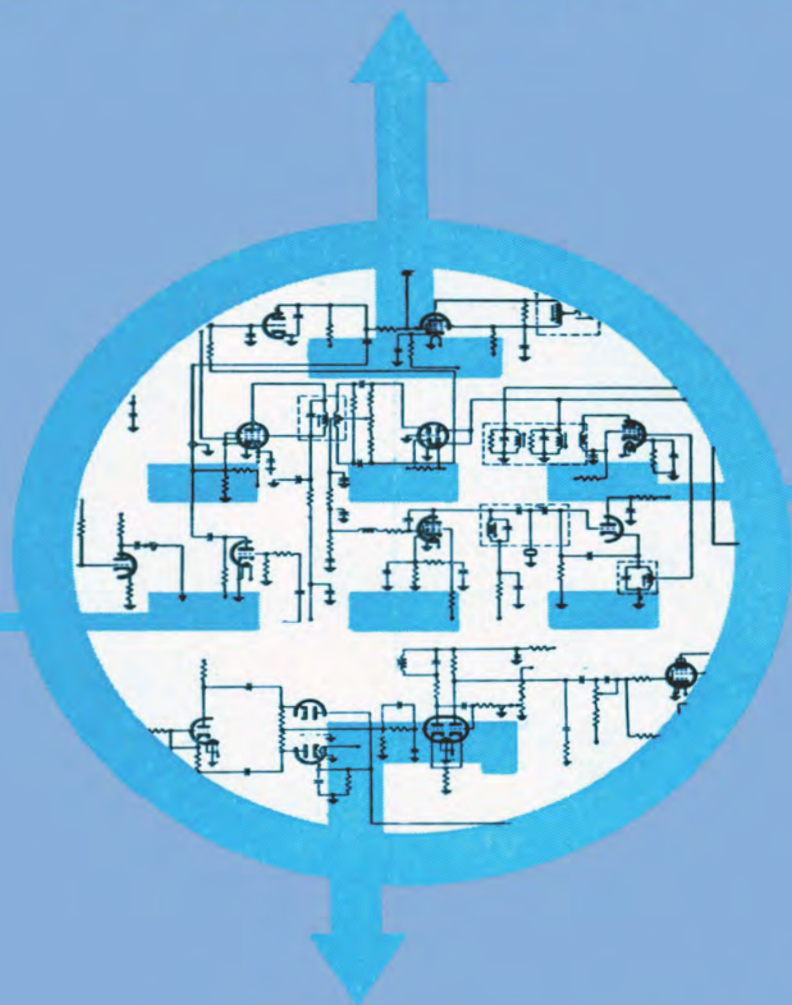


how to read

SCHEMATIC DIAGRAMS

by
DAVID MARK

N. COHEN



a RIDER publication

How to read
SCHEMATIC DIAGRAMS

How to read

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DAVID MARK



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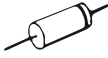
















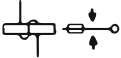


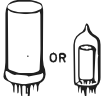

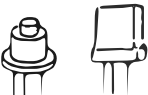
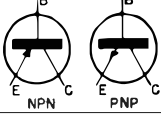
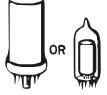



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








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SYMBOL IDENTIFICATION CHART

PART NAME	TYPICAL APPEARANCE	PREFERRED SCHEMATIC SYMBOL	LETTER SYMBOL
CAPACITOR, FIXED			C
CAPACITOR, ADJUSTABLE			C
MOTOR			B or MOT
GENERATOR			G or GEN
LOUDSPEAKER			LS or SPKR
RECTIFIER (DIODE)			V
DRY-METAL RECTIFIER			CR
CRYSTAL (PIEZOELECTRIC)			Y
VIBRATOR			G
PHOTOTUBE			V
VACUUM TUBE (TRIODE)			V
TRANSISTOR			Q
VACUUM TUBE (PENTODE)			V
GAS TUBE (TRIODE)			V

