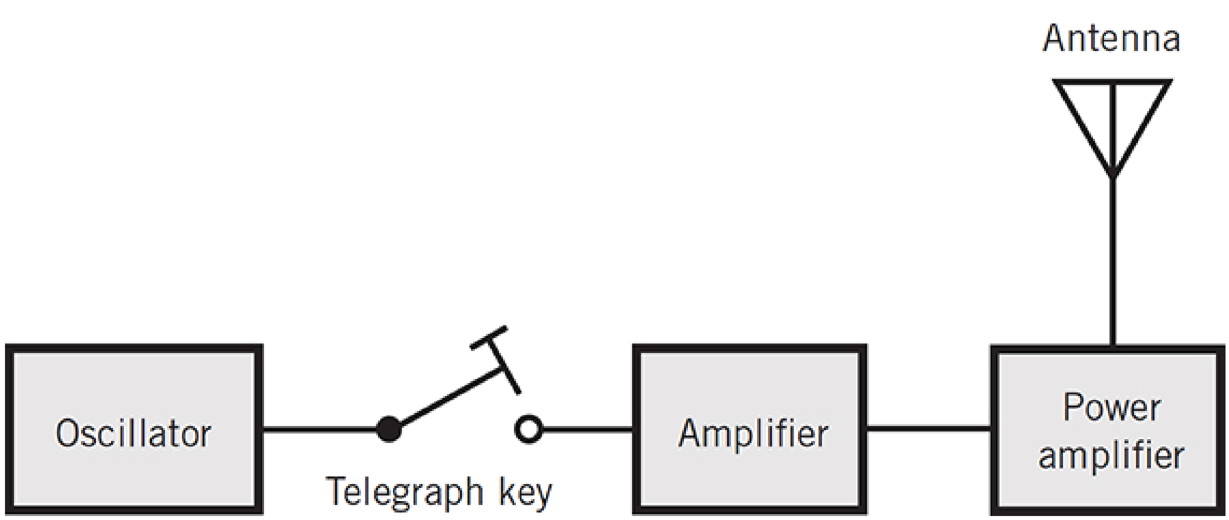

FIG. 1-1 *Block diagram of a radio transmitter that can send signals in Morse code.*

- A *schematic diagram* (often simply called a *schematic*) shows every component in a circuit. Each component has its own special symbol. Lines between the components reveal how they connect together, and to a source of power, so they perform a specific function or operation. This book deals mostly with schematics. Figure 1-2 is a simple example.

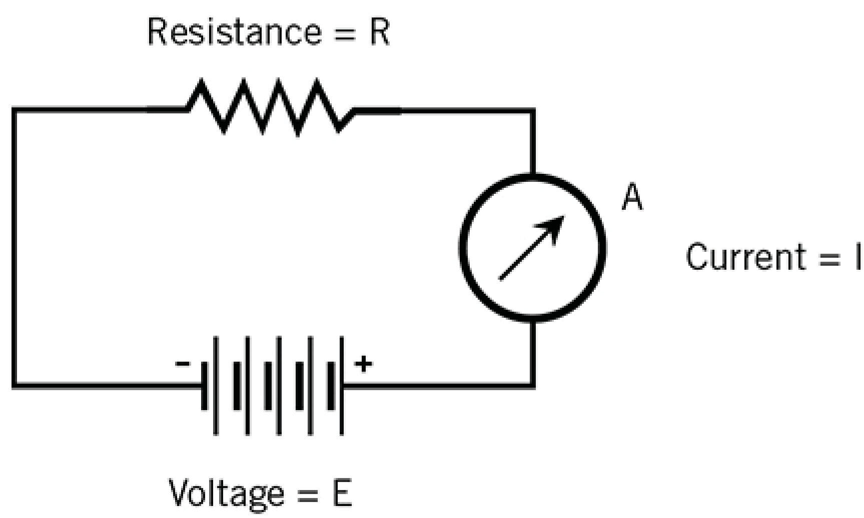

FIG. 1-2 *Schematic that includes a battery, a resistor, and an ammeter (labeled A).*

- A *pictorial diagram* (sometimes called a *layout diagram*) shows the physical arrangement of the components on a circuit board or chassis so you can identify them for installation, testing, or replacement. Some such “diagrams” are actual photographs. Keep in mind, however, that pictures rarely reveal the electrical events that occur in a circuit or system. Figure 1-3 is a simple example.

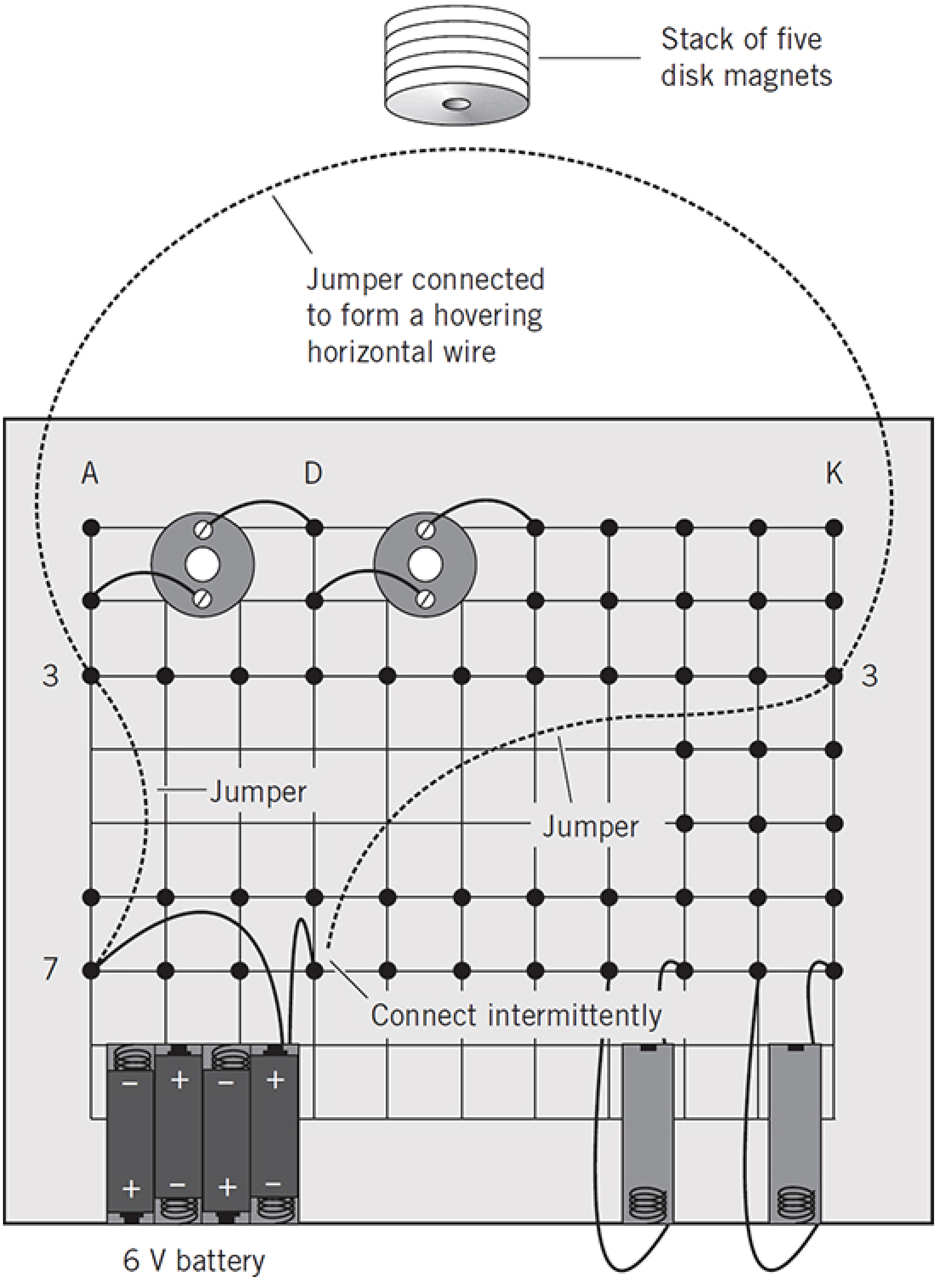

FIG. 1-3 *Pictorial drawing that shows the physical layout of a test circuit for magnetism experiments.*

Tip

When you troubleshoot a malfunctioning system, you'll usually start with its block diagram to find the circuit in which the problem originates. Then you'll refer to the schematic (or part of it) to find the faulty component. A pictorial diagram, if available, will show you what the bad component looks like and where it resides within the system structure.

Block Diagrams

A block diagram can help you understand how a system works, and can help you troubleshoot it when it malfunctions. Each block has a label that describes or names the circuit it represents, but it doesn't explain the workings of the circuit, nor does it depict the individual components. When you gain a general understanding of how a system operates by examining its block diagram, you can consult each of its circuit schematics for more details. Consider two examples.

- You want to design an electronic device to perform a specific task. You can simplify the process by drawing a block diagram that shows all the circuits you'll need to complete the project. Then you can expand each block into a schematic. In the end, you'll have a complete schematic that replaces all the blocks and shows the whole device in detail.
- Alternatively, you can approach the task the other way around. Imagine that you have a complicated schematic, and you want to use it to troubleshoot a device. Because the schematic shows every single component, you might find it difficult to determine which part of the device has the problem. A block diagram can help you envision how each circuit works in conjunction with the others. Once you've found the troublesome circuit with the aid of the block diagram, you can examine its schematic and do tests to isolate the faulty component.

