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UNDERSTANDING SCHEMATIC DIAGRAMS

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Preface

It is unfortunate that the average beginner or service technician considers the schematic somewhat complicated. In truth, the schematic is a short cut to learning the essential details about a circuit. As shown in the book, the schematic is, in fact, the easiest method of conveying information about the circuit. Thus, the understanding of the schematic is an ideal beginning in the study of electronics.

Learning how to read a schematic is not too difficult, because the schematic can be broken down into easily understandable symbols. The schematic has aptly been described as "the roadmap of electronics," and just as a roadmap is easy to read, once the symbols are understood, so can the mysteries of the schematic be divulged.

This book approaches the subject from the beginning. You will learn about the various components—resistors, capacitors, coils, etc.—that make up the circuit, and the symbols for these components. Then you will learn how these components are joined together, just as the towns and cities on a roadmap are linked by highways. Finally, with this background you are able to read a complete schematic.

No knowledge of electronics is required to understand this book. It includes the necessary elementary electronics for the beginner's benefit. The book will also be useful as a brush-up for the service technician who may not be familiar with all the latest symbols.

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Contents

CHAPTER 1

GETTING STARTED

The understanding of schematic diagrams is probably the most important single item for anyone connected with the science of electronics. Nobody who has even the slightest interest in the subject can escape the schematic diagram. From the casual hobbyist to the advanced engineer—if it is electronics, there is a schematic diagram somewhere. Since schematic diagrams are so important to electronics, it follows then that obtaining a sound understanding of schematics* is the only logical place to start.

WHY SCHEMATICS?

Why is the schematic such an important item in electronics? To the novice, the schematic may seem to be only a way to confuse the subject. After all, the symbols used to represent the components do seem unfamiliar at first. Couldn't the schematic just be dispensed with and thereby eliminate a lot of confusion? The answer is no! Through the years, experience has proven that nothing can show as much information in such a small space as the schematic. In fact, the schematic is universally understood. Even if you cannot understand a word of the language a manual is printed in, the symbols will be so close to those given in this book that you will be able to understand the schematic.

A schematic shows all of the electrical connections and circuit components in a piece of electronic equipment. It also tells you the electrical value or the type used for each component in the unit. Just to list the components and to explain the connections in words would take many pages. In fact, for a typical television receiver the explanation would probably fill more pages than this book contains. A schematic of a television receiver will fit on two pages, as shown in Fig. 1-1. If a draw-

***The word schematic is an adjective; however, it is commonly used in both the singular and plural form as a noun.**

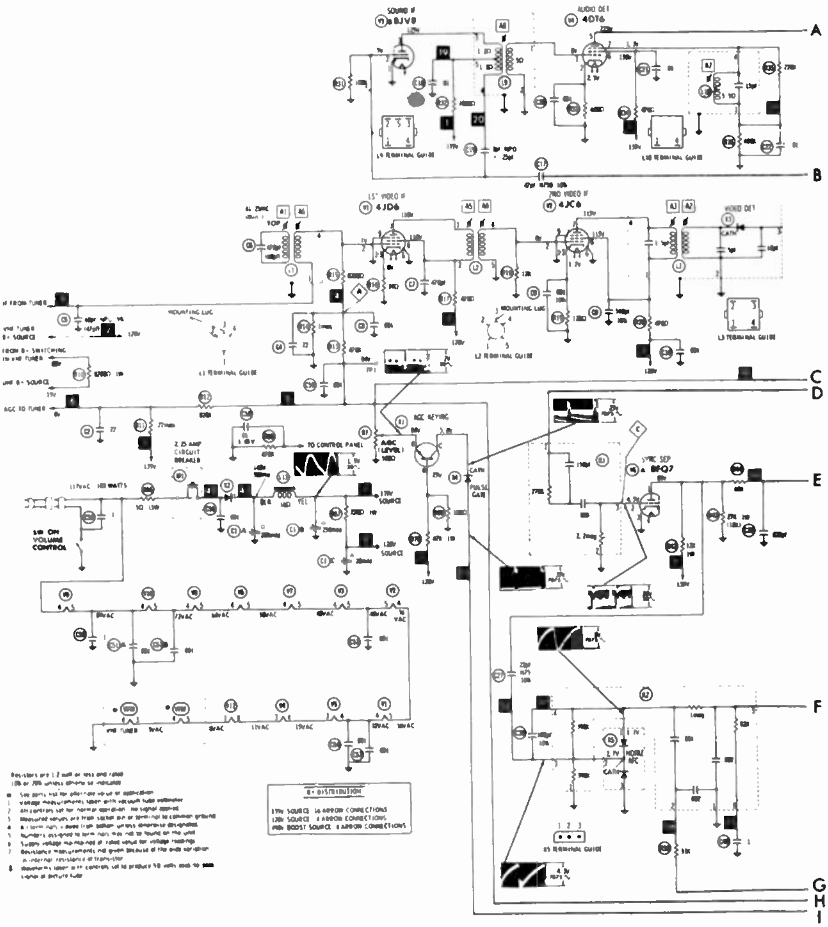
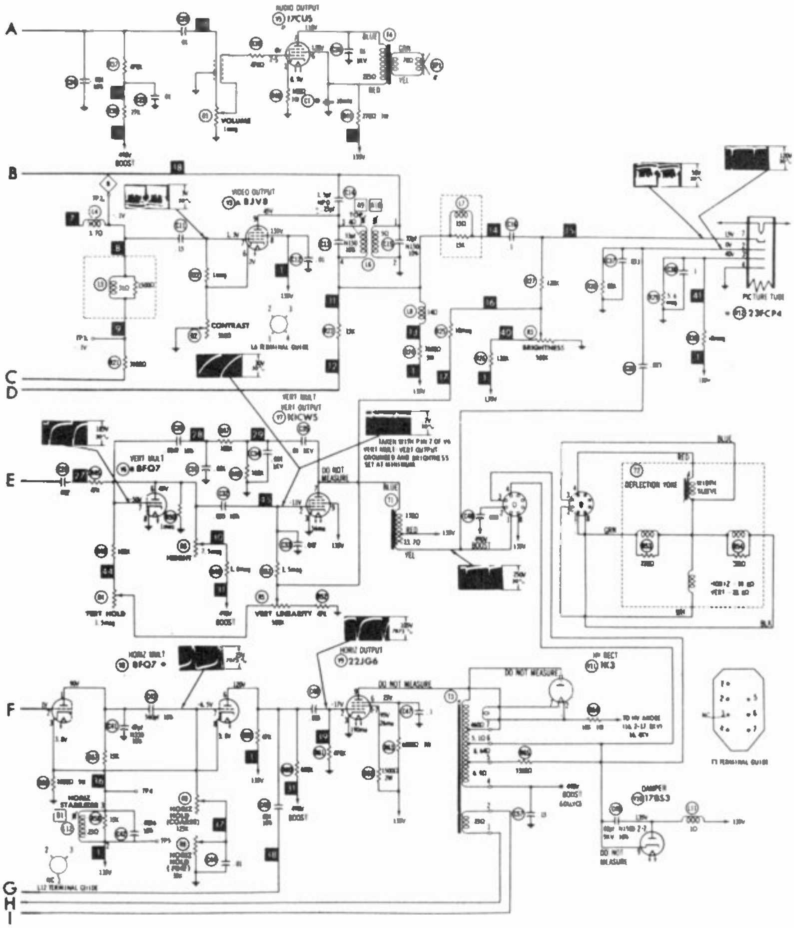


Fig. 1-1. Schematic of a

ing were made showing the actual components, it would take far longer to prepare, require more space, and still not be as useful.

The schematic in Fig. 1-1 contains much more information than just the components, values, and their connections. It is often all the television service technician needs to locate a trouble in the receiver. To the uninitiated, the schematic in Fig. 1-1 seems quite confusing, but to anyone experienced in electronics it is as easy to "read" as a newspaper. By the time you have finished this book, you, too, will be able to read this diagram and understand much of the information it conveys.



typical television receiver.

Of course, understanding it thoroughly requires a knowledge of the theory and operation of television. This is beyond the scope of this book, but after it has been read and understood, you will have the sound basis needed for further study.

The symbols used to represent the various components have been carefully selected. There is a relationship between the function or construction of the various components and the symbols chosen. These relationships will be explained. Once this correlation between components and symbols becomes apparent, you will have attained not only considerable knowledge of electronics, but also an understanding of schematics.

SYMBOL DIFFERENCES

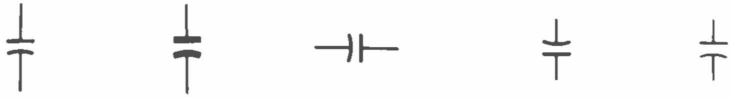
It would be convenient if everyone used identical symbols on his schematics. Unfortunately, this is not the case. In recent years, there has been much progress in the standardization of symbols. The American Standards Association (ASA) and the military services have published standards for symbols. Fortunately they are identical. Other organizations have also adopted standards. Recently, the Electronic Industries Association, a voluntary association of electronics manufacturers, surveyed the member companies and published a list of suggested symbols based on a composite of those used by the various member companies. Since this is a voluntary organization, members are not compelled to comply with the published symbols. In most cases a choice of symbols was given in this report.

Actually there is nothing to prevent any company—or person for that matter—from adopting any symbol he chooses to represent a given component. However, the desire to make schematics as understandable as possible has led to a general agreement on standard symbols. There are a few differences in ones chosen by various companies for components, but the areas of agreement far outnumber the areas of disagreement.

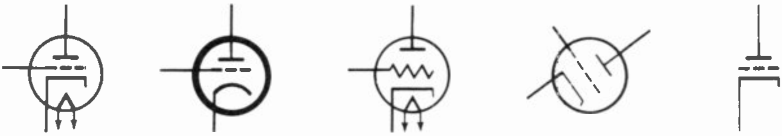
Symbols are much like traffic signs. As we travel across the country, we will notice that most of the traffic signs look about the same, although there are differences. Sometimes these differences are only minor. For example, one sign may use bolder letters, a different style of letter, or a different color from the one to which we are accustomed. It is the same with schematic symbols. Most of the differences involve heavier or lighter lines, a slightly different shape, or similar minor items, as shown in Fig. 1-2.

In general, the weight of a line makes no difference. Arrowheads are often used in schematic symbols; usually they can be solid or open without changing the meaning. The symbol can be laid on its side, upside down, or in any other position without changing its meaning. In fact, it can even be the mirror image of the symbol—that is, exactly opposite, as shown by the first two symbols in Fig. 1-2C—and not change the meaning. (In each part of Fig. 1-2, the symbols represent the same item.)

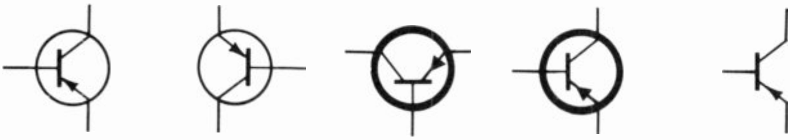
Most of the differences in schematics stem from the means used to prepare the drawing. Originally they were drawn with pencil or pen and ink, and the information was hand lettered on the schematic. This system is very time consuming. Many differences would creep into schematics prepared in this way,



(A) Capacitor symbols.



(B) Tube symbols.



(C) Transistor symbols.

Fig. 1-2. Symbol differences.

since each draftsman might show a symbol in a slightly different manner.

In an effort to speed up the drafting process and at the same time to "standardize" the symbols, most companies went to a system in which all the symbols were preprinted. Usually the symbol is printed on a clear acetate sheet which is cut out and placed on the sheet of paper on which the schematic is "drawn." Symbols of this nature are available for all types of components and special ones can be made up by using combinations of other symbols. The acetate may have a wax backing for affixing it to the paper. In another method, rubbing the acetate sheet removes the printing from the back of the sheet. The sheet is placed in the correct spot, and then the printing is transferred to the paper on which the drawing is desired.