SYMBOL IDENTIFICATION CHART

PART NAME	TYPICAL APPEARANCE	PREFERRED SCHEMATIC SYMBOL	LETTER SYMBOL
CELL			BT
BATTERY			BT
LAMP			I
SWITCH			S
ANTENNA			E
TV ANTENNA			E
FUSE			F
RELAY			K
CIRCUIT BREAKER			CB
RESISTOR			R
POTENTIOMETER (ALSO VARIABLE RESISTOR)			R
RHEOSTAT			R
TRANSFORMER (IRON CORE)			T
TRANSFORMER (AIR CORE)			T
TRANSFORMER (SLUG-TUNED)			T
CHOKE			L
R-F CHOKE			L
COIL (SLUG-TUNED)			L

Preface

Years of progress in the application of electronics has resulted in a vast variety of circuits for high-fidelity sound systems, radios, television sets, cars, intercommunications systems, industrial automation, and special devices and instruments in almost every field of science and technology. But this complex electrical and electronic equipment is no longer confined to use by engineers and technicians with special education and experience in these fields. An increasing number of technicians, students, hobbyists, and even persons with interests varying from agriculture to zoology, are becoming aware that they must be able to read schematic diagrams if they are to progress in their chosen fields.

This book is written to teach the reader, regardless of background or experience, how to *interpret* such diagrams. It makes no pretense to being a shortcut substitute for the years of diligent study and practical experience necessary for a true familiarity with electricity and electronics. Its purpose is to bring about an understanding of the various circuits, and indicate how their recognition may be used as a *basis* for reading and interpreting electrical and electronic schematic diagrams. This general ability will enable the reader to examine the diagram of an equipment and determine its fundamental purpose and principles of operation. In addition, manufacturers' instructions and diagrams will no longer be a thing of mystery, but will serve as a guide for more effective use, new applications, and proper installation, maintenance, and emergency servicing.

Schematic symbols and notations sometimes differ from manufacturer to manufacturer. In order to acquaint the reader with practical schematic diagram reading this text gives the accepted, preferred symbols, and also presents typical illustrations to show some of the differences in notation which may be encountered.

Types of diagrams encountered in electronic and electrical equipment, are discussed in Chapter 1. Chapter 2 explains the parts and schematic symbols most commonly found in connection with direct-current circuits. Chapter 3 reviews alternating-current circuits, their components and schematic symbols. Electronic equipment power supply circuits are considered in Chapter 4. This chapter also includes a number of complete schematic diagram analyses of various power supplies used in electronic equipment.

Chapter 5 examines various types of audio amplifier circuits and their schematics. Also included is an analysis of a complete audio amplifier and the methods of locating parts from the schematic diagram to the equipment itself, and vice versa. In Chapter 6 the knowledge and experience gained during the course of studying this book side-by-side with illustrations, is used in showing the reader how to interpret complete schematic diagrams.

Because of the wide recognition of the term RETMA (Radio Electronic Television Manufacturers Association) in engineering fields, we have retained the use of this term throughout this book rather than use the newer abbreviation—EIA, resulting from the recent name change to Electronic Industries Association.

The author offers his grateful acknowledgement to the following organizations for making available the diagrams and photographs of their equipment which have been used in this book: Allied Radio Corporation; Emerson Radio & Phonograph; Heath Company; Motorola, Inc.; Worner Electronic Devices; Lafayette Radio.

DAVID MARK

Stamford, Connecticut

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Chapter 1

ELECTRICAL AND ELECTRONIC DIAGRAMS

The old saying that one picture is worth ten thousand words was never more true than when applied to modern technology. Imagine the number of words that would be required to describe, without pictures, the construction and operation of the radio shown in Fig. 1-1. Ignoring the problems of manufacturing the various parts, consider the task of correctly assembling and interconnecting them to make a completely operating unit. Think of the number of words required merely to describe accurately the location of each component on the chassis; then consider the involved explanations necessary to indicate the various connections. Next, imagine explaining, still without pictures, how the radio operates and how to service it.