Schematic Diagrams

A schematic acts as a “map” of a circuit, showing all of the individual components and how they interconnect with one another. According to one popular dictionary, the term *schematic* means “of or relating to a scheme; diagrammatic.” Therefore, you can call any drawing that depicts a scheme (electronic, physiological, geographic, or whatever) a schematic diagram.

One of the most common types of schematic is a road map for use in motor vehicles. The map might show all the navigable paths of travel inside a town, within a state or province, or across multiple states or provinces. Like a schematic of an electronic circuit, a road map shows all the landmarks relevant to a geographic region. In electronics, a schematic allows a technician to extrapolate the components and interconnections when testing, troubleshooting, and repairing a small circuit, a large device, or a huge system.

Suppose that you want to drive your truck from one place to another. Your road map shows all the landmarks between these two locations. By comparison, a schematic shows all the components between any two points in an electronic circuit. But both diagrams indicate more than mere points. You need to know more than which towns lie between two fixed locations to get an idea of the overall nature of the region. You could write down the names of the various towns or landmarks along a chosen route, but such a list couldn’t take the place of a good road map. From an electronics standpoint, you could do the same thing by compiling a list of the components in certain circuit, such as:

- Two 120-ohm resistors
- One 1000-ohm resistor
- One PNP transistor
- Two 0.47-microfarad capacitors
- 90 centimeters of hookup wire
- One 6-volt “lantern” battery
- One switch with a built-in circuit breaker

This list tells you the “ingredients” of the circuit, but nothing in a functional sense. You know all the components necessary to build the circuit, but you don’t know what it will do when you put it together! In fact, you might combine these components in several different ways to make circuits that do different things.

A schematic must not only show all the components in a circuit, but also how these components work with each other. A road map connects towns and other points of interest with lines that represent streets and highways. A line that indicates a secondary road differs from a line that represents a four-lane highway. With practice, you can learn to tell at a glance which sorts of lines indicate which types of roads. In electronics, a schematic uses a solid line to indicate a plain electrical conductor such as a wire or foil run; other types of lines (or sets of lines) represent cables, logical pathways, shielding enclosures, and wireless links. Whenever you draw an interconnecting line or set of lines, you portray some relationship between the connected components.

Schematic Symbology

A schematic uses *symbology* to reveal the anatomy of a system. On a road map, many of the symbols are lines to indicate roadways. But of course, a single black line that portrays State Route 522 doesn't resemble the appearance of this highway as you drive along it! You need only know the fact that the line symbolizes State Route 522. You can make up the other details in your mind. If you always had to see pictorial drawings of highways on paper road maps, those maps would take up thousands of times more space than the folded-up papers that you keep in your vehicle.

On a well-produced road map, you'll find a key to the symbols. The key shows each symbol and explains in simple language what each one means. If a small airplane drawn on the map indicates an airport and you memorize this fact, then each time you see the airplane symbol, you'll know that an airport exists at that particular site as shown on the map. Symbology depicts a physical object (such as an airport) in the form of another physical object (such as an airplane image).

Tip

In the few years since the previous edition of this book hit the presses, the Internet has evolved to the extent that you can use a computer, tablet device, or mobile phone to access road maps that show photographs of the views you'll see as you drive along some roads and highways. Many vehicles feature Global Positioning System (GPS) displays that show your location on a regular map (but beware: they're not always right!). You can look at photos taken from satellites, aircraft, and vehicles that have driven along specific routes. Check out "Google Maps," for example. These maps aren't printed on physical sheets of paper, so they aren't confined to the space limitations that paper maps impose. But they can distract you from the business of driving. I personally avoid them, or pull off the road and out of the way of traffic, before I look at them.

A road map contains many different symbols. Each symbol is "human engineered" to make sense in your mind. For instance, when you see a miniature airplane on a road map, you'll probably know that this location has something to do with airplanes, so you won't need a detailed explanation. If, on the other hand, the mapmaker used a beer bottle to represent an airport, anyone who failed to read the key would probably think of a saloon, not an airport! Because a map needs many different symbols, a good mapmaker tries to make sure that the symbols make sense.

Logical thinking will only take you to a certain point in devising schemes to represent complicated things, especially when you get into the realm of electronic circuits and systems. For example, a circle (or sometimes an ellipse) normally forms the basis for a transistor symbol, a silicon-controlled rectifier (SCR) symbol, and an electric outlet symbol. Additional symbols inside the circle reveal which type of component it represents.

In the olden days of electronics, engineers used circles containing various electrode symbols to represent vacuum tubes. (Sometimes they still do!) Transistors have evolved to replace vacuum tubes in most situations, so the schematic symbol for a transistor also starts with a circle. Electrode markings go into the circle as before, but transistor elements differ from tube elements, so transistor circles contain different markings than tube symbols did. Transistors perform many of the same functions as vacuum tubes did (and sometimes still do!) so their symbols look somewhat alike, but they're far from identical.

Inconsistencies arise in schematic symbology, so electronics-related diagrams can get a lot more sophisticated and subtle than any road map you'll ever see. For example, you can portray an SCR as a circle with a diode symbol inside and an extra line coming out of it. But an SCR performs a function that differs from what a tube or transistor does. An electric outlet can serve as another example. It doesn't work anything like a tube or transistor or SCR, but the basis for the symbol is a circle, just like the circle for a tube or transistor or SCR. You'll learn more about schematic symbols in Chapter 3.

Variations on a Theme

Sometimes you'll see a circle-free schematic symbol for a component that normally includes a circle. This non-standard style appears fairly often with the symbols for diodes, transistors, and SCRs. (It almost never happens with the symbols for vacuum tubes or electric outlets.) Figure 1-4 shows a PNP bipolar transistor symbol with the usual circle (A) and without it (B). Don't let "mutants" like this confuse you! The symbols differ but the components are identical.

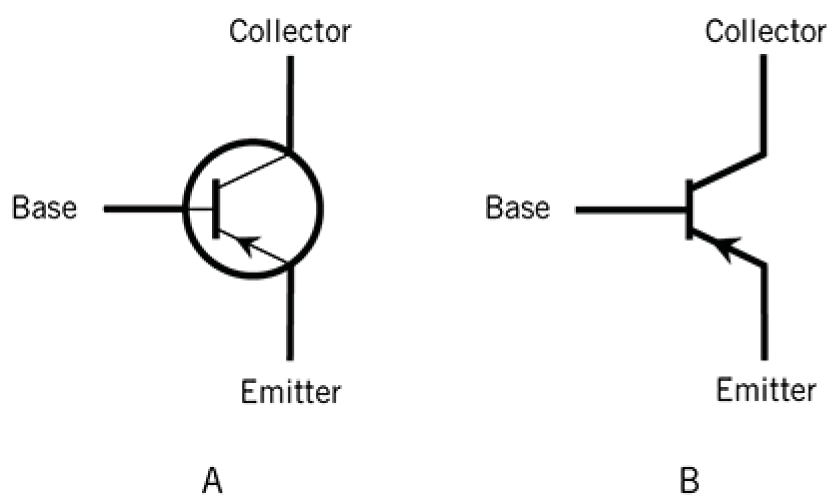

FIG. 1-4 *At A, the schematic symbol for a PNP bipolar transistor including a circle. At B, the same symbol without the circle.*

Component Interconnections

Consider a single, commonplace electronic component: a PNP bipolar transistor. This device has three electrode elements, and although many different varieties of PNP bipolar transistors exist, you draw all their symbols in pretty much the same way. You might find a PNP bipolar transistor in any one of thousands of different circuits! A good schematic will describe:

- How that particular component fits into the circuit.
- Which other components work in conjunction with it.
- Which other circuit elements depend on it for proper operation.

A PNP bipolar transistor can act as a switch, an amplifier, an oscillator, or an impedance-matching device. If a PNP bipolar transistor functions in some circuit as a *radio-frequency* (RF) amplifier, you can't conclude that a PNP bipolar transistor can operate as an RF amplifier only, and nothing else. For example, you could pull the thing out of the RF amplifier circuit and put it into another circuit to serve as the "heart" of an *audio-frequency* (AF) oscillator.

Tip

If you know the identity of a component (say, a PNP transistor) but nothing else about it, you can't tell what role it plays in a circuit until you see a schematic that shows all the components in the circuit and how they interconnect. Rarely can you get all this information in easy-to-read form by examining the physical hardware. You need a "road map" (schematic) to show you all the connections that the engineers and technicians made when they designed and built the circuit.

Imagine that you decide to drive your car from Baltimore, Maryland to Los Angeles, California. Even if you've made the trip several times in the past, you probably don't recall all the routes that you'll need to take and all the towns and cities that you'll pass along the way. (They might have changed, anyway, if you haven't made the trip for some time!) An up-to-date road map will give you an overall picture of the whole trip. Because all the trip data exists in a form that you can scan at a glance, the road map plays a critical role in allowing you to envision the entire trip rather than each and every piece, one at a time. A schematic does the same thing for a "trip" through an electronic circuit. And, like road maps, schematics can evolve over time as engineers make improvements to the original design.

Continuing with the road map and the coast-to-coast trip as an example, imagine that you've memorized the entire route from Baltimore to Los Angeles. Assume also that one of the prime highways along the way has gone under construction, forcing you to take an alternate route. Without a road map, you'll have no idea what other roads exist in that area, which alternate route to take, and which detour will keep you on course as much as possible and eventually return you to the original travel route with a minimum of delay and inconvenience.

An electronic circuit has many "highways" and "byways." Occasionally, some of these routes break down, making it necessary to seek out the problem and correct it. Even if you can visualize the circuit in your head, you'll find it impossible to keep in your "mind's eye" all the different electrical paths that exist, one or more of which could prove defective. When I write of visualizing the circuit, I don't mean the schematic equivalent of the circuit, but the circuit's actual components and interconnections, known as the *hard wiring*.