The latest development in the art of schematic drafting is pictured in Fig. 1-3. This unit, called the *Diagrammer*, is manufactured by the same company which makes the *Linotype* machines for typesetting. In much the same way as the typesetter punched the keys on a keyboard to produce the type for this book, the operator of the unit in Fig. 1-3 can "type" a schematic on this electromechanical-optical system. The symbol is selected on the keyboard at the left, which contains 256 keys, and positioned on the screen in the center by using the keys

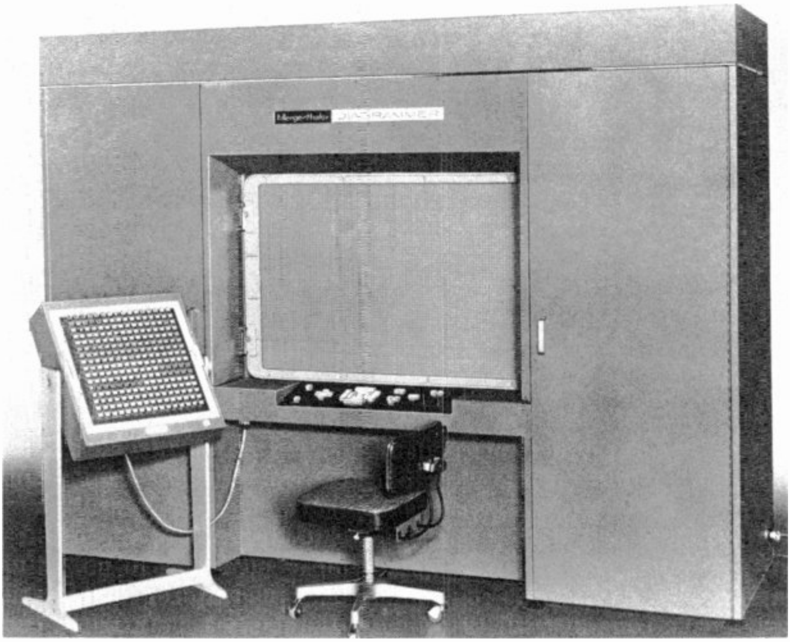


Fig. 1-3. A machine for "typesetting" schematics.

below the screen. When properly positioned the symbol is exposed on photographic film. This process is repeated until an entire schematic, including all symbols, words, values, lines, etc., is produced. The individual keys or the entire keyboard can be changed as desired. The individual symbols used for the exposure are stored on glass slides in a magazine within the machine.

OTHER TYPES OF DIAGRAMS

The schematic is not the only type of diagram used in electronics. As stated before, it *is* the most useful because it conveys more information than any other type of diagram, but even the schematic does have limitations. There are things that cannot be shown by a schematic, or that can be shown much more efficiently by other diagrams. In this section, some of the other types of diagrams will be examined and their advantages and disadvantages discussed.

Block Diagram

The block diagram (Fig. 1-4) is about the simplest of all diagrams used in electronics. It gives only limited information,

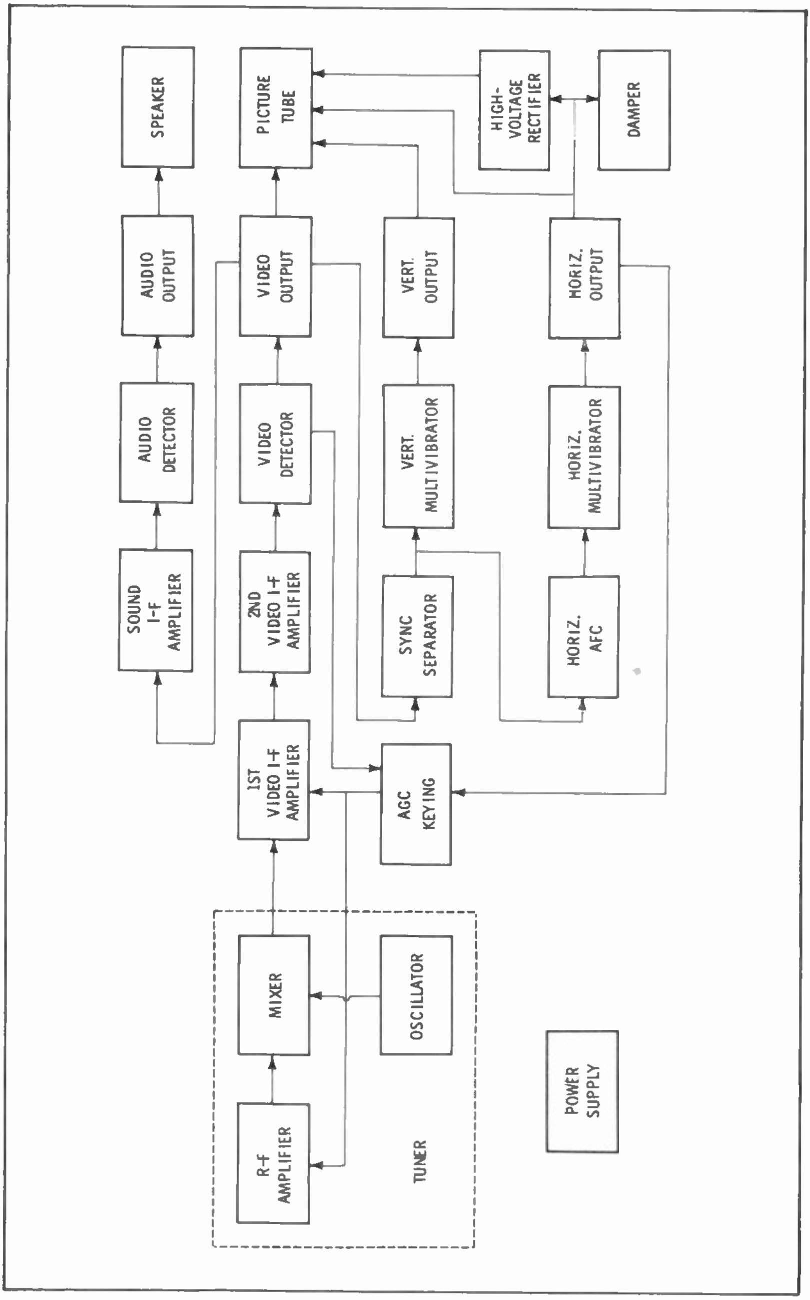


Fig. 1-4. Block diagram of the TV receiver in Fig. 1-1.

but in some applications it serves a valuable purpose. As shown in Fig. 1-4, the block diagram consists of a series of "boxes" connected by lines with arrows. (This is a block diagram of the television set in Fig. 1-1.) If all that is needed is a brief look at the overall operation of a unit, the block diagram is the best means of showing the desired information. Usually a separate "box" is used to show each tube or transistor and its associated components (called a stage). The box is labeled by the function performed by this stage. The lines and arrows show how the various stages fit together to provide the desired results. Some boxes may not be a tube or transistor, but some other component or group of components which performs a specific function in the overall operation.

After you are familiar with schematics, you will be able to look at one and mentally break it down with a block diagram. In fact, this is the only way that a schematic can actually be understood. However, if a knowledge of the individual component is not important and all that is needed is a general idea of what is happening in the unit, the block diagram will suffice. It is particularly useful for complicated pieces of equipment. For example, an entire broadcasting station might be shown in a block diagram, with each block representing a unit of equipment such as a tape player, turntable, or amplifier—each of which might contain many stages.

Chassis Layouts

The schematic cannot show the placement of parts. Usually you can assume that a part associated with a given tube or other large component will be physically located close to the larger, easier-to-find component, but this assumption is not always true.

Sometimes it is even difficult to locate a given tube or other component. If several tubes of the same type are used, it is difficult to determine which one performs which function. The chassis-layout diagram of Fig. 1-5 is useful in this case. It shows the location of each tube and some of the other components on the top of the chassis for the television set of Figs. 1-1 and 1-4. By looking at this diagram you can easily locate each tube associated with the blocks in the diagram of Fig. 1-4. Sometimes a photograph with the various items labeled will be used in place of the drawing of Fig. 1-5.

Underneath the chassis (Fig. 1-6), the problem of locating the components is even greater. Two systems are used to aid in locating a given component. In the first, each component in the photograph of Fig. 1-6 is identified and pointed out with an arrow, as shown in Fig. 1-7. This is the method most commonly used in service literature.

In the photographs of Figs. 1-6 and 1-7, most of the components are apparent, but it is impossible to tell just how they are connected. Of course, in service literature the actual physical points of connection are not needed—they can be seen by

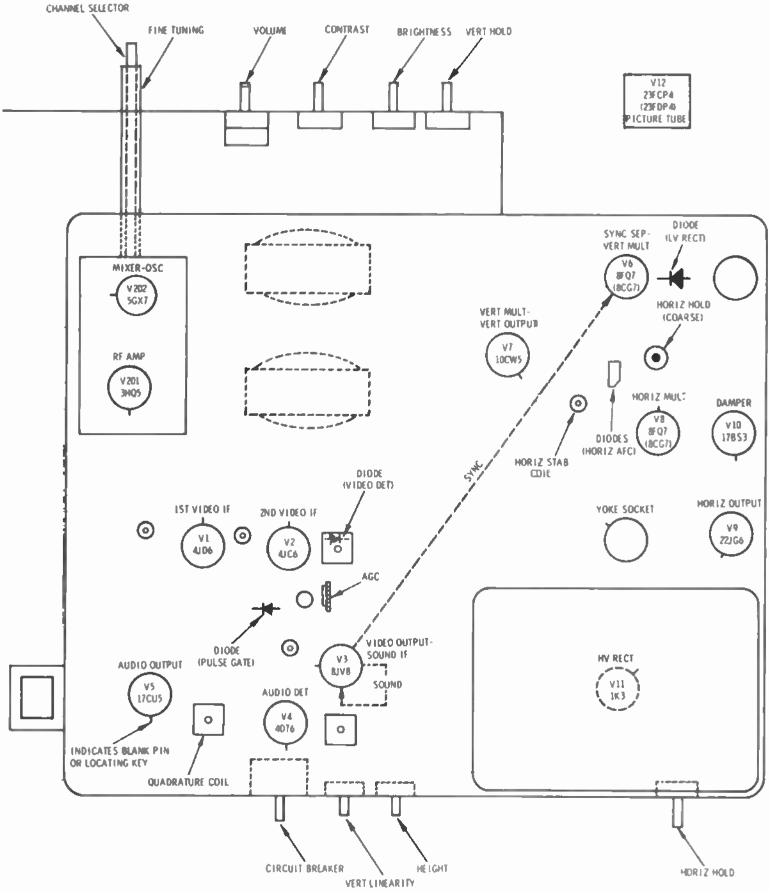


Fig. 1-5. Chassis-layout diagram of the TV receiver in Fig. 1-1.

looking at the unit. The schematic provides the information on how they are connected in the circuit, and it is far more useful than the photograph for tracing the actual circuit. The purpose of the photograph in Fig. 1-7 is to aid in locating a specific point where measurements can be made in checking the equipment or to locate a component that is suspected of being bad.

Fig. 1-7 is adequate—and, in fact, the most desirable way—for these purposes.

In the construction of kits, it is essential that not only the location of the components, but the connections as well, be shown. The *pictorial diagram* shown in Fig. 1-8 is commonly used in the construction manuals for kits. Here, each component is identified, its location shown, and the points where it is connected given. It may be necessary to "move" a few components slightly to prevent one from being on top of the other in Fig. 1-8, but this does not affect its usefulness.

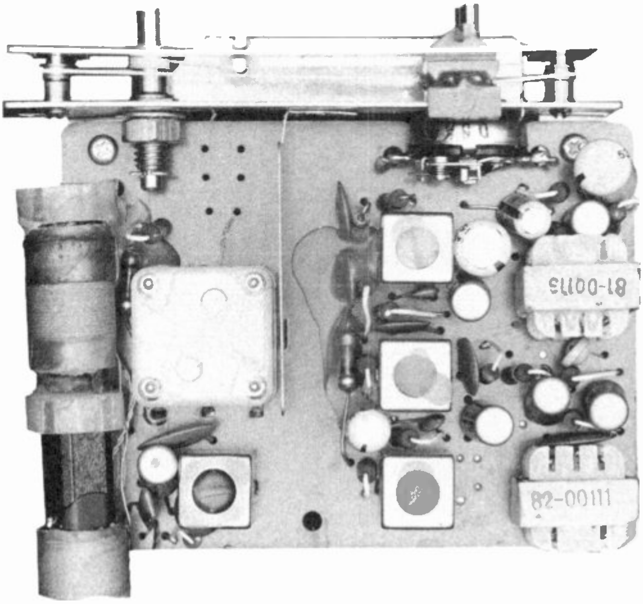


Fig. 1-6. A radio chassis.