It is obvious that a concise and accurate method of presenting this complex information is needed. All fields of science and engineering (and many of the arts) have systems of notation that enable people to obtain the desired results with a minimum of effort.

SCHEMATIC DIAGRAMS

The field of electricity and electronics has its own form of notation. A technician with adequate experience in electronics, and the necessary parts and equipment, could construct or repair the radio from the information included in Fig. 1-2; and very few, if any, words of additional explanation would be necessary. This illustration is known as a *schematic diagram* and applies specifically to the radio receiver shown in Fig. 1-1. It reveals all the details of overall operation, as well as the functions of the various parts. It

shows the number and kinds of parts required and their interconnections.

A schematic diagram is a complete symbolic representation of all parts and their interconnection in a specific equipment. Because of its peculiar symbolic form, a schematic reveals all details of opera-

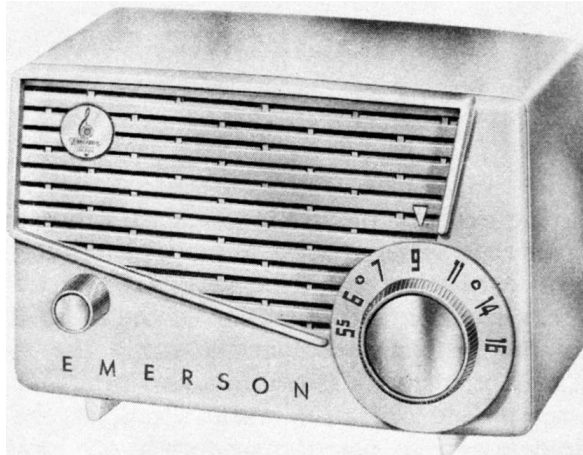


Fig. 1-1. A typical radio. Courtesy Emerson Radio & Phonograph Corp.

tion in a straightforward and concise manner. Examination of Fig. 1-2 will reveal many basic symbols and a number of variations. All the required information is shown. There is no repetition, nor is any necessary. The basic fault with such a schematic diagram is that it has no physical resemblance to the equipment (shown in Fig. 1-1). To the untrained it apparently contains no information concerning the physical locations of the parts. It will be demonstrated during the course of this book that these inadequacies are relatively unimportant, and that they are solved either by special techniques (which will be explained) or by the use of other types of diagrams. The different types of diagrams give a pictorial representation of the equipment under consideration.

Many attempts have been made to standardize the symbols used in schematic diagrams. During the past 10 years various manufacturers, publications, engineering societies, and military organizations have worked out widely accepted standard systems of presentation. Since variations do exist at the present time, the important differences will be presented in this book; but preference