A schematic gives you an overall map of a circuit and shows you how the various routes and components interact. When you can see how the complete circuit depends on each individual route and component, you can diagnose and repair any problem that might arise. Without such a view, you'll have to "shoot in the dark" if you want to get a malfunctioning circuit working again. You might even introduce a new problem instead of resolving the original one!

Fear Not!

Look at the schematic of Fig. 1-5. If you've had little or no experience with these types of diagrams, you might wonder how you'll ever manage to interpret it and follow the flow of currents and signals through the circuit that it represents. Fear not! When you finish this book, assuming that you knew some basic electricity and electronics principles to begin with, you'll wonder how you could ever have let a diagram like this intimidate you. (By the way, you'll see this diagram again in Chapter 5.)

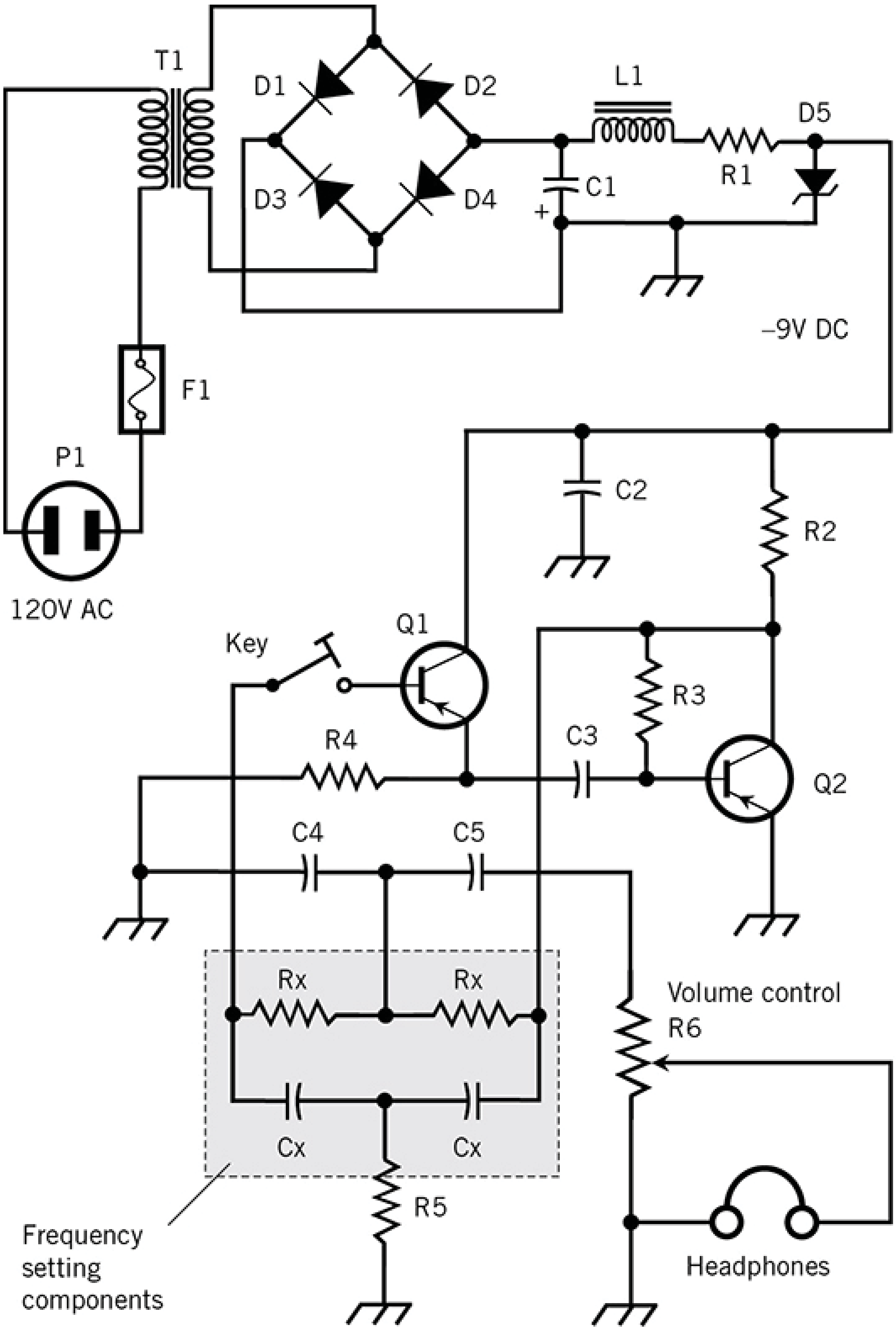

FIG. 1-5 *A rather complicated schematic. When you've finished this book, you'll think it's simple! (Don't worry about the component designators right*

now.)

A Visual Language

Every word in English or any other verbal language is a complex symbol made from simpler elements called *characters*. Let's take the word "stop," for example. Without a reference key, this sound means nothing. A newborn infant hears noise coming out of your mouth, that's all! But through learning the symbology, this word acquires meaning because the child, who has begun to speak and understand, can compare "stop" to other words, and also to actions. You can even say that the word "stop" is a sort of symbology within symbology. Your intent, when using the word "stop," can also be expressed by the phrase "Do not proceed further." This phrase also constitutes symbology, expressing a mental image of a desired action.

If people could communicate by mental telepathy, then no one would need language or the symbols that it comprises. Thinking happens faster than anyone can speak or read or write. Brain processes are the same from human to human, regardless of what language any particular person employs when speaking, reading, or writing. A newborn baby speaks and understands no language. But whether that baby was born in America, South Africa, China, India, or wherever, the same thought processes take place.

A baby knows when it's hungry, in pain, frightened, or happy. It needs no language to comprehend these states. But the baby does have to communicate right from the start. For this reason, all newborns communicate in the same language (crying and laughing, mostly). As babies comprehend more of their environment through improved sensory equipment (eyes, ears, nose, fingers), they collect more data. Then the various languages come into play, with different societies using different verbal symbols to express mental processes. The human brain nevertheless carries on the same nonlinguistic thought processes as before, because thinking in terms of symbols alone would take too much time and "brain storage."

The brain helps a human to transpose complex thoughts into language and vice-versa, just as a computer translates programming languages into electronic impulses and vice-versa. Imagine that a child is about to step in front of a speeding automobile. If your brain had to handle millions of data elements symbolically, you would spend a lot of time waiting for your brain to deliver the correct processed information, and that child would probably get killed before you could take any action. Rather, your brain scans all the data received by your sensory organs in quick time and then sums it up into a single symbol for communication. A good audible (and hopefully loud) symbol in the above-mentioned case is "Stop!" You, seeing a child about to walk into heavy traffic, might shout that word and produce in the child's brain the appropriate sequences of processes.

Not all languages involve spoken words. You've doubtless heard of sign language, whereby a person's arms and hands move to communicate ideas. If you've done any amateur ("ham") radio communication, especially if you got your "ham" license back in the time when I got mine (the 1960s), you know the Morse code as a set of communication symbols. In most instances, a language comprising only visual symbols or audio symbols is not as efficient for us humans as one composed of visual and audio symbols combined. Using the symbol "stop" again, you can utter this word in many different ways. The word in itself means something, but the way we say it (our "tone of voice") augments the meaning. You can't do all that with the printed or audible characters S, T, O, and P in plain text or in Morse code.

We humans have arrived at universal methods of modifying visual symbols. For example, we often use color in conjunction with the visual symbol for a spoken word. Think of a "stop" sign. It's red, right? People tend to associate red with the word "stop" or "danger." Or think of a "yield" sign. It's yellow, representing something that demands attention, but in a less forceful way than red does; you "proceed with caution." When a traffic light turns green, you can "go!" (But considering how some fools drive nowadays, you'd better use caution all the time if you want to live very long.)

Tip

Schematic diagrams rarely include color. Look in the back of a technical manual for an amateur radio receiver or transmitter. Does the schematic have color? I'll bet that it doesn't. (A few high-end magazines do, though.) The schematic in the back matter of a technical manual might not even have grayscale shading. Schematics resemble printed text or

Morse code in this respect; engineers must convey a lot of information with a limited set of symbols, and they're constrained even as to the way in which they can portray those symbols.

Schematics don't lend themselves to any form of oral (audible) symbology either. When you see the symbol for, say, a field-effect transistor (FET) in a schematic diagram, you don't hear the paper or computer say, "Field-effect transistor, for heaven's sake, not bipolar transistor!" You have to make sure that you read the symbol correctly. If you want to build the circuit and you mistakenly put a bipolar transistor where an FET should go, then you can't expect the final device or system to work. Something might burn out, so that when you recognize your error and bipolar transistor with an FET, you'll have to troubleshoot the whole circuit before you can use it. You might even have to start all over again and replace every single component!

Your senses along with your central processor (your brain) render you less than proficient at mentally conceiving all the workings of electronic circuits by dealing with them directly. You must accept data one small step at a time, compiling it in hardcopy form (through symbology) and providing a hardcopy readout. You can liken this method to "connect-the-dots" drawings in children's school workbooks. Individually, the dots mean nothing, but once they're arranged in logical form and connected by lines, you get an overall picture. The dots' relationships to each other and to the sequence in which they're connected tell you all you need to know.

The remaining chapters in this book start with the symbols for individual electronic components, then move on to simple circuits, and finally show you a few rather complicated circuits. Schematic symbols and diagrams are designed for humans, so human logic plays a prime role in determining which symbols mean which things. In that respect, the creation and reading of schematic diagrams resembles mathematics, and in particular, old-fashioned plane geometry!