Mechanical Diagrams

There is one item that cannot be shown by a schematic or a chassis diagram. Often, some form of mechanical action takes place in a piece of electronic equipment. For instance, a record changer or antenna rotator is entirely mechanical. Likewise, the system of pulleys and the drive cord used to pull the pointer across a radio dial is mechanical. These actions are shown by drawings of the units. Fig. 1-9 is a drawing showing a typical dial-cord stringing. This one is fairly simple and could probably be determined without the aid of the draw-

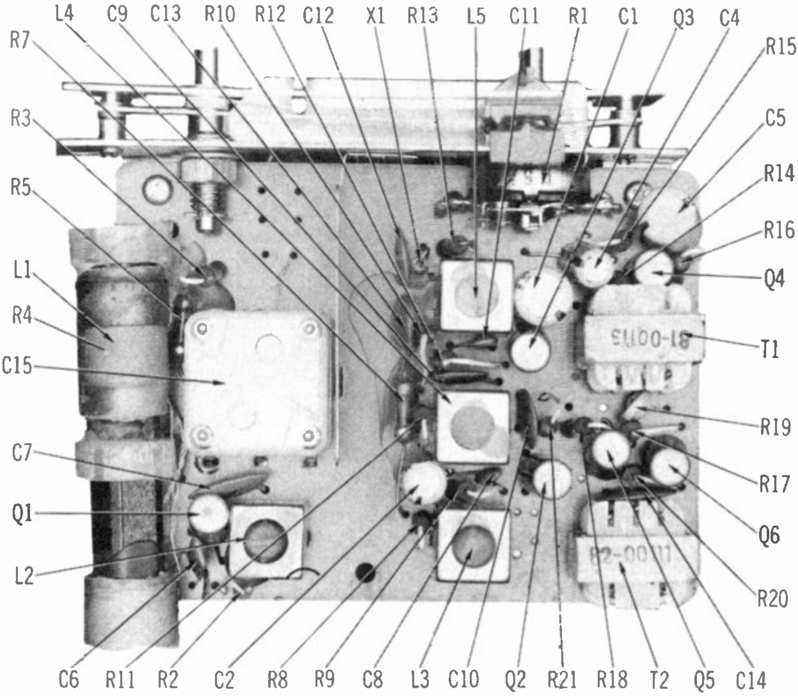


Fig. 1-7. The radio chassis in Fig. 1-6 with the components identified.

ing, but others are quite complicated and have more than one cord. Without a drawing, it might take hours to determine how the cord should be strung, and even then you would not be sure that you had it right.

The mechanical parts of a record player or tape recorder are usually drawn as shown in Fig. 1-10. Each part is shown separated but still in the same general relationship with the other parts it is associated with. This type of drawing is often called an *exploded view* because each item is "exploded" from its normal position so that you can see it more clearly, but still it is in the same relationship so its operation can be determined. The numbers are used for identification. By referring to the parts list, you can find the part number and the name of each component, should you need a replacement part.

FUNDAMENTALS

Before studying the individual components and the symbols used to represent them on schematics, it is first necessary to

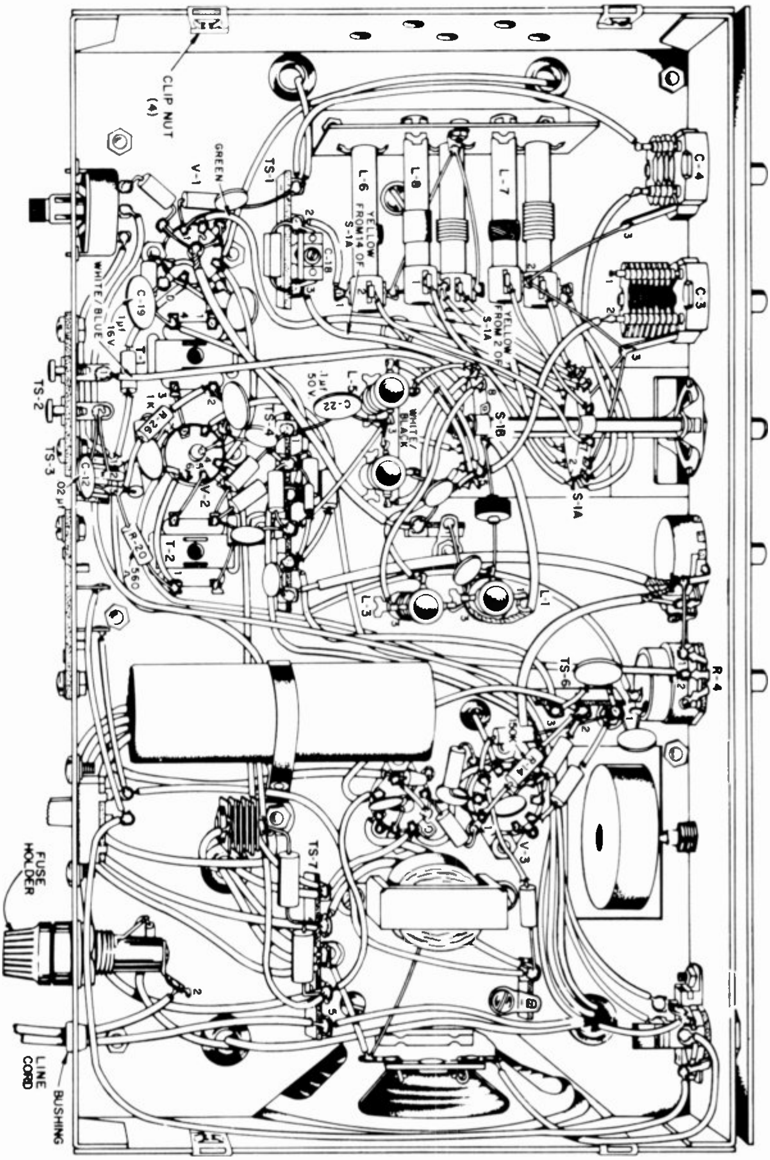


Fig. 1-8. Pictorial diagram of the Knight-Kit ® *Star Roamer* receiver.

understand a few of the principles and terms employed in electronics. It is not the author's intention to make this book a course in electronics. However, as an introduction to the uninitiated and as a review for others, a brief summary of the fundamentals is given in the following.

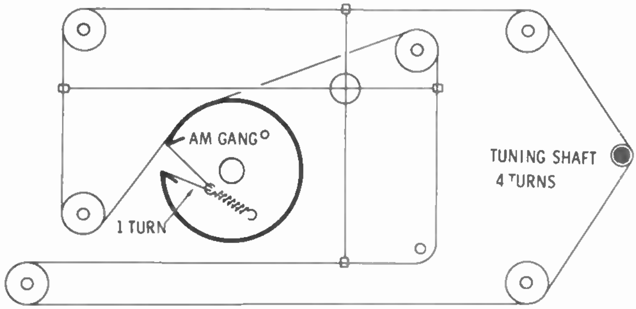


Fig. 1-9. A typical dial-cord stringing diagram.

All matter is made up of about a hundred fundamental materials called *elements.* (Actually, there are 104 known elements, but several are man-made and do not occur in nature.) Examples of elements are common materials such as gold, copper, and oxygen, rarer materials such as helium, tantalum, and xenon, and man-made elements such as californium, einsteinium, and nobelium. All material on earth is made up of these elements or combinations of them. The elements, in turn, are made up of *atoms,* which are minute particles so small that one cannot be seen under even the most powerful microscope.

These atoms are also composed of even smaller particles, and the composition of the atoms for each element is different from that for every other element. Fig. 1-11 shows a representation of a simple element (helium). The center of an atom is called the nucleus. In Fig. 1-11 it is represented by the shaded circle with the plus sign and consists of a cluster of positively charged particles called *protons.* Circling the nucleus in orbits similar to the way the planets orbit about the sun are negatively charged particles called *electrons* (represented by the circles with the minus signs in Fig. 1-11). There are several other particles within an atom, but the electron and proton are sufficient for our purposes.

In the normal condition, the electrical charge of the electrons and the protons is such that it holds the atom together. Under certain conditions, however, an electron can be made to move from its orbit to a similar orbit around the nucleus of a neigh-

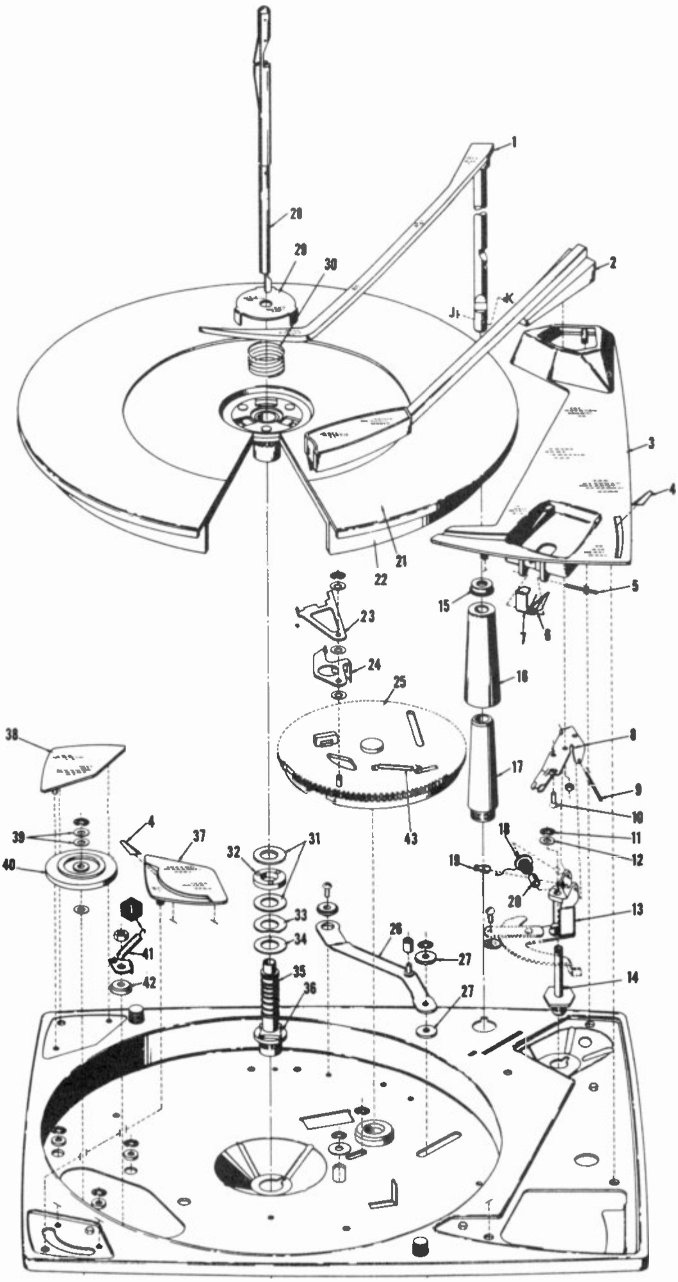


Fig. 1-10. "Exploded" view of a record changer.

boring atom. When the electron moves into orbit around the neighboring atom, it "bumps" an electron from this atom into orbit around another atom, etc. Thus, once started, a chain reaction is set up, and, in effect, electrons move from one point to the other. The control of this electron movement, called *electron flow,* is the basis for all of electronics.