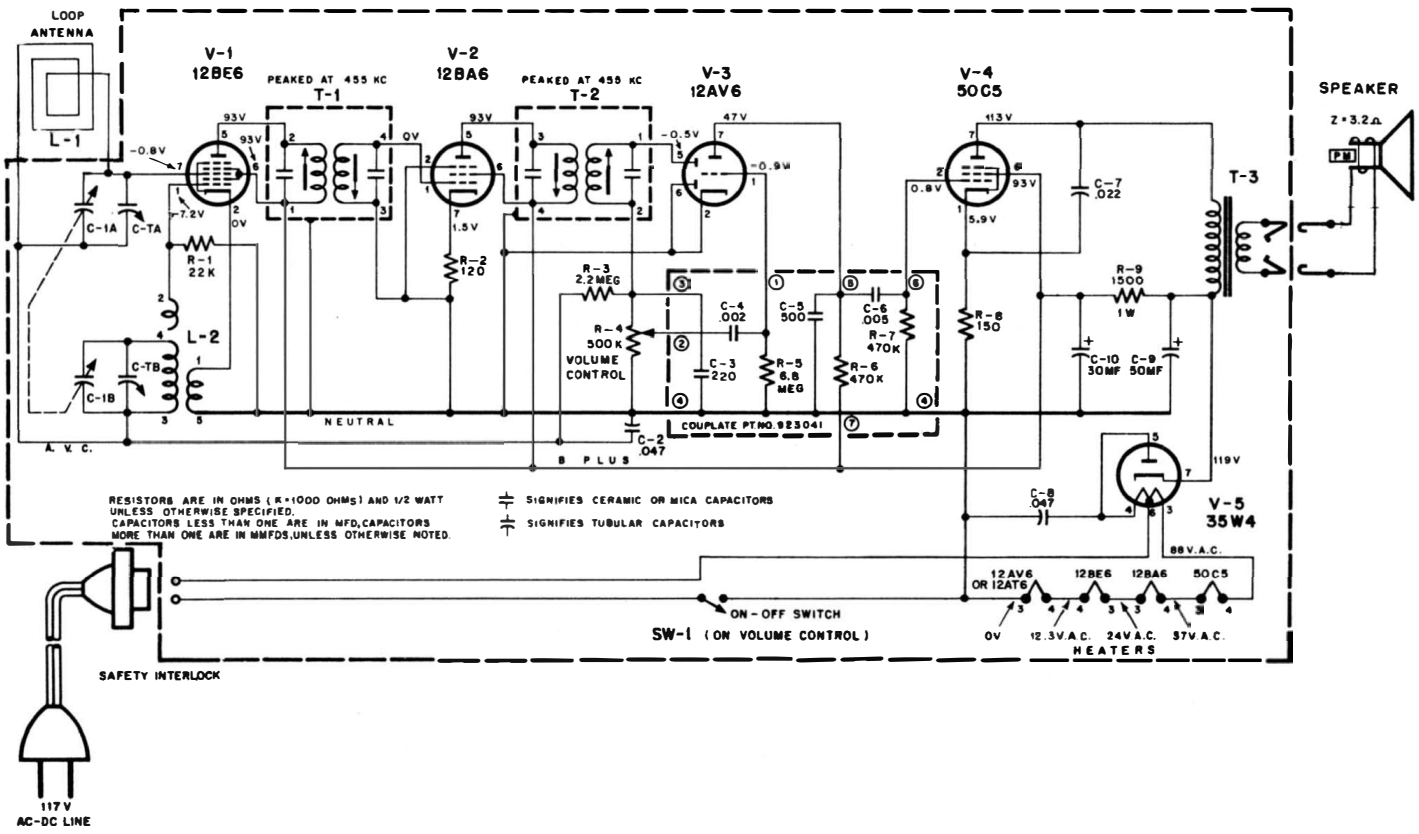


Fig. 1-2. Schematic diagram of a typical radio. Courtesy Emerson Radio & Phonograph Corp.

will be given to the standard forms of the Institute of Radio Engineers (I.R.E.) and to military standards.

Although other types of diagrams are sometimes used in connection with electrical and electronic equipment, the schematic is usually the only one that is absolutely necessary. It is frequently the only one supplied by the manufacturers of equipment. The purpose of other types of diagrams is merely to present the sche-