Homogenize This!

Schematics comprise encoded representations of circuits, while pictorials show you the physical objects, often proportioned according to their relative size, and sometimes rendered to appear three-dimensional by means of shading and perspective. Schematics depict circuit components as symbols only, without regard to their real-world size or shape, and in two dimensions (on a flat piece of paper or computer screen), lacking depth or perspective. Nevertheless, in a few short decades, your computer will create a three-dimensional schematic or pictorial hologram within which you can walk around and see components to your left, to your right, in front of you, behind you, over your head, under your feet, and maybe (gulp) inside your body.

2

Block Diagrams

A block diagram portrays the general structure of a device or system. Such a diagram can provide a simplified rendition of a complicated system by separating its main parts and showing you how they interconnect and interact. In computer engineering, block diagrams can help you envision how programs or other processes work.

A Simple Example

Figure 2-1 shows a block diagram of a device that converts *alternating current* (AC), of the sort you find at the electric outlets in your house, to *direct current* (DC), of the sort you get from an electrochemical battery. Hobbyists and professionals call this type of device a *power supply*.

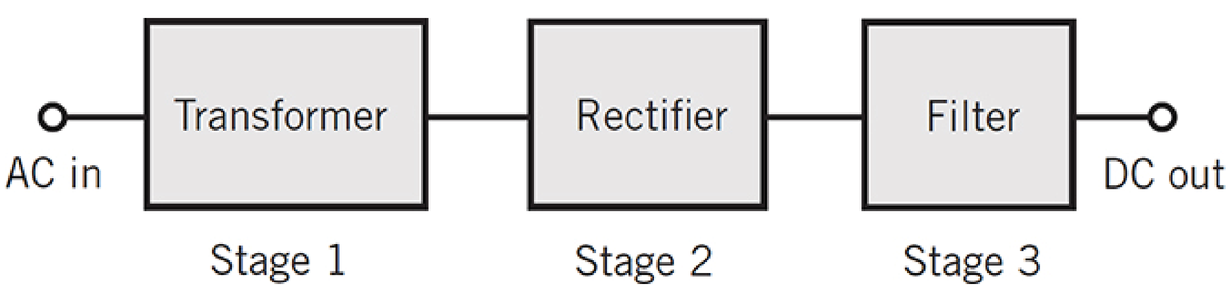

FIG. 2-1 *Block diagram of an AC-to-DC converter, also called a power supply. You'll naturally sense that the electricity flows from left to right, so the lines have no arrows.*

The terminal at the far left accepts the AC input. As you go from left to right, the electricity passes through the transformer, the rectifier, and the filter before arriving at the output as *pure DC*. In this case, the lines between blocks have no arrows; the diagram's creators assume that you can sense the process direction without them.

Tip

In some block diagrams, the interconnecting lines include arrows to clarify which block affects which, or to indicate the general direction of signal flow when you might not sense it by instinct.

Functional Drawings

Block diagrams can indicate the interconnections among small circuits in a larger device, or among diverse devices in a massive system. When you see a block diagram rendered in the style of Fig. 2-1, you can call it a *functional diagram* because it tells you something (but not a lot) about what the device does. If you want to know more detail, you'll need to see the schematic.

An engineer who wants to design a complex electronic system can start with a block diagram. It shows all the circuit sections (stages) in a functioning device, but none of the internal details of those stages. Then the engineer develops schematics of circuits that fill each block and serve the appropriate function. The first block gets replaced by the schematic of the circuit it represents. The engineer proceeds through the blocks in functional order, creating schematics that you can use to build each stage in the system. When every block has been replaced with a schematic, a detailed (but so far only theoretical) system design exists.

Another way of using block diagrams involves starting with the complete schematic of a system. Imagine that the schematic is quite complicated, and for some unknown reason the system doesn't work as the engineer thinks it should. Although a schematic can describe the functioning of an electronic system, it's not as clear as a functional block diagram for that purpose. The schematic literally has *too much* information! Lacking a block diagram, a repair technician would have to start with the schematic, laboriously identify each stage in the system, and then draw the entire system diagram in block form. When finished, the block diagram would reveal how each stage interacts with the others. Using this method, the technician could identify one or more stages as likely trouble zones, and refer back to the original schematic to conduct tests in those suspect circuits.

Tip

Even when presented without accompanying schematics, a block diagram can tell you the functional operation of an electronic system. The block diagram can come in handy when you don't need to know all the details about what every single component does, but only the general way that the system works.

You can describe the operation of a specific type of radio system, for example, an *amplitude-modulated* (AM) voice transmitter, by means of a block diagram. Of course, no two AM transmitters built by different manufacturers are identical, but all of them contain similar functional stages. One type of oscillator might work differently from another type, but all oscillators do the same thing: generate an RF signal! When you want to know or portray small differences among circuits that do essentially the same things, then you need schematics of them all.

Believe It or Not!

Although "plain old AM" is technically obsolete, some radio broadcast stations and *Citizens Band* (CB) radio transmitters still use it, and will probably keep on using it for decades to come!

The block diagram of Fig. 2-2 shows a strobe light system as you might see it in the assembly manual for a kit comprising self-contained circuits, a set of cables, and an instruction manual. You connect the cables (solid lines with arrows) among the self-contained circuits (blocks) provided with the kit, meticulously following the instructions in the manual.

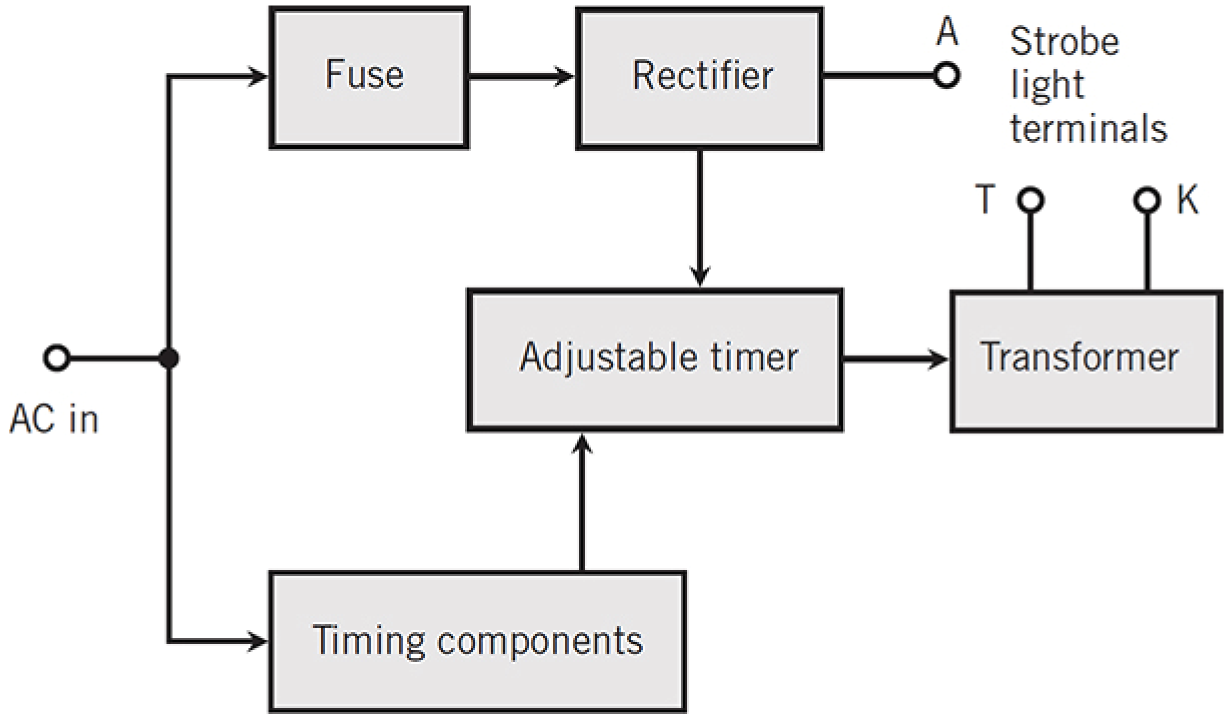

FIG. 2-2 *Block diagram of a circuit designed to provide power to a strobe light. Arrows show how the electricity flows.*

The input signal enters at the left; it's utility AC such as you get from a standard wall outlet. In the United States, this AC has a nominal voltage of 117 volts (117 V) and a frequency of 60 hertz (60 Hz), where "hertz" means "cycles per second." (In some countries the voltage is about 234 V, and in some countries you'll find a frequency of 50 Hz rather than 60 Hz.) The input AC goes to a fuse, and also to a combination of components that provide timing.

The top path, where you see the fuse, leads to a rectifier whose output passes to one terminal of a three-terminal strobe lamp. The rectifier output also connects to an adjustable timer that provides a variable flash rate for the lamp. The timer output goes to a transformer, which in turn connects to two more lamp terminals. You don't have to know what the designators "A," "T," and "K" mean; you need only know how to hook up the cables as you assemble the kit! Some people call this sort of "monkey see, monkey do" instructional drawing a *wiring diagram*.

Current and Signal Paths

Figure 2-3 is a block diagram of a power supply that produces several outputs having various electrical characteristics. As you proceed through the diagram from the left-hand end (the input) to the right and downward (the outputs) according to the arrows, you'll see that the system operates from 117 volts AC (117 VAC), commonly found at utility outlets in the United States. The entire power supply could reside in a single cabinet with a single cord and plug for a wall outlet and screw-on terminals for connection to multiple devices.