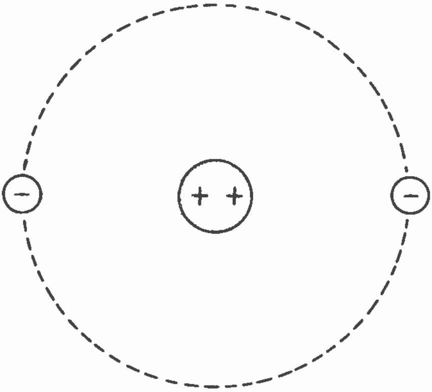


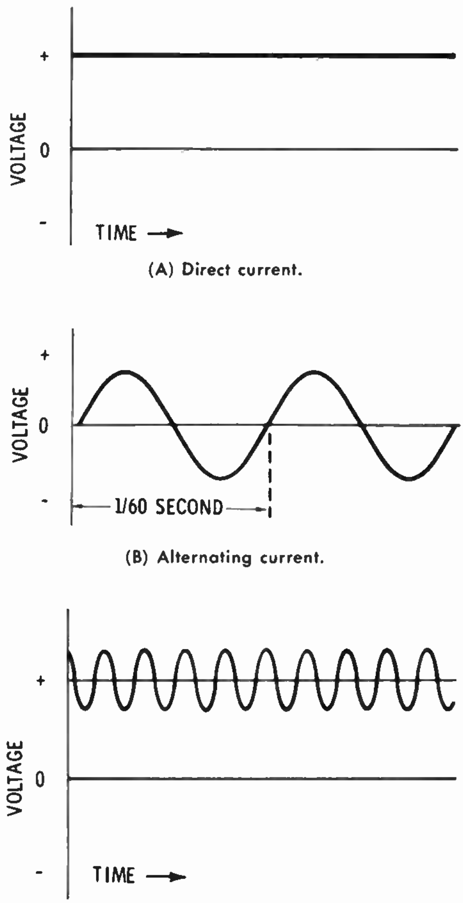
Fig. 1-11. Diagram of a helium atom.

In some substances, the electrons are held very tightly in orbit, making it difficult for them to be dislodged and move to the next atom. These substances are called *insulators.* For other elements, great numbers of electrons are easily dislodged and the electrons move freely from one atom to the next. These elements are called *conductors.*

Before electrons can move (flow) in a particular direction, there must be some force which causes them to do so. If a body has a surplus of electrons, it is said to be negatively charged. If a deficiency of electrons is present in a body, it is said to have a positive charge. If a suitable path (conductor) is placed between these two bodies, electrons will try to move from the negatively charged to the positively charged material. The movement of electrons through the conductor is called *current.* It is measured in amperes, which is the rate at which the electrons flow. The greater the difference between the two points—that is, the greater the difference in the number of electrons present in the two materials—the greater the current will be through the conductor. This difference between the two points is the force which causes electrons to flow and is called *electromotive force* (abbreviated emf), or more commonly, *voltage.* It is measured in units called volts. Voltage can be supplied to a circuit by a battery, the AC power lines, or one of several other methods.

The voltage applied to a circuit can be in many different forms. The battery mentioned previously is the simplest form. A battery will present a constant voltage—negative at one point and positive at the other. Therefore, electrons will flow from the negative terminal, through the circuit, to the positive terminal. The current will be constant and always in one direction. Graphically, such an electron flow is represented in Fig. 1-12A and is called *direct current* (abbreviated DC).

If the applied voltage is caused to change periodically—that is, to vary first positive and then negative—the resulting current is first in one direction and then in the other. This is



(A) Direct current.

(B) Alternating current.

(C) Pulsating direct current.

Fig. 1-12. Voltage plotted against time.

called *alternating current* and is shown graphically in Fig. 1-12B. The most common example of this type of current is the power supplied by the power lines to our homes. This current reverses itself 60 times each second. Hence, it is termed 60-cycle-per-second (cps) AC. More recently, the term "hertz" is being used for cycles per second. Therefore a 60-hertz (abbreviated Hz) current is a 60-cps current.

Another type of current is shown graphically in Fig. 1-12C. It is one of the most common encountered in electronics. The fact that the line does not extend below the center line representing zero volts shows that it is direct current. However, it is not constant and varies around a point above the line. Essentially it is a combination of the two previous examples, with the alternating current riding "piggyback" on the direct current. Such a current is called a *pulsating direct current.*

The foregoing points should be remembered. Once you have mastered them, you should have no trouble understanding the remainder of this book.

CHAPTER 2

FUNDAMENTAL COMPONENTS

Certain circuit components are found in nearly every type of electronic equipment, regardless of its purpose. The components discussed in this chapter—resistors, capacitors, coils, and transformers—are used in virtually every electronic device found in the home and industry.

RESISTORS

The resistor is probably the most common of all circuit components. Several are used in practically every piece of electronic equipment, whether it is a radio, television receiver, or signal generator.

A resistor performs exactly the function in an electronic circuit that its name implies. It *resists*, or opposes, the flow of electrons through a circuit. In any component, even a piece of wire, there is a certain amount of resistance, or "electrical friction," as the electrons attempt to move from one atom to the next. However, electrons flow more easily in certain materials than in others. A resistor is made of a material through which it is rather difficult for electrons to flow. In other words, a resistor introduces a high amount of electrical friction in the circuit.

There are two types of values (ratings) specified for resistors. The electrical value—that is, how much resistance the resistor will introduce in the circuit—is one. This value is given in *ohms*, the unit of resistance measurement. If the resistor has a value of 10 ohms, it will introduce 10 units of opposition to the flow of electrons through it.

At first thought it might appear that an opposition to electron flow such as that presented by a resistor would not be desirable, but such is not the case. The opposition presented by the resistor will reduce the amount of current in the circuit. At the same time, a voltage will be developed across the resistor. That is, as the electrons flow through the circuit, a voltage will appear across the resistor. The amount of this voltage depends on the amount of resistance (ohms) and the amount of current (amperes) through the circuit. The formula for determining the amount of this voltage is known as Ohm's law, which states that $E = I \times R$, where E is the voltage (in volts), I is the current (in amperes), and R is the resistance (in ohms).

The second value by which resistors are rated is *wattage*. Wattage is a measure of how much current there can be through the resistor before it will be damaged. Wattage is measured in *watts*, and in general, the larger the physical size of the resistor, the higher the wattage it will handle. Regardless of the wattage, the resistance (in ohms) does not change. Thus, any resistor can be replaced with one having a higher wattage without affecting the operation. A resistor should *never* be replaced with one having a lower wattage.

Quite often the word "ohm" is abbreviated Ω. This symbol is the Greek letter *omega*. Also, it is quite common to use the letter *K* for 1000 in electronics terminology. Thus a 1K (or 1KΩ) resistor is a one thousand-ohm resistor. Likewise, the letter *M* or the prefix *meg* is used for one million. Thus, 1M, 1MΩ, 1 meg, or 1 megohm are all ways of designating a resistor having one million units of electrical resistance. Watts are usually designated by the letter *W*.

Fixed Resistor

A fixed resistor means one that is constant in value. The ohmic value cannot be changed or will not change under normal usage conditions. Its value depends on the composition and amount of material used in the manufacture of the resistor.

The most common fixed resistors are made entirely of carbon (A in Fig. 2-1) or a metal, carbon, or other composition deposited on glass, ceramic, or other material (B in Fig. 2-1). Other fixed resistors are made of a length of wire having a high resistance (such as *Nichrome*) wound around a form made of porcelain. Two examples of this type of resistor are pictured at C and D in Fig. 2-1.

Most carbon resistors have a color code printed on them to designate their value. Notice the bands around the resistor at A in Fig. 2-1. These colored bands are the code for the value. Table 2-1 gives the code used. The first band represents the first digit in the resistor value, and the second band, the second digit. The third band is the multiplier. That is, the first two digits are multiplied by the value shown in the multiplier column to obtain the value of the resistor.

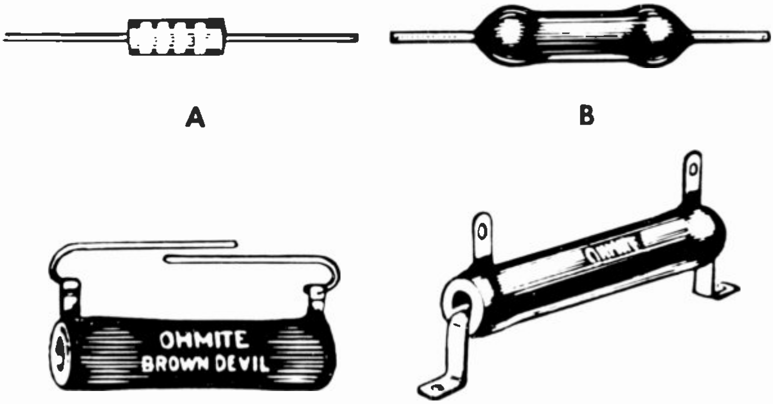


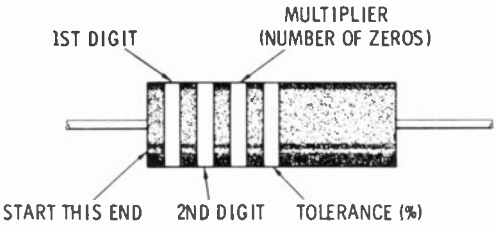
Fig. 2-1. Fixed resistors.

A fourth band is often added to specify the tolerance of the resistor, or within what percentage of the value given by the color code the actual resistor value falls. It is impossible to make each resistor an exact value, so certain standard values have been adopted, and if a resistor falls within a certain percentage of this value, it is coded with that value. When no fourth band is included, the resistor is within 20% of the value specified. The tolerances specified by the fourth band are also given in Table 2-1. Thus, a resistor with a red, violet, orange, and silver band indicates that it is a 27,000-ohm resistor and that its actual value will be within ±10% of the rated value. That is, it can be between 24,300 and 29,700 ohms and in most cases still be capable of meeting the circuit requirements. In actual practice, only the silver, gold, or no band is usually encountered for the tolerance. Resistors having other tolerances normally will not be carbon units, and the value and tolerance are normally printed on the sides of other types of resistors.

The symbol at A in Fig. 2-2 is almost universally employed to represent a fixed resistor on schematics. Recall that the function of a resistor is to present an opposition to electron flow. The zigzag line of the symbol presents a mental picture of opposition similar to that of a maze.

The symbol at B in Fig. 2-2 is for a special type of fixed resistor called a tapped resistor. In certain applications, it is desirable to "tap in" at a point along the resistance element, and on wirewound resistors a connection can be made at any

Table 2-1. Resistor color code



Color	Digits	Multiplier	Tolerance
Black	0	1	20%
Brown	1	10	±1%
Red	2	100	±2%
Orange	3	1000	±3%
Yellow	4	10,000	GMV*
Green	5	100,000	±5%
Blue	6	1,000,000	±6%
Violet	7	10,000,000	±12½%
Gray	8	.01	±30%
White	9	.1	±10%
Gold	—	.1	±5%
Silver	—	.01	±10%
No Color	—	—	±20%

*Guaranteed Minimum Value—That is, —0% + 100% tolerance

point along the wire. Thus, only a portion of the total resistance will be present between the tap and either end. Two taps are shown in the symbol at B in Fig. 2-2; however, any desired configuration can be made. Sometimes the dot at the point of connection will be omitted, as shown by the symbol at C.

Variable Resistors

It is often desirable to have a means of varying the value of a resistor. For example, the volume control of a radio or television set is a variable resistor. Other variable resistors are used in lighting and power circuits. Fig. 2-3 shows some of the many types in use. Most consist of a circular resistance element (either wire or carbon) with connections to one or both ends. A movable arm is placed in contact with the resistance and mechanically attached to the shaft, which protrudes from the unit. Moving this shaft changes the position of the movable arm on the resistance element. By connecting one of the termi-

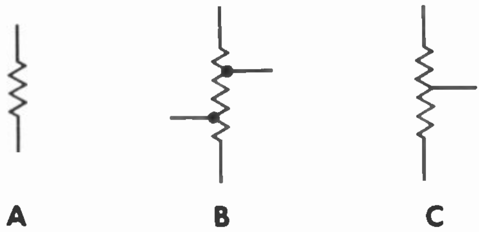
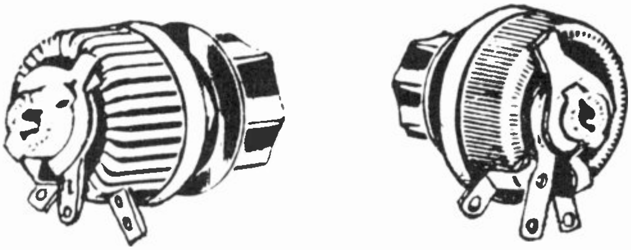
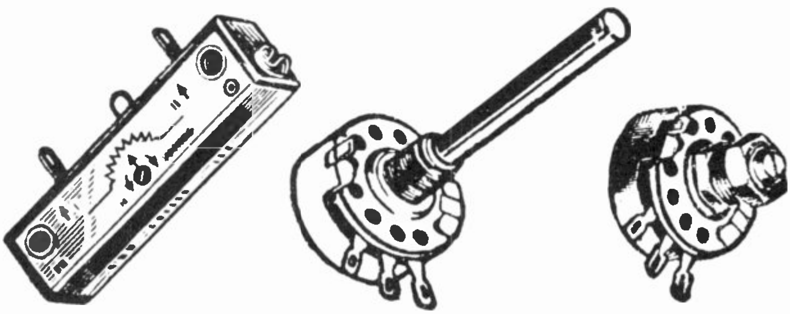


Fig. 2-2. Fixed resistor symbols.