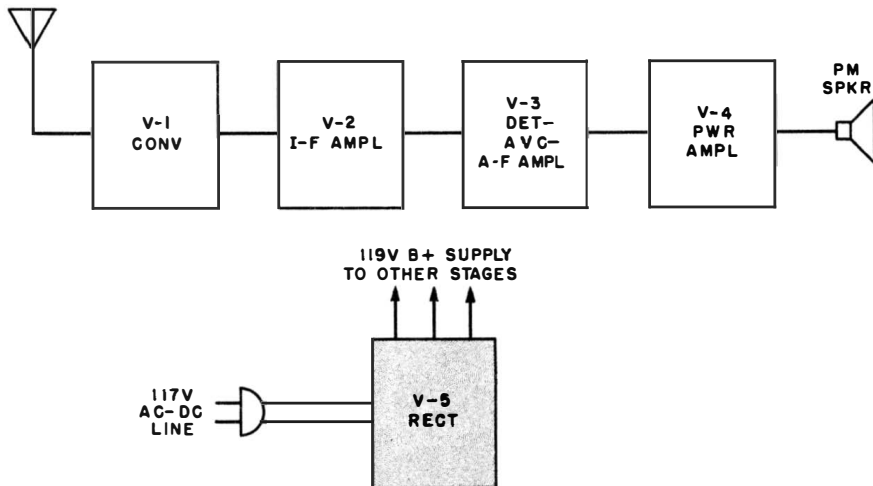


Fig. 1-3. Block diagram of a radio set.

matic in abbreviated form or to reveal the physical layout of the parts and certain details of mechanical construction.

Other types of diagrams that will be encountered in association with electrical and electronic equipment include block, interconnection, wiring, layout, pictorial, and construction diagrams. These other types will be described and evaluated in this chapter. However, since they serve only a limited purpose, their use in later chapters will be confined mainly to the explanation of the various features of schematic diagrams.

BLOCK DIAGRAMS

Block diagrams are shorthand versions of schematic diagrams. Figure 1-3 shows a block diagram of the same radio set discussed previously. In a block diagram, major sections of the schematic diagram are drawn as squares or rectangles containing words and

symbols to identify their functions (and sometimes their major components). What is shown depends upon the intended use. When working with equipments of complexity equal to or less than that of a television set, it is not unusual to draw each tube and its associated parts as a separate block, although a series of tubes of similar function is often depicted by a single block. In working with large systems, such as a complete television studio, a major equipment unit containing dozens of tubes may be drawn as a single block.

The block diagram is used mainly by designers, technicians, repairmen, and advanced students for depicting the operation of a complete equipment or system. It is a concentrate of the major features of the schematic. Its lack of detail enables the user to see quickly the relationships and interconnections between major portions of the equipment.

There also is a special type of block diagram that is used for showing the hookup between a large number of equipment units, such as A-M and F-M tuners, phonograph, tape recorder, amplifier, and loudspeaker systems. This type of block diagram is called an *interconnection diagram*. In it each equipment unit is shown as a block, and only the details of the connections between the blocks are shown. An example of this type of diagram will be seen in Chapter 6.

WIRING AND CABLING DIAGRAMS

Although a schematic or a block diagram may *imply* the general location of the parts, there is a need for a type of illustration that shows the location of parts and connecting wires. Layout and pictorial diagrams (to be considered later), are all attempts to solve this problem in a practical manner. These methods do not succeed in showing the details of each and every connection. Wiring and cabling diagrams show the desired information, but they are very rarely supplied with equipment intended for commercial distribution.

Wiring and cabling diagrams consist of simplified outlines of all of the parts and the connecting wires or cables. This type of drawing is to be preferred to a photograph because, to the trained eye, it shows all the required information much more clearly. While wiring diagrams reveal the location of the parts and the required connections, they give little or no information concerning the function and relationships of the components. This can be accomplished only by schematic and block diagrams.