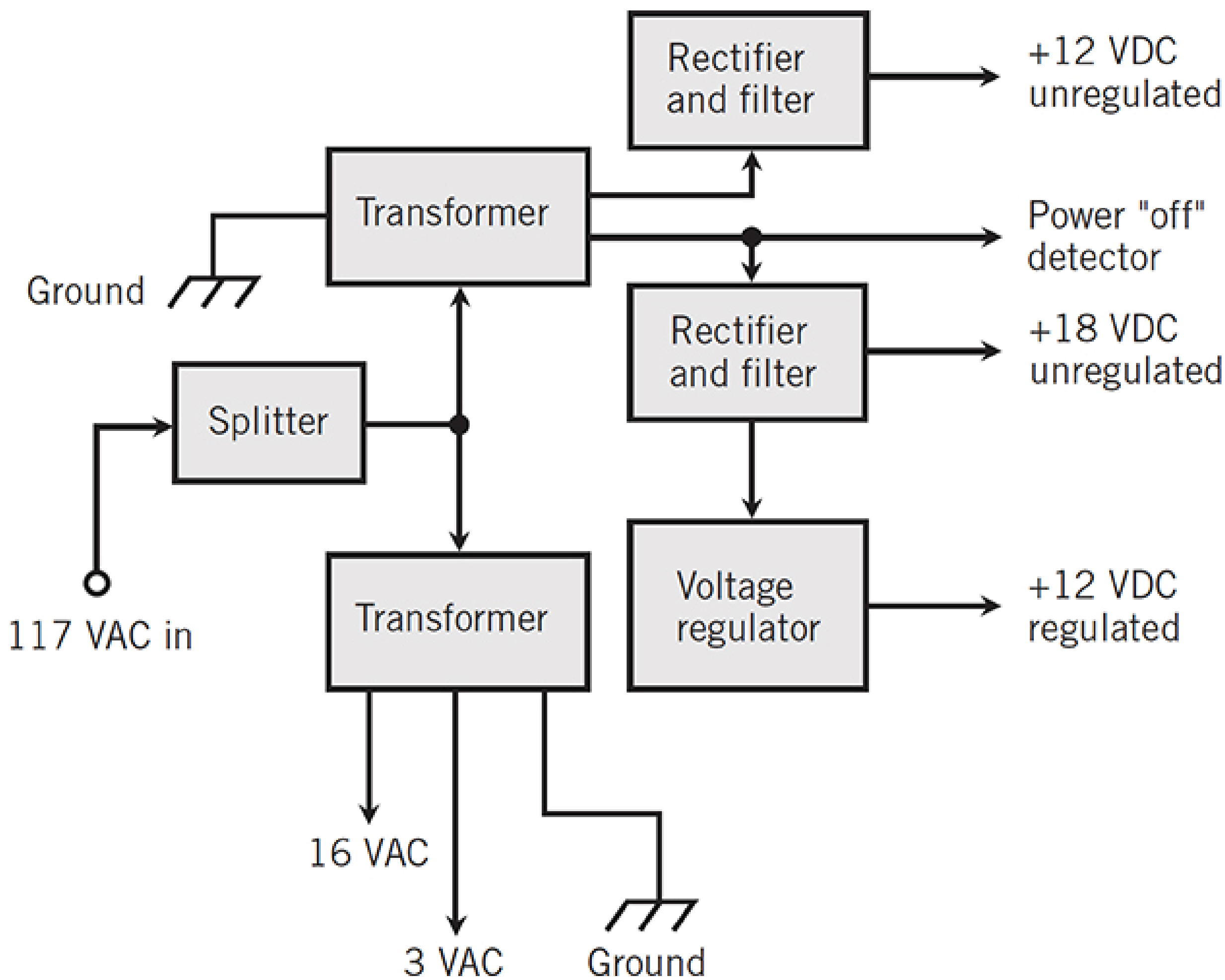

FIG. 2-3 *Block diagram of a power supply that produces several different outputs.*

The input AC gets split into two identical paths, both at 117 VAC. One splitter output goes to the "lower" transformer that provides 16 VAC and 3 VAC output. The other splitter output runs to the "upper" transformer, which goes to:

- A “top” rectifier/filter that provides +12 volts DC (+12 VDC) without voltage regulation
- A power “off” detector, such as an AC voltmeter or alarm
- A “bottom” rectifier/filter that provides +18 VDC without voltage regulation

In addition, the “bottom” rectifier/filter output connects to a voltage regulator that maintains it at a steady +12 VDC regardless of minor power surges and dips in your household voltage as it comes from the utility company.

Did You Know?

Most voltage regulators work by brute-force limiting. They take DC electricity at a certain voltage (say, +18 VDC) and hold it down so that it can’t exceed a certain lower voltage (say +12 VDC). This methodology can go only so far, however. If the utility electricity dips to 80 or 90 VAC, the regulator of Fig. 2-3 will probably manage to keep the output at +12 VDC. But a utility dip to only 40 VAC would likely cause the “regulated” voltage to fall from +12 VDC to something like +6 VDC.

Figure 2-4 is a block diagram of a simple AM radio transmitter. You speak into the microphone, which leads to an AF preamplifier to give your voice signal some power (but not much). A second AF amplifier gives your voice a lot of “punch”! The AF matching network ensures that the voice signal will deliver the most possible power to the modulator/amplifier, which receives its RF energy from an oscillator whose frequency is determined by a quartz crystal. The instantaneous RF modulator/amplifier output power fluctuates in accordance with the instantaneous AF input level to produce an AM signal, which passes through an RF tuning network to the antenna.

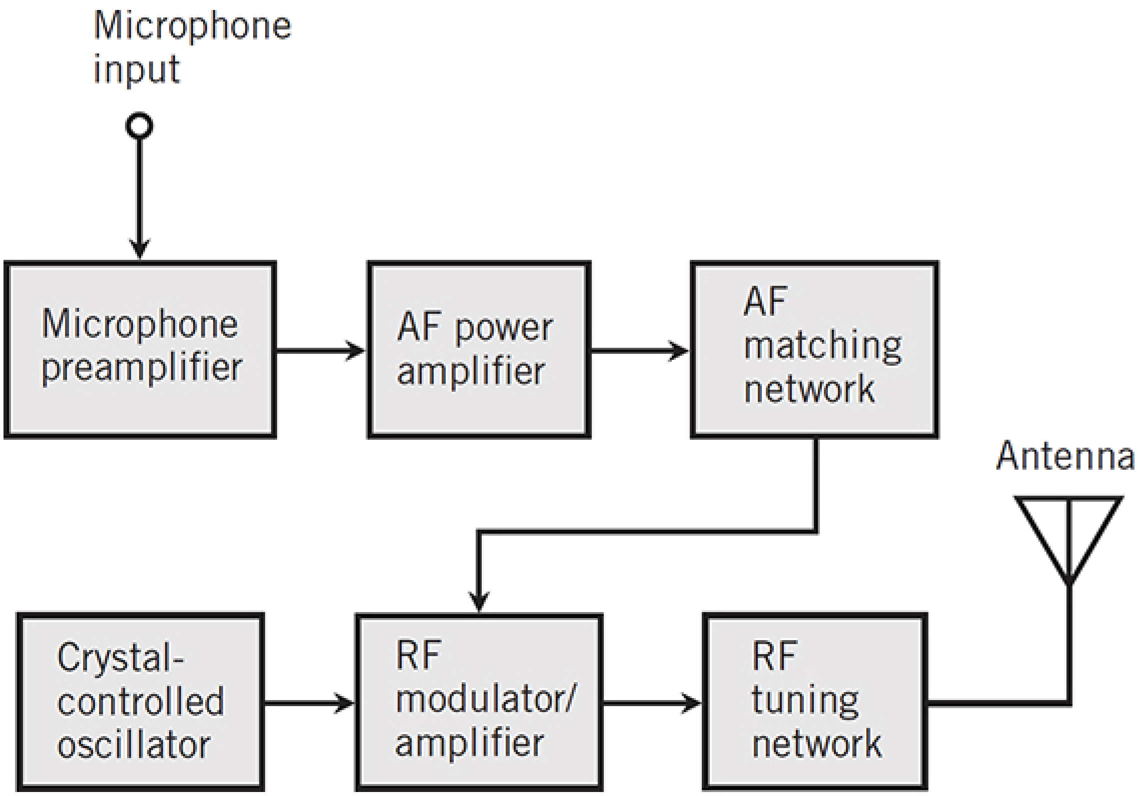

FIG. 2-4 *Block diagram of an AM radio transmitter.*

Aha!
Figure 2-4, with its arrows, tells you not only how the system components connect to each other, but also the sequence of events and the directions in which the AF and RF signals flow from the microphone and oscillator to the antenna.

Flowcharts

Block diagrams can describe how electronic systems work, but in the world of computers, another form of diagram, called a *flowchart*, can portray the functioning of a program or *software*. A flowchart resembles a block diagram, except that the symbology applies to the sections of a computer program, an intangible thing (as opposed to an electronic system, a tangible thing). A flowchart provides a graphic representation of the logical steps that a computer takes as it executes a program. Software engineers prepare flowcharts in conjunction with specifications, and modify the flowcharts as user requirements change.

For complex problems, a formal written specification can ensure that everyone involved understands and agrees on the nature of the problem, and on the desired results of the program. For example, suppose that a schoolteacher (that’s you!) uses a computer program to help determine a student’s final course grade by calculating an average from scores the student got for quizzes during the course period. You input each and every quiz score to the program. The program outputs the average of all those scores. Figure 2-5 shows a flowchart of the program process, as follows.