(A) Rheostats.



(B) Potentiometers.

Fig. 2-3. Variable resistors.

nals to this movable arm, a point is obtained which can be adjusted to any desired value of resistance between the two ends.

When terminals are attached to both ends of the resistance element, the resistor is called a *potentiometer*; when a terminal is attached to only one end, it is called a *rheostat*. The most common symbols for potentiometers and rheostats are given at A and B in Fig. 2-4. Notice that it is the normal resistor symbol, with the arrow denoting the sliding contact. Sometimes a circle is added to the movable contact, as shown at C and D.

The only difference between the potentiometer and rheostat symbols is that in B and D, no provision is made for a connection to the bottom end of the resistance element. The reason is that a rheostat has a connection at only one end, as stated previously; however, this same symbol can denote a potentiometer with one terminal unused. Another symbol which is frequently encountered for a variable resistor is given at E in Fig. 2-4. Here the arrow through the resistor symbol denotes that it is variable. Use of this symbol should be avoided, however, because no provision is made for the third connection to a potentiometer.

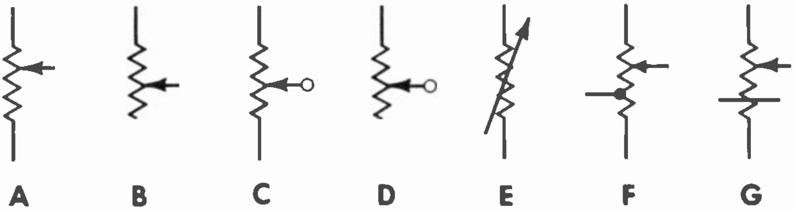


Fig. 2-4. Variable resistor symbols.

The symbols at F and G in Fig. 2-4 are for two special types of variable resistors. The one at F is for a potentiometer with a tap on the resistance element. Such units are often used in tone controls and other circuits. The symbol at G is for a potentiometer in which the movable arm cannot move to the end of the resistance element. Thus, there will always be a certain amount of resistance between the movable arm and the bottom of the control. The stop is symbolized by the line drawn across the resistance element.

Special Resistors

Occasionally there is a need for a resistor with special characteristics which cause its resistance to vary because conditions in the circuit or the area surrounding it change. Many of these units are actually semiconductors (to be discussed later) ; however, they are included here because they function in the circuit like a resistor.

The temperature of a resistor may rise because of heat from the surrounding components or from the electrons flowing through it. As this happens, the actual resistance of the unit will increase. By varying the composition, special resistors can be produced whose resistance can be made to increase or decrease by certain specified amounts, or to remain constant regardless of the direction of temperature change (within limits, of course). Thus, a special resistor which decreases in resistance can compensate for a normal resistor which increases in resistance. Such resistors are called *temperature-compensating resistors, thermal resistors*, or *Thermistors*.

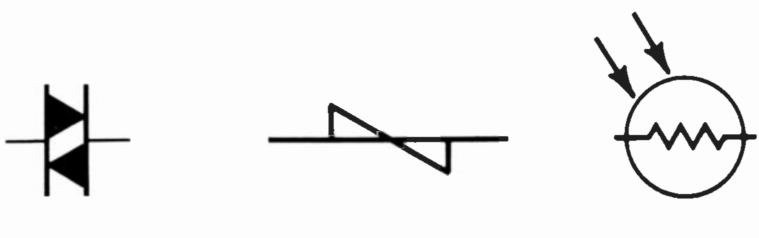
The symbols used to designate temperature-compensating resistors are given in Fig. 2-5. Notice that they are made up with the regular resistor symbol plus the letter *T* (for temperature). The arrow in the symbol at B and the line through the symbol at C designate that the resistance of the unit varies.

When its resistance decreases as the temperature increases, the unit is said to have a *negative temperature coefficient*, abbreviated NTC. When the resistance increases as the temperature does, the unit is said to have a *positive temperature coefficient* (PTC). The abbreviation signifying the type of temperature compensation is usually placed beside the symbol.

A B C

Fig. 2-5. Temperature compensating resistor symbols.

There are other resistors which will vary in value when the current through them or the voltage across them changes. In others, the amount of light striking the resistor changes the resistance value. Usually the same symbols shown in Fig. 2-5 will be used for such resistors, except that the letters *I* (for current), *V* (voltage), *VDR* (voltage- dependent resistor), *L* (light), or *LDR* (light-dependent resistor) will be substituted



A B C

Fig. 2-6. Special resistor symbols.

for the *T* in Fig. 2-5. The Greek letter *lambda* (λ) may also be used for light-dependent resistors. (*Lambda* is the Greek letter "L", which stands for light.)

Two additional symbols used for voltage-dependent resistors are given at A and B in Fig. 2-6. Two arrows, as shown at C, may be used with the resistor symbol to designate a light-dependent unit. The circles around the symbol for the resistance elements in some of the symbols in Fig. 2-5 and 2-6 may be omitted, but usually a circle or rectangle is included.

CAPACITORS

Like the resistor, several capacitors are found in nearly every electronic circuit. Another name for the capacitor is *condenser*; however, the latter term is seldom used today except for the "condenser" used in automotive electrical systems and condenser microphones. Formerly, "condenser" was the accepted term for this unit, but since a capacitor doesn't "condense" anything, the term "capacitor" is preferred by most of the industry.

The elementary capacitor consists of two metal plates with connections to them, separated by an insulating material as shown in Fig. 2-7. Here the insulating material is the air be-

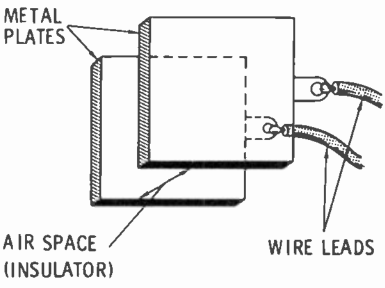


Fig. 2-7. The elementary capacitor.

tween the two plates. A capacitor has the ability to store and release electrons as dictated by the external circuit. This storage and release of electrons is called the charge and discharge of the capacitor.

Electrons cannot flow through the insulating material between the two plates. As far as direct current is concerned, a capacitor acts as an open circuit. However, when an AC voltage is applied to one of the plates, this plate will alternately store and discharge electrons in step with the applied voltage. (During the negative half-cycle, electrons will be stored, and during the positive half-cycle, they will be discharged.) Furthermore, when an excess of electrons is stored on one plate, electrons will be driven away from the other plate and through the circuit connected to it. Also, when there is a deficiency of electrons on one plate (during the positive half-cycle), electrons will be attracted to the opposite plate. Thus, while no electrons actually flow *through* the capacitor, the effect is the same as if they do whenever an alternating current is connected to one plate and the other plate is connected to some circuit or ground.

The foregoing are the three important properties of capacitors: (1) storing electrons, (2) blocking direct current, and (3) "coupling" alternating current.

The electrical property of capacitors which enables them to store electrons is called capacitance. The unit of measurement for capacitance is the *farad*. For most applications the farad is too large a unit, so the *microfarad*, which is one millionth of a farad, and *picofarad*, equal to one millionth of a microfarad, are more common. Microfarad is abbreviated mf, mfd, μF, μf, or μfd, and picofarad is abbreviated pf, pF, or pfd (μ is the greek letter *mu* and is commonly used in electronics terminology to signify one millionth). The term "picofarad" is relatively new in the United States; formerly the term "micromicrofarad" (mmf, mmfd, $\mu\mu$f, $\mu\mu$F, or $\mu\mu$fd) was used, but is losing favor to the newer term. Thus:

$$1 \text{ pF} = 1\ \mu\mu\text{F} = .000001\ \mu\text{Fd} = .000000000001 \text{ farad}$$

Fixed Capacitors

The capacitor in Fig. 2-7 is not practical because it is too large physically for use in most applications. As the area of

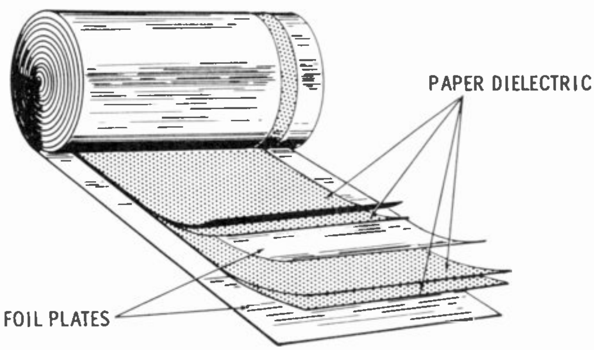


Fig. 2-8. Basic construction of a tubular capacitor.

the plates is increased, there will be a greater capacity for electron storage and hence a greater capacitance. To make a practical capacitor a different type of insulation (called the dielectric) must be used to concentrate a large plate area within a small space. The tubular capacitor (Fig. 2-8) is one of the most common types. Here an insulating material, which may be paper as shown in Fig. 2-8, or Mylar or some other material, is placed between the metal foil plates, which are the conductors. The entire structure is rolled up as shown, and connection

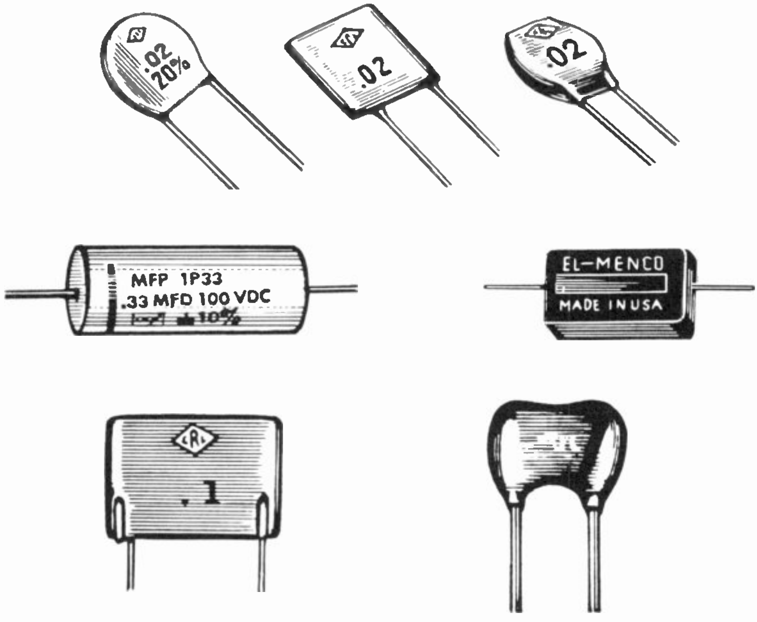


Fig. 2-9. Typical fixed capacitors.

made to the ends of the foil. In other types of construction, mica, ceramic, glass, and other insulation may be used. In any type, the construction is essentially the same—layers of conductors separated by an insulating material. Fig. 2-9 shows the appearance of several types of capacitors.

Once their construction is understood, it is easy to see why the symbols shown in Fig. 2-10 were chosen to represent them. The two horizontal bars (or the bar and arc) represent the two conducting plates; the vertical lines are the leads connected to them; and the space between represents the dielectric. Usually one of the lines is curved, as shown at A.

A color code similar to that used for resistors is employed for capacitors. Quite often, however, the value of the capacitor will be stamped on the unit. Also, like resistors, temperature-compensating capacitors are available. Such capacitors can de-

Fig. 2-10. Fixed capacitor symbols.

crease or increase in value with a rise in temperature; units are available for several different rates of variation. Capacitors whose values do not vary with temperature are called NPO capacitors.