LAYOUT DIAGRAMS

Layout diagrams are simplifications of wiring diagrams. Figure

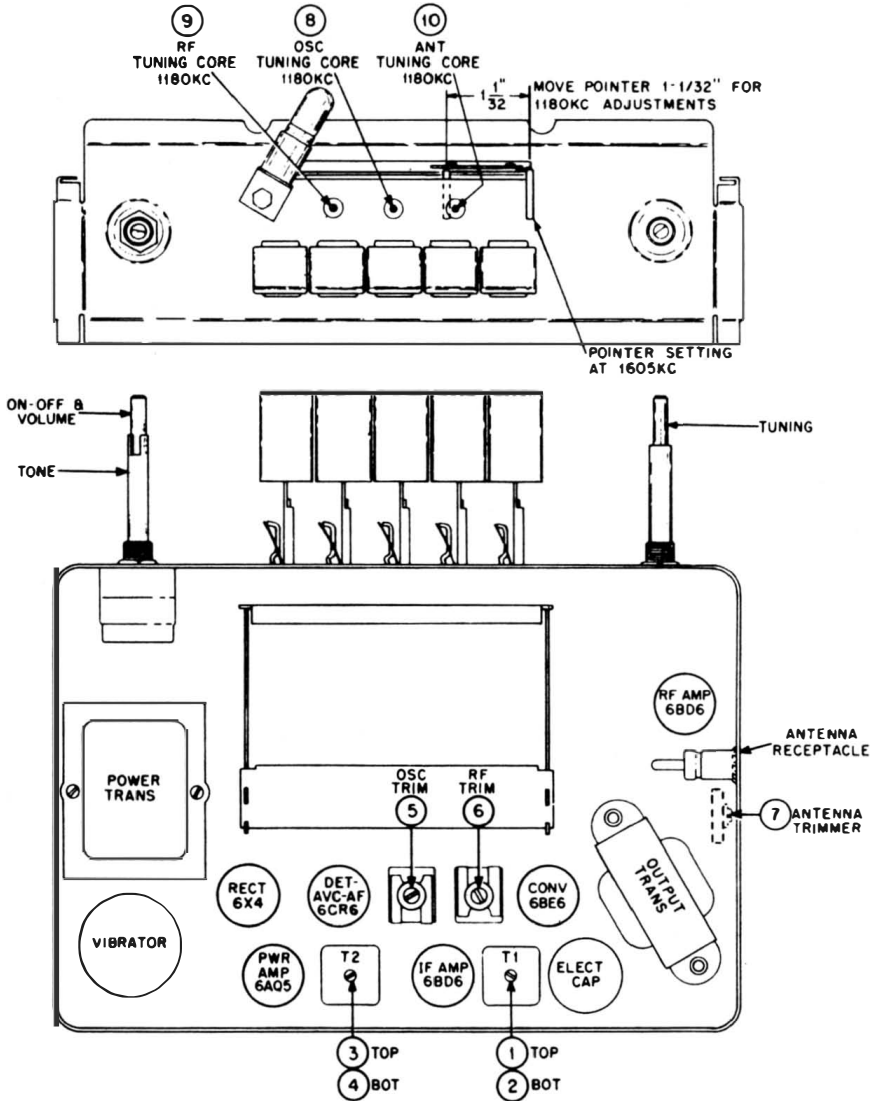


Fig. 1-4. Layout diagram of a typical radio. Courtesy Motorola, Inc.

1-4 is a manufacturer's layout diagram for a typical automobile radio. In such a drawing only the outlines of the major parts are

shown. The purpose of a layout diagram is to provide a means of rapidly locating the major parts without consideration of the details. Layout diagrams are generally used during the process of equipment design and manufacture, although they are also useful to repairmen.

PICTORIAL WIRING DIAGRAMS

Pictorial wiring diagrams are drawings or photographs upon which arrows or key symbols are added to identify the parts. Figure 1-5 is a pictorial wiring diagram of a high-fidelity amplifier. Such drawings are often used in place of photographs because they eliminate confusing shadows and provide a method of "moving" certain parts to reveal components which would be blocked, in a photograph. For simple equipment it is sometimes possible to use this type of illustration as a substitute for the wiring diagram.

The use of pictorial diagrams is rather limited, because the equipment layout usually makes it extremely difficult to present all of the required information by means of this technique. Pictorial diagrams or labeled photographs are generally found in instruction books supplied with kits for building radios, hi-fi amplifiers, test equipment, etc., and in repair manuals for military equipment. In these cases, the supplier of the equipment does not wish to take a chance on any part being incorrectly identified, and the pictorial diagram provides a positive check when used in conjunction with the schematic diagram.