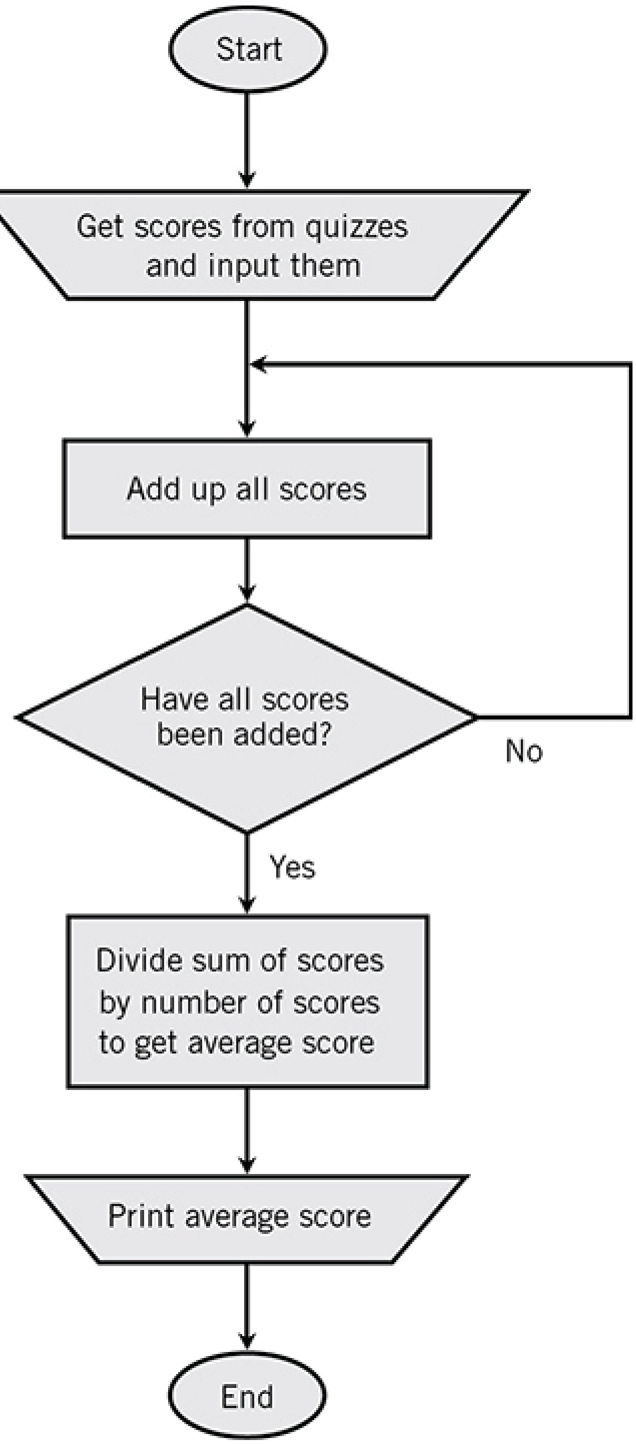

FIG. 2-5 *A flowchart that describes a computer program.*

- Receive the quiz scores from you.
- Add up all the quiz scores to get their sum.
- Verify that you have accounted for all the quiz scores.

- Divide the sum by the number of quizzes to get the average quiz score.
- Print the average quiz score.

The computer leaves the hardest task in the process to you, the teacher: Decide what grade the student deserves! If the quizzes were difficult, you might accept fairly low average scores for standard “letter grades” (such as A, B, C, D, or F); if the quizzes were easy, you might demand higher average scores for given grades.

The flowchart graphically presents the structure of the program, revealing the relationship among the steps and paths. When a program has many different paths that result from numerous decisions, a flowchart can help you sort things out. You can use the flowchart as a tool to understand the problem and to aid in program design.

Tip

Flowchart symbols contain narrative descriptions rather than programming language statements, because you want to describe what happens, not how it happens. Later, if you want to create flowcharts for documentation, they can contain statements in a programming language. These flowcharts might prove helpful to another person who at some future time wants to understand or modify the program.

You might need quite a lot of time to conceive and draw up a good formal flowchart. Modifying a flowchart to incorporate changes, once a program has been written and its flowchart composed, can prove difficult. Because of these limitations, some programmers shy away from flowcharts, but for others they provide valuable assistance in understanding a program. In order to promote uniformity in flowcharts, standard symbols have been adopted. Figure 2-6 shows the most common ones. In a sophisticated flowchart, you might find them all.

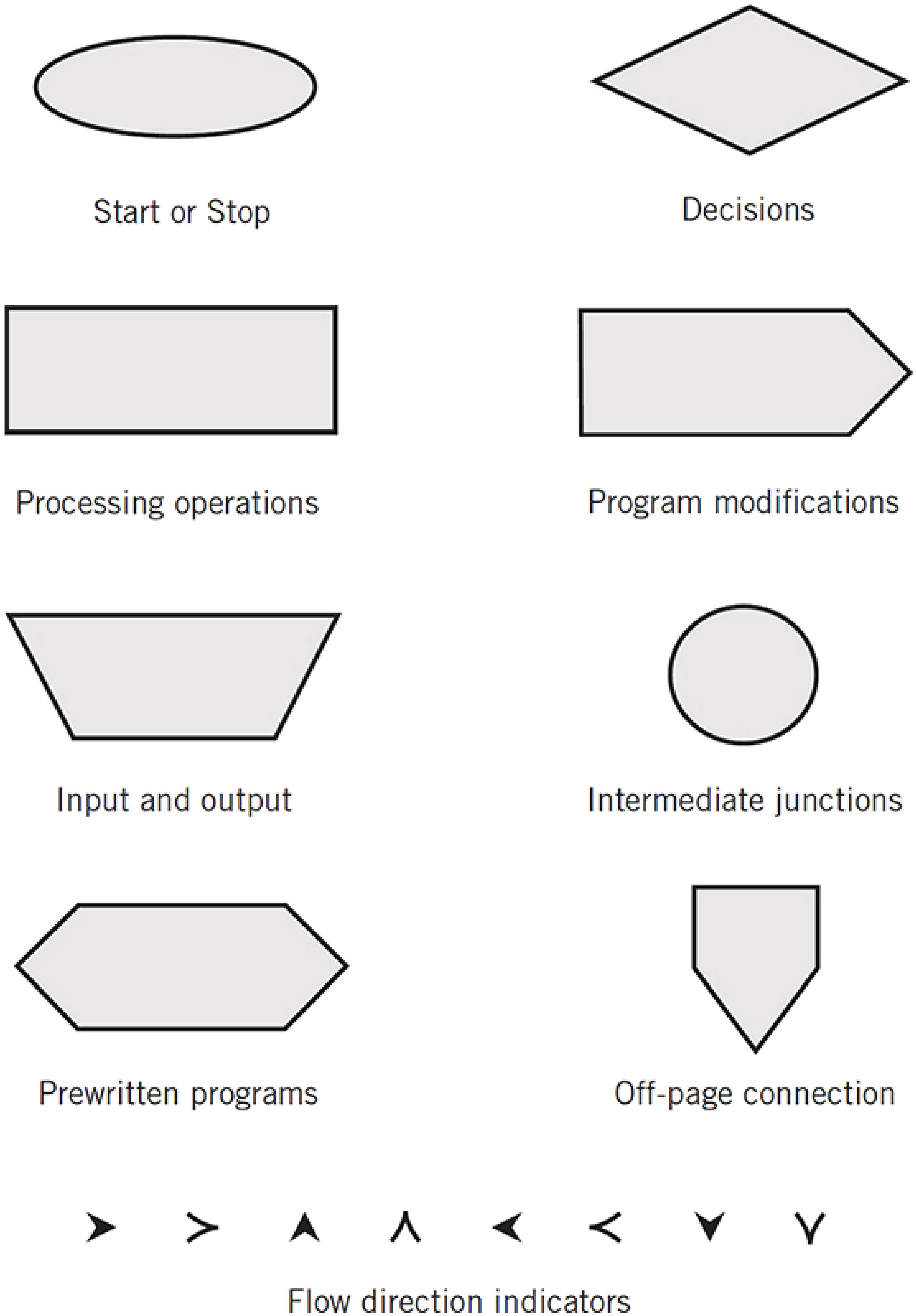

FIG. 2-6 *Common symbols for flowcharts intended to represent computer programs.*

Ovals show start or stop points. Arithmetic operations go in rectangular boxes. Input and output instructions go in trapezoids. If you want to show a program that someone wrote earlier within the context of a larger flowchart, you don't necessarily have to draw the flowchart for the entire "subprogram." Instead, you might represent the entire program as a flattened hexagon. If a box indicates a decision, you use a diamond shape. A five-sided box portrays a part of the program that changes itself. A small circle identifies a processing junction point. Such a point in the program can go to several places. A small five-sided box, which has the shape of the home plate on a baseball field, shows where one page of a flowchart connects to the next, if the entire flowchart has more than one page.

You should label all intermediate junction and off-page connection points with numbers and letters to tell your readers that all like symbols with the same character inside connect together. Arrows indicate the direction of the flow.

Down and to the Right

The normal direction of processes in a flowchart runs from top to bottom and from left to right, the same way as people read books in most of the world. Arrowheads on flow lines indicate direction. You can omit the arrows if (but only if) the direction of flow is obvious without them.