Another important rating of capacitors is the working DC voltage. If this voltage is exceeded, the electrons will "jump" across the dielectric causing a very hot arc to occur. When this happens, the capacitor is usually destroyed. Hence, it is important that this voltage not be exceeded. Many capacitors have the working DC voltage stamped on them.

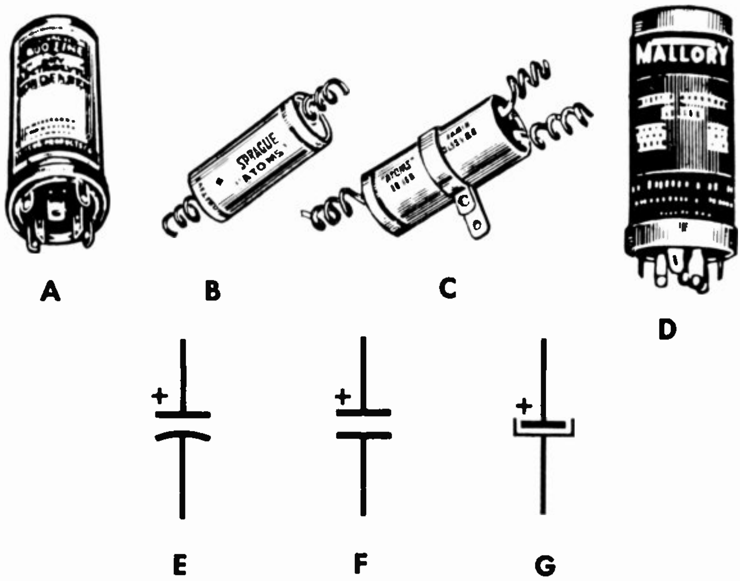


Fig. 2-11. Electrolytic capacitors and symbols.

Electrolytic Capacitors

In another type of capacitor, one of the plates is made up of a moist substance called an *electrolyte*; capacitors employing this construction are called *electrolytic capacitors* (Fig. 2-11). The electrolyte causes an oxide film to form on the aluminum plate. This film acts as the dielectric between the metal plate and the electrolyte. High values of capacitance can be obtained using this principle.

An electrolytic capacitor must be connected in the correct polarity. That is, the positive terminal must go to the most positive voltage point, and the negative terminal to the most

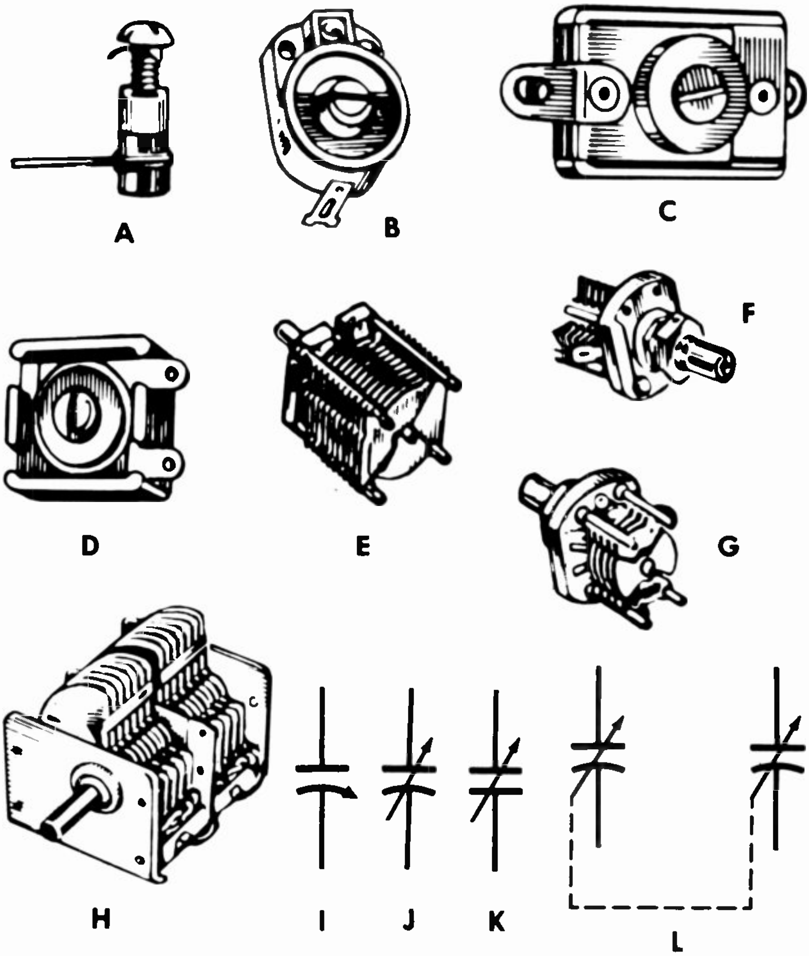


Fig. 2-12. Variable capacitors and symbols.

negative (or least positive) point. Plus signs are added to the basic capacitor symbols at E and F in Fig. 2-11 to distinguish these symbols as being for electrolytic capacitors. A minus sign may also be included (by the other plate) in the symbols at E and F. Another symbol for this type of unit is shown at G.

Variable Capacitors

Capacitors can also be constructed so their value can be adjusted by turning a shaft. The tuning control on most radios is a variable capacitor whose capacitance is varied as the tuning knob is rotated. In general, there are two types of adjustable capacitors. Those at A, B, C, and D in Fig. 2-12 are usually called trimmer capacitors. They have a dielectric of mica, ceramic, or similar material and are adjusted by a screwdriver-type adjustment. Those at E, F, G, and H in Fig. 2-12 normally have an air dielectric and are usually adjusted by a knob attached to the shaft. In general, the capacity of this type is greater than that of trimmer capacitors.

As stated, the capacitors at E, F, G, and H usually have air as the dielectric. The two sets of plates are meshed together; that is, one set moves inside the other, but they do not touch. As the shaft is rotated, one set of plates will move in or out and vary the area of the meshed plates, hence, the capacitance between the two. The symbols at I, J, and K in Fig. 2-12 designate either type of variable capacitor. They are identical to the fixed-capacitor symbols except for the arrow, which denotes they are variable.

The unit at H in Fig. 2-12 is actually two separate capacitors, with both being adjusted by the same shaft. Such a capacitor is used to tune two sections of a radio. The symbol at L is normally used to show this. Two capacitor symbols are included, and the dashed line between the arrows denotes that both capacitors are mechanically connected and tuned simultaneously.

COILS

The coil, or inductor as it is sometimes called, can be one of the simplest of all electronic components, but it can also be one of the most complex. In its simplest form, it is just what the name implies—a length of wire wound in the form of a coil. However, to be useful it is usually more complex. A useful coil must be wound in a certain way and have a certain size of wire.

When electrons flow through any conductor, magnetic lines of force are set up in the area around the conductor. As long as the current is steady, the magnetic field will be stationary, but if the current varies, so will the magnetic field. When the current stops, the magnetic field collapses.

If a magnetic field cuts across a conductor, an electric current will be set up in this conductor also. Thus, in a coil, the turns are placed close enough that the magnetic field set up by the current through one turn of the coil will cause a current to be set up in the adjustment turns, and vice versa. This is repeated for each turn of the coil.

The overall effect is that when a current increases, decreases, or changes direction through a coil, the coil will tend to oppose the changes and "smooth out" the variations in the current. For a steady current (direct current), the coil will present no opposition except the resistance of the wire itself.

The electrical property of the coil which tends to oppose any change in the current through it is called *inductance,* and the basic unit of measurement for it is called the *henry* (abbreviated H, h, or hy). Like the farad, the henry is too large a unit for many applications, so the millihenry (mH or mh), equal to one-thousandth of a henry, and the microhenry (μH or μh) are more common units of measure.

Air-Core Coils

If the wire is heavy enough, the loops of coil can be formed and held in place by the stiffness of the wire itself. Usually, however, the turns of wire will be wound around a plastic,

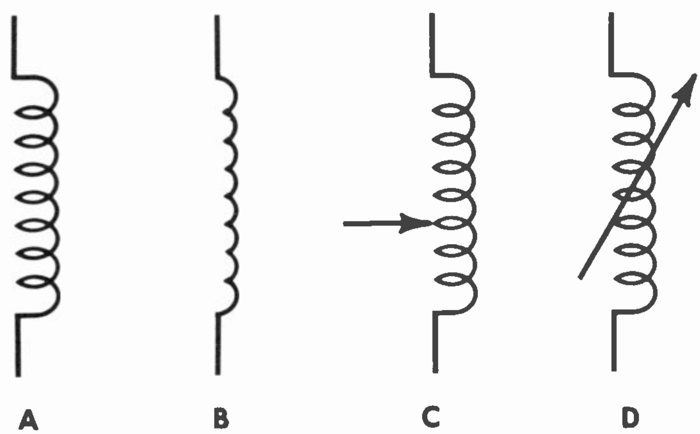


Fig. 2-13. Air-core coil symbols.

paper, or similar nonmetallic form for support. The entire coil may then be coated with plastic for protection. As long as no metallic substances are used for the form (called the core), the coil is considered an air-core coil.

Fig. 2-13 shows some symbols used for air-core coils. Each symbol has loops which represent the turns of wire in the coil. In other instances, the shape of the loops may vary slightly. While not common, it is possible to make an air-core coil adjustable, as shown by the addition of the arrow to the symbols at C and D. The symbol at C represents a system in which a sliding contact comes in contact with the loops of the coil. The one at D is usually employed to show that the loops of the coil can be stretched or compressed to change the inductance of the unit. This method is commonly used in adjusting high-frequency circuits.

Powdered-Iron Core Coils

Only a limited number of magnetic lines of force will find their way to the other turns of an air-core coil. Often a core made by molding ferrite or powdered iron to the desired shape is used instead of the air or other nonmetallic substance pre-

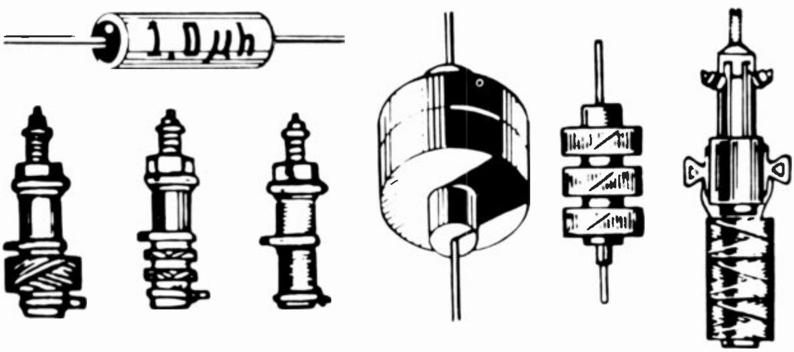


Fig. 2-14. Ferrite-core coils.

viously described. When brought near or inserted within the loops of the coil, a core of this type offers a convenient path for the magnetic lines of force. Thus, more lines of force will cut the other conductors in the coil, increasing the inductance. Coils of this type are available in many shapes and sizes, as shown by a few representative samples in Fig. 2-14.