Figure 2-7 shows a flowchart for a program that duplicates punched cards, and at the same time prints the data on each card. Let's trace the flow. The program begins at the "Start" oval at the top and proceeds in the direction of the arrows. According to the text in the trapezoid below "Start," the program reads a card. Proceeding on down the chart, the program punches the card's contents (data) as holes in a blank piece of heavy paper and sends the data to a printer. The program then goes back along the dashed line to the top and reads the next card. The circles marked "A" represent inflow and outflow points. In this case they're superfluous, but in a complicated flowchart they can prove useful when you'd get a mess by including all the applicable dashed lines. The program repeats itself as long as it has cards to read and punch.

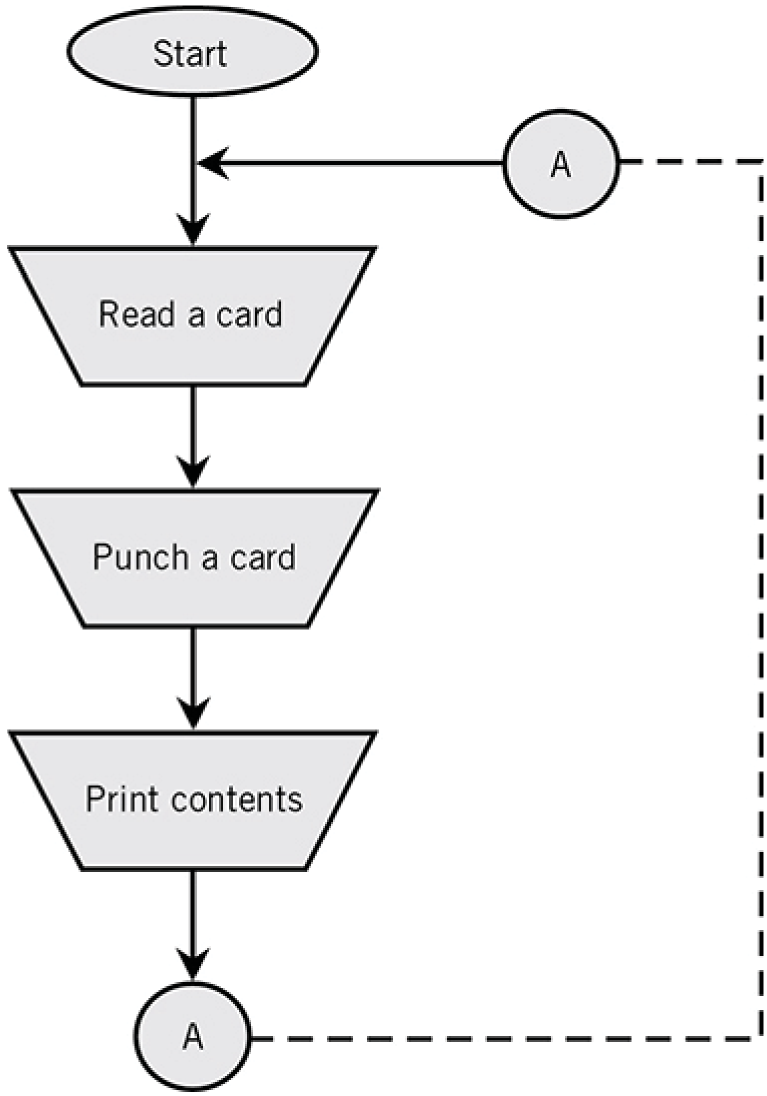

FIG. 2-7 *Flowchart that outlines the steps in a program intended to duplicate punched cards. The circles labeled "A" represent inflow and outflow points in the feedback loop shown by the dashed line.*

Old but Good

The foregoing program makes a good history lesson! Were you born long enough ago to remember punch cards for inputting programs to computers? I recall using them, all the way back in the 1970s, when I attended the University of Minnesota. That little factoid dates me, doesn't it?

Process Paths

Let's look some more at Fig. 2-7. Suppose that you want to change the card-punching program so that the computer ignores blank (hole-free) cards and duplicates only those cards that have at least one hole. Because the computer must make a decision about each card, you'll need to include a decision block in the flowchart. Figure 2-8 shows the result.

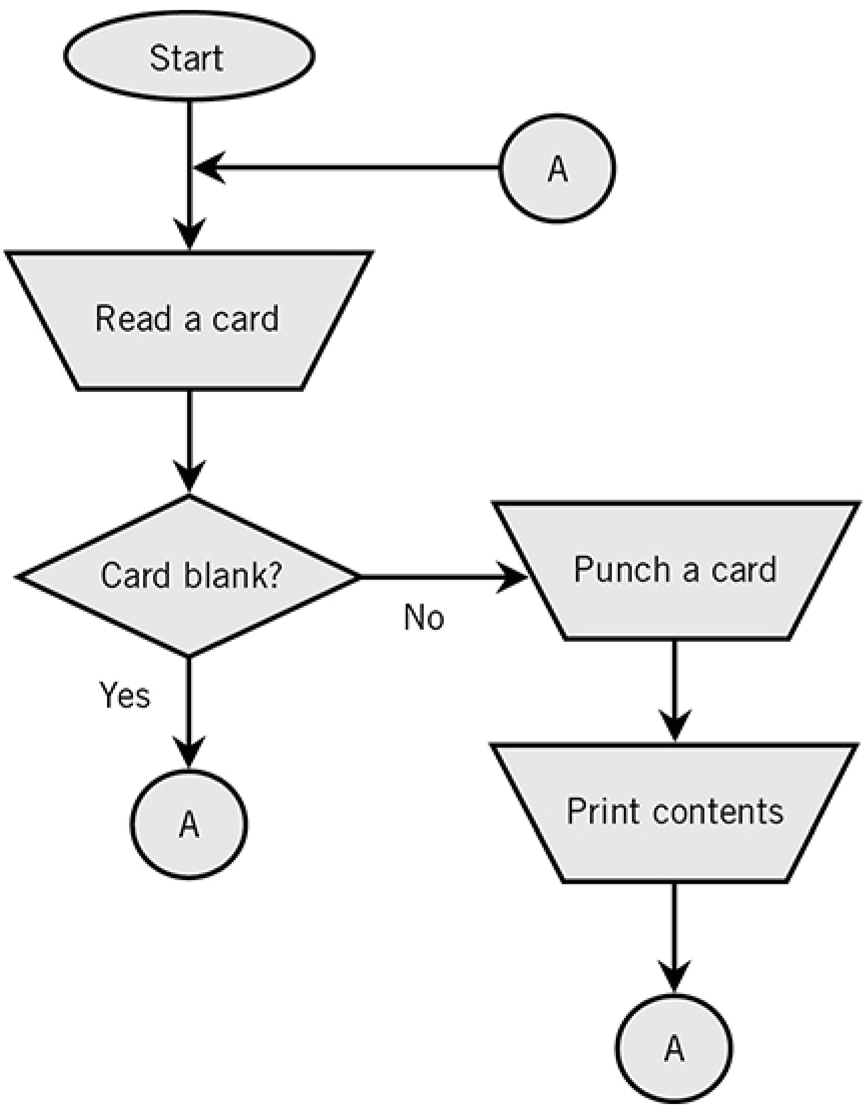

FIG. 2-8 *A flowchart with a decision block (diamond). The circles labeled "A" all represent a single junction point through which data moves as shown by the arrows.*

Follow the Flow

Except for the decision block, Fig. 2-8 shows the same process as Fig. 2-7 does. The program begins in the "Start" oval at the top and then goes to the block marked "Read a card." From there, the program moves on to the decision block labeled "Card blank?" If the answer is "Yes" (the card has no holes), the program proceeds to the connection circle marked "A" and back to the top to read the next card. If the answer is "No" (the card has at least one hole), the program instructs the hardware (the physical components of the computer and its peripherals) to punch a duplicate card and print its contents. Then the program goes to another circle marked "A" and back to the starting point.

Tip

Figure 2-8 is a simple flowchart, showing a process that uses only input and output devices and performs no calculations. Most programs and flowcharts involve more complicated processes.

Microcomputers use many different types of diagrams that deal mostly with software (operating systems and programs) rather than hardware (physical components). In the computer world, functional block diagrams abound and are usually more numerous than schematic diagrams. From an understanding standpoint, block diagrams can serve to portray machine functions in general, but hardware maintenance and repair procedures require well-defined schematic drawings. Computers take advantage of the latest state-of-the-art developments in electronic components and are relatively simple when you consider all the things they can do. However, from a pure electronics standpoint and as far as schematic diagrams are concerned, computers are immensely complicated. You'd need a lot of pages full of schematics to represent even the most rudimentary computer.

Summary

Block diagrams can help you show and understand how electronic circuits work. They're comparatively easy to draw, usually requiring only a marking instrument, some paper, and a straight edge (or a vector-graphics computer program and a little bit of training on it). Schematic diagrams, in contrast, need more tools and can, in some cases, take many hours to render in a form that people can read and interpret.

3

Components and Devices

On a road map, symbols indicate geographical features such as cities, highways, airports, railroad tracks, and other landmarks. The same rule applies to schematics in electricity and electronics. Specialized symbols portray conductors, switches, resistors, capacitors, inductors, transistors, and other circuit elements. Whenever engineers invent a component or device, they create a new schematic symbol for it.

Tip

In this chapter, you'll see common schematic symbols for some (but by no means all) of the components that you'll find in electrical and electronic systems. In the back of this book, Appendix A provides a more comprehensive listing.

Resistors

Resistors rank among the simplest electronic components. As the term implies, they resist or impair the flow of electric current. Engineers express *resistance* (the extent of current impairment) in units called *ohms*. Most real-world resistors have values ranging from approximately 1 ohm up to millions of ohms. Once in a while, you'll encounter resistors with values less than 1 ohm, or values in the thousand-millions (billions) or million-millions (trillions) of ohms.

Regardless of their ohmic value, nearly all *fixed resistors* have schematic symbols that look like Fig. 3-1A or B. The two horizontal lines at the left and right (A) or the top and bottom (B) depict wires called *leads* that protrude from the ends of the physical component. Some resistors have rigid metal terminals such as pins or lugs that don't necessarily come out of the ends.

Figure 3-2 shows a "transparent" pictorial of a *carbon-composition* fixed resistor with wire leads on both ends. Figure 3-3 shows pictorials of two other types of resistors: *wirewound* (A) and *film* (B). You can denote any resistor of the sort shown in Fig. 3-2 or Fig. 3-3 with either of the symbols in Fig. 3-1.

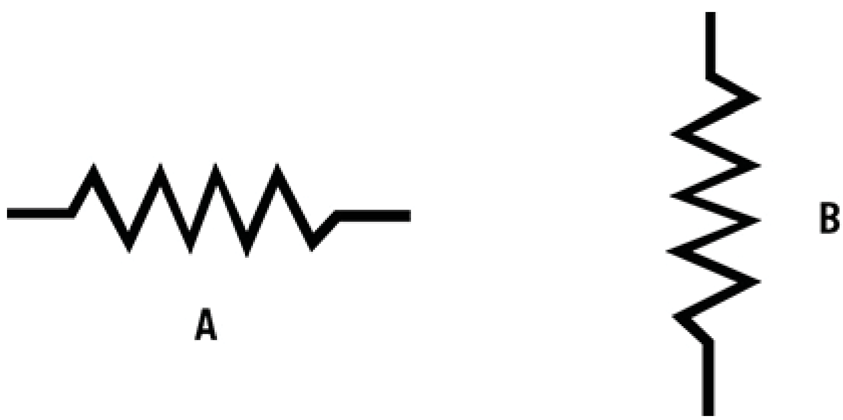

FIG. 3-1 *Symbol for a fixed-value resistor. In a schematic, it can appear horizontal (A) or vertical (B).*

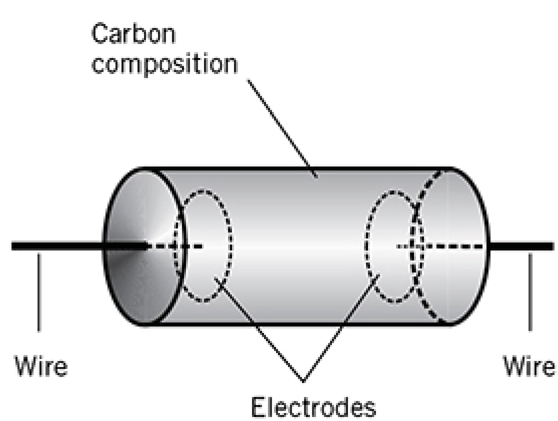

FIG. 3-2 *"Transparent" pictorial of a carbon-composition resistor.*

Tip

You can rotate almost any schematic symbol by 90 degrees, as in Fig. 3-1, to make it fit in a diagram. You can even turn it upside down or backwards if necessary! If your viewers know what a symbol means, its orientation doesn't matter.

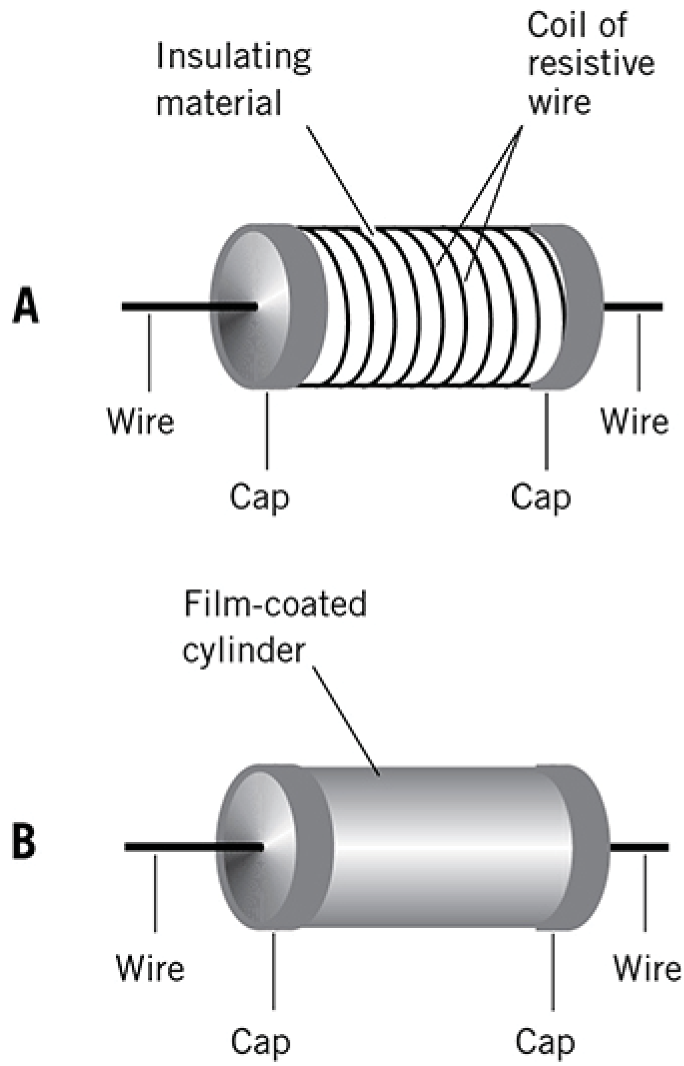

FIG. 3-3 *Pictorials showing the anatomy of a wirewound resistor (A) and a film type resistor (B).*

A *variable resistor* has an ohmic value that you can adjust by moving a slide or tap along the resistive element. You set the resistance to a specific value, where it remains until you deliberately change it. The circuit "sees" the component as a fixed resistor at any given time.

When a circuit contains a variable resistor, the schematic reveals that fact. Figure 3-4 shows a common symbol for a variable resistor with two terminals. Some variable resistors have three terminals. Figure 3-5 shows two examples of schematic symbols for a three-terminal variable resistor known as a *potentiometer* or *rheostat*, depending on the method of construction.

FIG. 3-4 *Symbol for a two-terminal variable resistor.*

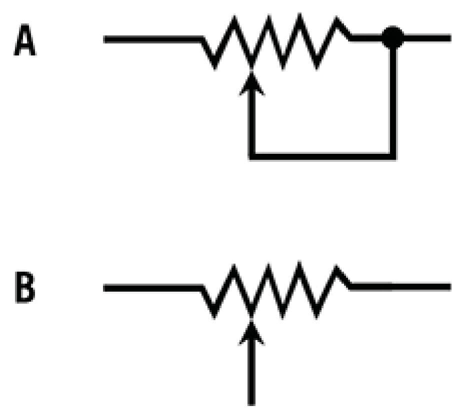

FIG. 3-5 *Symbols for three-terminal variable resistors, also known as potentiometers or rheostats (depending on the method of manufacture). At A, the center terminal connects to one end terminal to obtain, in effect, a two-terminal component. The resistor at B has three independent terminals.*

Did You Know?

A rheostat contains a wirewound resistance element, while a potentiometer is normally of the carbon-composition or carbon-film type. You can vary a rheostat's value in small increments or steps, but you can adjust a potentiometer's value over a continuous range.

Rheostats contain inductance along with resistance, while potentiometers have pure resistance with essentially no inductance.

Tip

In a schematic symbol, an arrow sometimes indicates that a component has variable or adjustable value. But not always! The symbols for transistors, diodes, and some other solid-state devices contain arrows that have nothing to do with variable or adjustable properties.

Figure 3-6 shows a variable resistor of the wirewound type, manufactured to expose an uninsulated coil of resistance wire. You can adjust a sliding metallic collar, which goes around the body of the resistor, to intercept different points along the coil. A flexible conductor connects the collar to one of the two end leads. The collar shorts out more or less of the coil turns, depending on where it rests along the length of the coil. As you move the collar to the right along the wire coil, the ohmic value between the two end leads decreases.

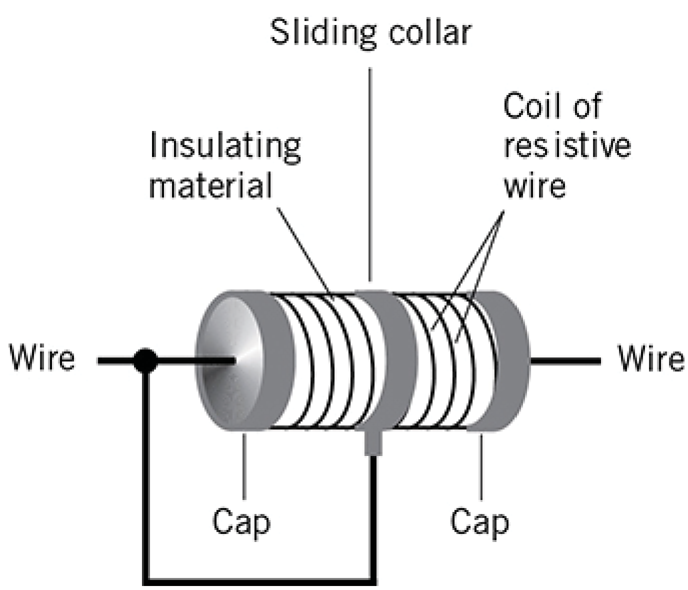

FIG. 3-6 *Pictorial of a wirewound variable resistor with the movable middle sleeve connected to one of the fixed end leads.*