The symbol for powdered-iron or ferrite-core coils is similar to the one for the air-core symbol except for the dashed lines

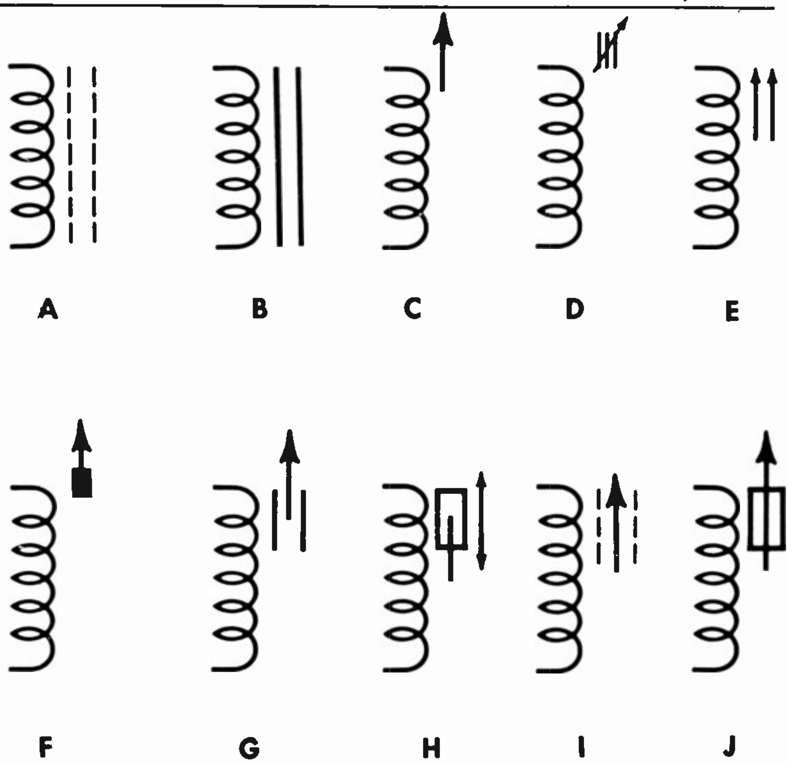


Fig. 2-15. Powdered-iron core coil symbols.

which represent the core, as shown at A in Fig. 2-15. Sometimes the core will be represented by solid lines, as shown at B. Quite often the core is adjustable in this type of coil. Many ways are used to show this variability. All, however, use an arrow in the same manner. The dashed line representing the core may also be included, but quite often it is omitted and only the symbol representing adjustability is added to the basic coil symbol.

Iron-Core Coils

The third method of coil construction uses an iron core. This type of coil is normally called a choke; its primary purpose is to "choke," or smooth out, variations in the current through it. The construction of a typical iron-core choke is shown in Fig. 2-16. The core is usually constructed of a series of thin sheets of steel called laminations and stacked one on top of another, visible in the center of the unit. The wire of the coil is wound around the core and separated from it by insulation

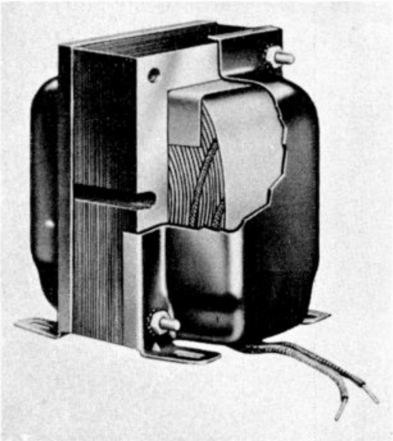


Fig. 2-16. Iron-core choke construction.

(usually paper). In the unit of Fig. 2-16, the entire assembly is then enclosed within a metal shell, but in some units no shell is used. The metal in this core provides even more coupling between windings, and iron-core chokes are characterized by high inductance, usually in the henry range. Fig. 2-17 shows the symbols used for iron-core chokes. They are the same as for an air-core coil except for the two or three solid lines, which represent the core. Usually such

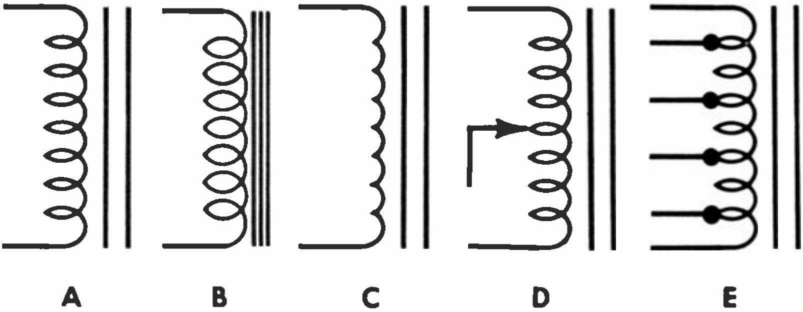


Fig. 2-17. Iron-core choke symbols.

chokes are not variable. If so, however, an arrow is added as shown at D. This represents a sliding contact which moves along the winding of a coil. At other times, several taps are connected to the winding, and a switch is used to select the desired amount of inductance. The symbol for this is given at E.

TRANSFORMERS

Essentially, a transformer consists of two or more coils (called windings), positioned close enough that the lines of force of the magnetic field set up by current in one coil will cut across the windings of the other coil, setting up a current in the second coil. The winding connected to the source of current is called the primary, and the other winding (or windings) is called the secondary.

When a varying current is connected to the primary winding, the resulting current set up in the secondary winding will vary in step with the current in the primary winding. Thus, a transformer can be used for coupling in much the same way as a capacitor.

If a capacitor is connected across the primary winding, it will "tune" the winding so that only one frequency, or a small group of frequencies, will be coupled to the secondary winding. Likewise, adding a capacitor across the secondary winding causes it to accept only certain frequencies. By proper choice of the inductance of the transformer windings and capacitance of the capacitors, only the desired frequency—i.e., those of a particular radio station—will be passed; all others will be rejected.

If the number of turns in the two windings is the same, the voltage across the secondary will be nearly equal to that across the primary. If the secondary has more turns than the primary, the voltage across the secondary will be greater than that across the primary, but the current will be less. If the secondary has fewer turns, the secondary voltage will be less, but the current will be greater.

Thus, the two main purposes of transformers are coupling between circuits and stepping voltages up or down.

Air-Core Transformers

Transformers, like coils, may have an air, ferrite, or iron core. Fig. 2-18 shows symbols used to depict air-core transformers. Notice that they are the same as for air-core coils except that two windings are shown. Usually the winding on

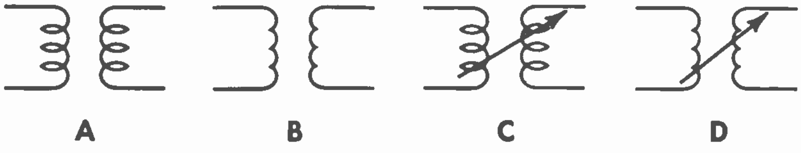


Fig. 2-18. Air-core transformer symbols.

the left is the primary and the one on the right is the secondary, but there are exceptions to this general rule. An air-core transformer is normally not adjustable, since the only way to make it variable is to move one winding closer to or farther from the other. When made variable, however, it is usually represented by an arrow through both windings, as shown at C and D in Fig. 2-18.

Powdered-Iron Core Transformers

There are many different sizes and shapes of transformers using powdered-iron or ferrite cores. Fig. 2-19 shows the appearance of a few of them. Notice that some are enclosed in

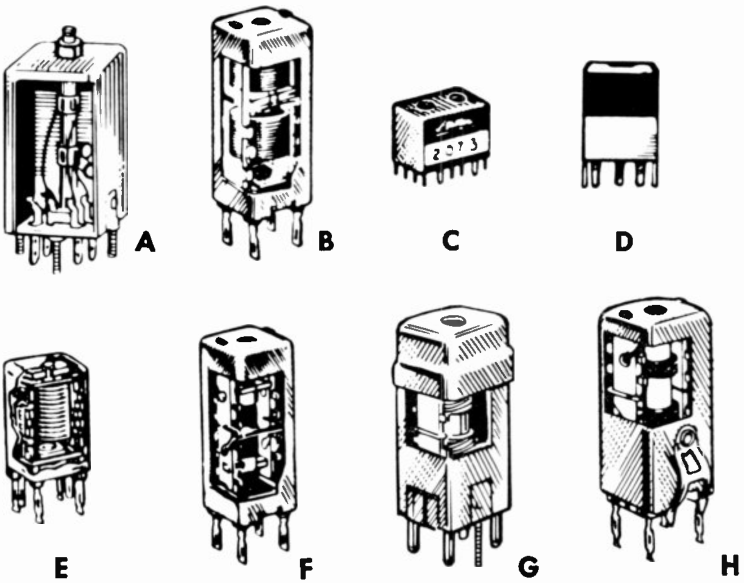


Fig. 2-19. Powdered-iron core transformers.

metal enclosures called "cans." This metal can serves to keep signals from other unwanted sources from interfering with the desired signals. Usually such units, called permeability-tuned transformers, are adjustable, enabling the desired frequencies to be "tuned in."

Just as for powdered-iron core coils, there are many ways to show powdered-iron core transformers on schematics. The first two symbols in Fig. 2-20 are for untuned coils. The remaining symbols show some of the many ways used to show variable transformers. Notice that on some of the symbols, only one

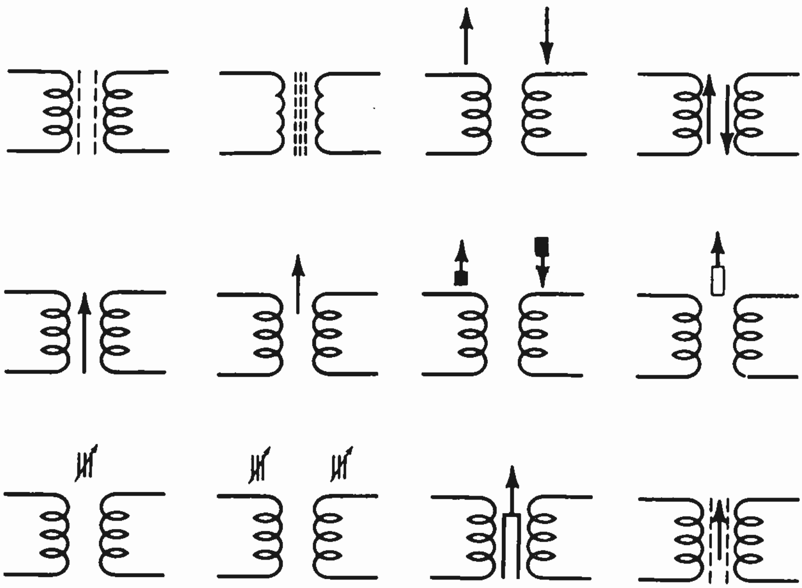


Fig. 2-20. Powdered-iron core transformer symbols.

tuning adjustment is shown. Here, one adjustment affects both windings simultaneously. As for coils, the core material may not be shown in the adjustable symbols. Various types of loops may be used to designate the coils for any of the drawings given; the shape of the loop and whether it is open or closed makes no difference.

Iron-Core Transformers

Fig. 2-21 gives a representative sampling of the many types of iron-core transformers. Notice that as with chokes, some are encased in metal cases; others are not. Unlike other transformers, iron-core transformers often have more than one secondary. For example, a typical power transformer may have one secondary which delivers approximately 300 volts for the B+ supply. Another secondary may supply 6.3 volts and still another 5 volts for the tube filaments (explained in the next chapter).

The symbol at A in Fig. 2-22 is for this power transformer. The winding marked A is the 5-volt secondary, the one labeled B is the 300-volt one, and C is the 6.3-volt winding. Notice that windings at A and C have fewer loops than the primary, denoting a step-down function, and winding B has more loops, representing a step-up winding. The number of loops shown is not

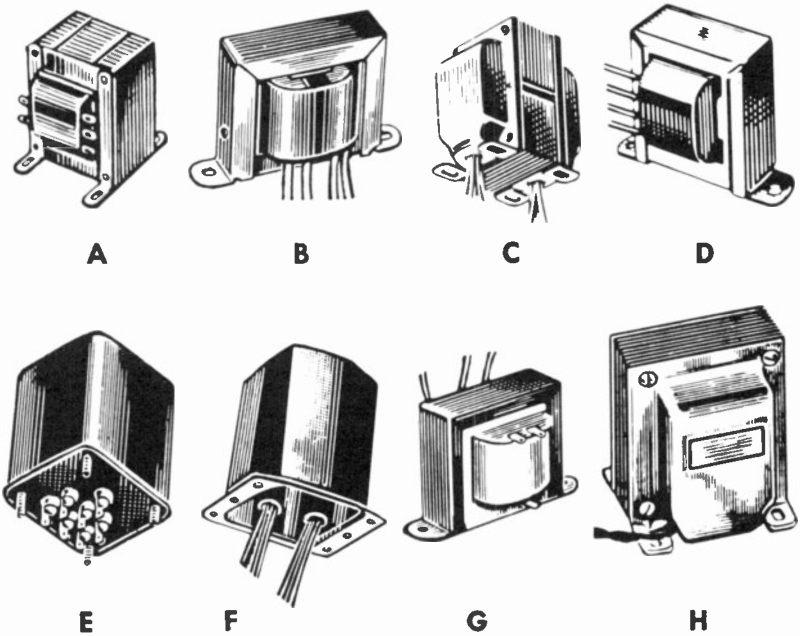


Fig. 2-21. Typical iron-core transformers.

actually proportional to the voltage; it merely indicates a step-up or step-down transformer.

The symbol at B in Fig. 2-22 is for a two-winding step-down transformer, and the one at C is for a transformer that has equal windings. Here the voltage across the secondary is the

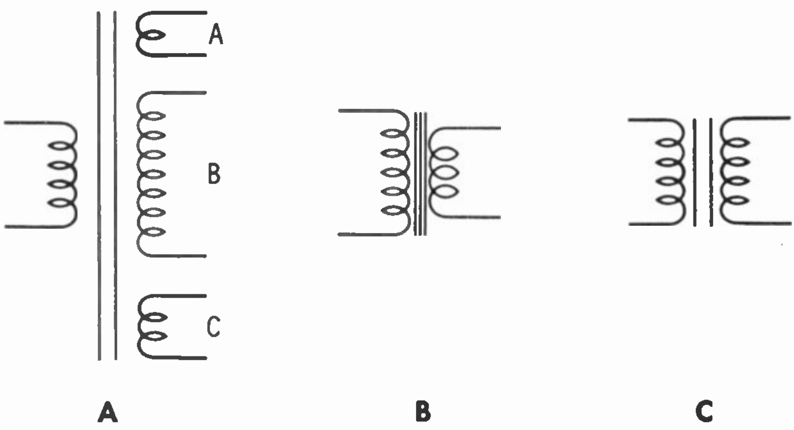


Fig. 2-22. Iron-core transformer symbols.

same as that across the primary. (This type is called an isolation transformer.)

All iron-core transformers will follow the general patterns given in Fig. 2-22. The two or three lines represent the core, and the windings, as drawn, represent the actual windings of the transformers. Normally such transformers are not variable, but if so the variability is represented by an arrow as was done for iron-core chokes.

SUMMARY

In this chapter, the three properties most important in electronic circuits—resistance, capacitance, and inductance—and the components associated with these properties—resistor, capacitor, and coil—have been examined. Any piece of electronic equipment will usually contain several of each of the fundamental components explained in this chapter. In the following chapters, additional components will be examined; when used with the three components of this chapter, they accomplish the desired results for all the various types of electronic equipment.

CHAPTER 3

TUBES AND SEMICONDUCTORS

The entire foundation of electronics is based on the control of a tiny, negatively charged particle called the *electron.* It has been shown (Chapter 1) how this electron will flow from a negative to a positive voltage source as long as there is a complete conductive path between the two points. It has also been shown how resistors, capacitors, and coils will affect this electron flow, called electron current.

Before this electron flow can serve much of a useful purpose, however, some means must be provided to control it. We must be able to turn it on, shut if off, increase, decrease, or change its frequency. These functions are provided by the tubes, transistors, diodes, and other devices to be explained in this chapter.

VACUUM TUBES

Ever since Dr. Lee de Forest invented his *audion* tube early in the 20th Century, the vacuum tube has been the heart of nearly every piece of electronic equipment. In recent years the transistor has replaced it in many applications, but the vacuum tube has not been obsoleted by this amazing device, as was once forecast. There are applications where each is better suited, and each is destined to be used for years to come. In the future, the vacuum tube may indeed be replaced by semiconductor devices, but it will be many years before a complete changeover takes place.

The Diode

The simplest vacuum tube is called a *diode.* Fig. 3-1 shows its basic construction. It consists of a glass case (called an envelope), a base through which pins are inserted for connection to the individual parts, and the individual parts themselves (called elements) inside the tube. All the air has been removed from the inside of the tube envelope leaving the elements in a vacuum.

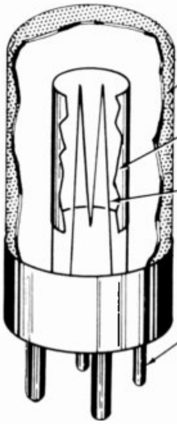


Fig. 3-1. Construction of a diode tube.

At the center of Fig. 3-1 is an element labeled the *filament*. It is a length of special-resistance wire which becomes hot when electrons flow through it. The filament has a coating which, when heated, causes electrons to be expelled from the filament into the vacuum space. In other tubes another element, called the cathode and shaped like a sleeve, is placed around the filament. Here, the only function of the filament is to heat the cathode, which, in turn, expels electrons into the surrounding vacuum when hot. (In this latter application, the filament is often called the heater.)

Another element called the plate is shown in the tube of Fig. 3-1. If this element is connected to a source of positive voltage, the electrons which were expelled from the filament (or cathode) will be attracted to it. Recall that electrons flow from negative to positive as long as there is a conductor connected between the two points. In a vacuum, the conductor is not necessary and the electrons will flow across the vacuum of the tube *as long as the plate is more positive than the filament (or cathode)*.

This introduces us to the most important function of the diode tube—rectification. If an AC voltage is connected to the plate, electrons will flow from the filament to the plate during the positive half-cycles of the applied alternating current. During the negative half-cycles, no electrons will flow. Thus, the alternating current is changed to pulsating direct current at the cathode. This pulsating current is smoothed out by an electrolytic capacitor, giving us a relatively steady direct current.

Fig. 3-2 shows the symbols for a diode tube. The one at A is for a tube having only a filament and plate, and the one at B is for a tube which also contains a cathode. The circle represents

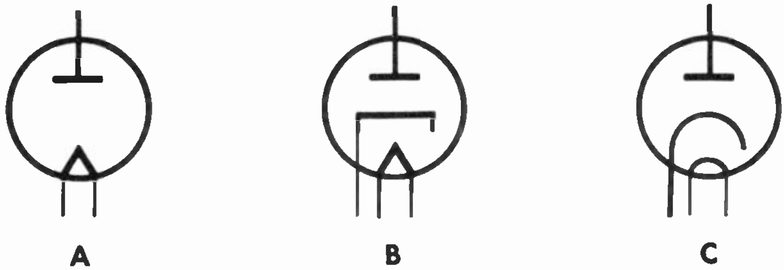


Fig. 3-2. Diode tube symbols.

the glass envelope; the pointed element at the bottom is the filament. The element that looks like an inverted T at the top is the plate. The additional element is the cathode.

Most manufacturers follow essentially the same symbols shown in Fig. 3-2. Some of the lines may be heavier or lighter, or longer or shorter; the connections which extend from the element may go in a different direction, but it makes no difference. About the only significant difference is that the cathode or filament may be rounded by some manufacturers, as shown at C. Sometimes the heater will not be shown as part of the symbol, but will be shown separately in the power-supply section since its only function is to heat the cathode.

The Triode

Fig. 3-3 shows the construction of a triode tube. Notice that it is essentially the same as the diode shown previously except for an added element called the grid. (A cathode, explained previously, is also shown in Fig. 3-3).

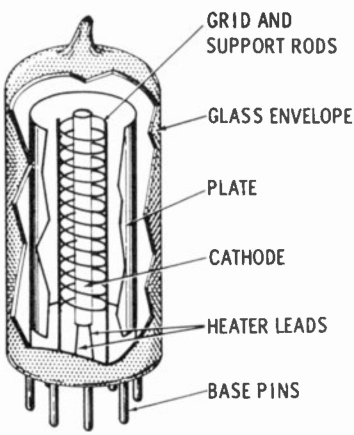


Fig. 3-3. Construction of a triode tube.

The diode tube, as explained previously, can change alternating current to direct currrent, but it cannot increase the strength of a signal. It will actually introduce a slight loss in the circuit.

The triode overcomes this disadvantage. Notice in Fig. 3-3 that the grid is made of a fine-mesh wire supported by two supports whose only purpose is to hold the grid wires in place. Fig. 3-4 shows the symbol for the triode tube. The grid is represented by the dashed lines between the cathode and plate. Thus, all electrons trying to flow between the cathode and plate must flow through the holes in the grid. If this grid is made negative enough, it will repel all the electrons, forcing them back to the cathode. As it is made less negative, some electrons

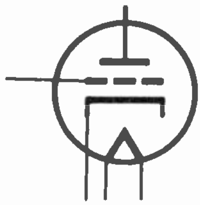


Fig. 3-4. Triode tube symbol.

will flow through it and on to the plate. When made still less negative (more positive), more electrons will flow on to the plate. Only a small change is required in the grid voltage to produce a large change in the electron current which travels from the cathode to the plate. If a small AC voltage representing the signal (for example, the music, speech, etc., of a radio program) is applied to the grid, the signal at the plate will vary with the one at the grid, but will be much larger. This is amplification—the primary function of a triode tube. Because of its function in controlling the number of electrons flowing through the tube, the grid is usually called the control grid.

Other Tubes

The triode can be used to amplify practically any signal, but in many applications additional elements are desired. The symbol at A in Fig. 3-5 is for a *tetrode* tube. As you might guess from looking at the symbol, it contains another element, similar in construction to the control grid, added between the grid and the plate. This grid is called the *screen grid,* and sometimes the tetrode tube is called a screen-grid tube. As mentioned previously, any two conductors will have a certain amount of capacitance between them. The screen grid is placed in the

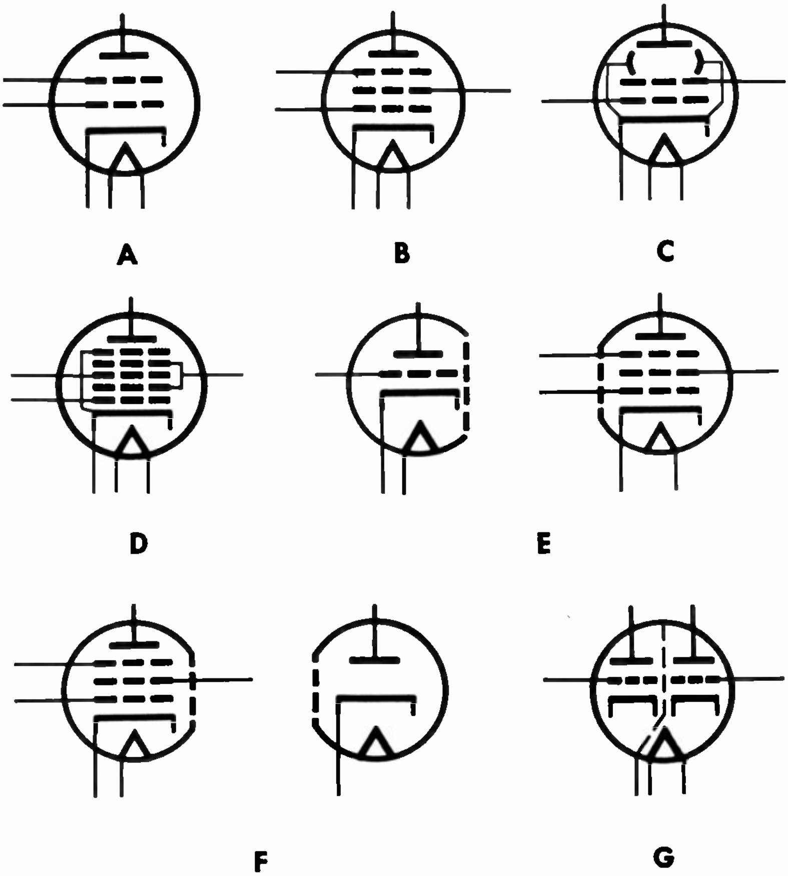


Fig. 3-5. Other vacuum tube symbols.

tube to minimize capacitance between the control grid and plate. Usually a capacitor is connected between the screen grid and ground to remove any signal voltage on this element and keep it at a neutral position. Thus, it acts as a shield between the control grid and plate. Much higher gain (amplification) can be obtained from a tetrode tube than from a triode.

The tetrode offers considerable advantage over the triode in many applications, but another problem is often encountered, called *secondary emission.* It occurs when the electrons from the cathode strike the plate with such force that they bounce off and also knock off some electrons already on the plate. These electrons will be attracted by the positive voltage on the screen and collect on it, causing the screen to receive more than