MECHANICAL CONSTRUCTION DIAGRAMS

Certain specialized types of electrical and electronic equipments require the use of mechanical devices that cannot be described by means of schematic or wiring diagram techniques. Such devices may include push-button control systems, rotating antenna drives, optical components, hydraulic control systems, magnetic tape drives, etc. When the presentation of such information is necessary for an understanding of the electrical or electronic equipment, *mechanical construction diagrams* are used.

These diagrams are not the complex drawings used in the manufacture of the equipment. They are extremely simplified to enable the user of the electrical or electronic equipment to understand their purpose. Depending upon the detail to be shown, mechanical construction diagrams generally consist of labeled

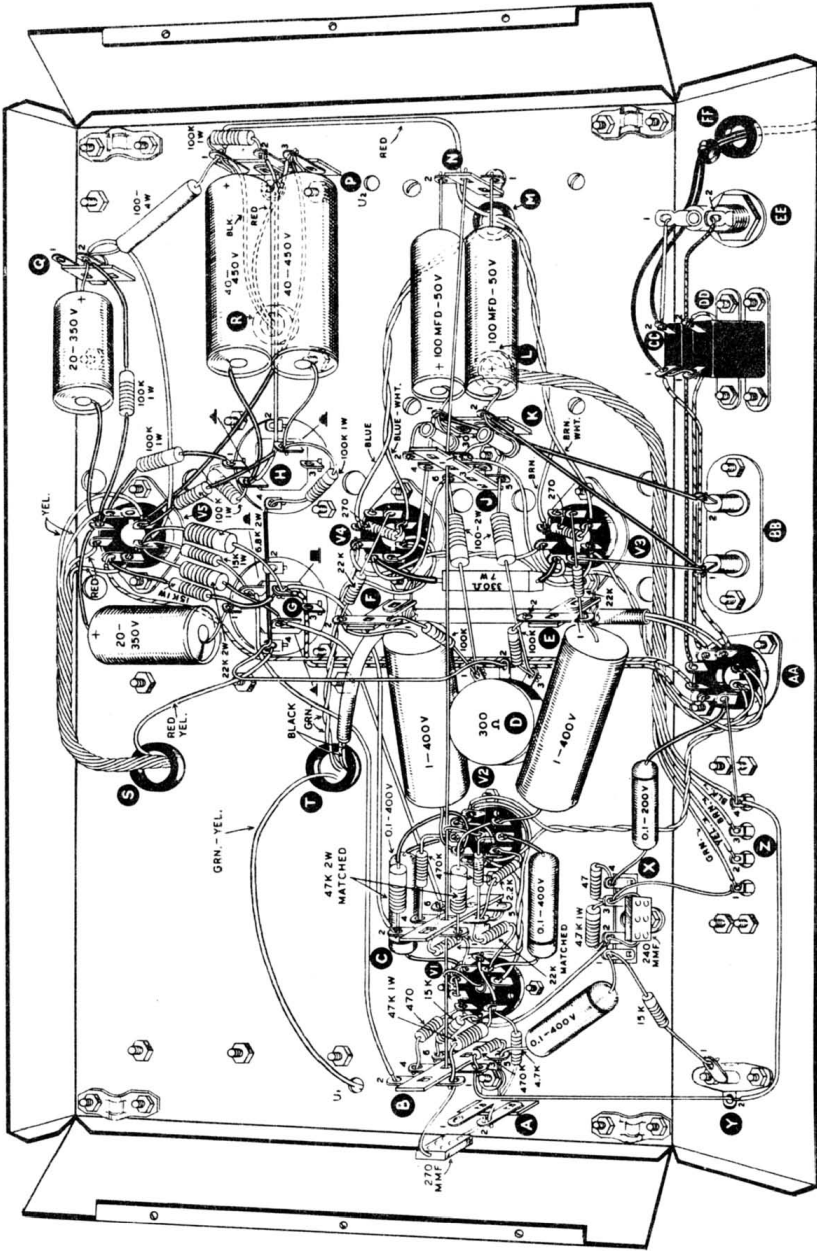


Fig. 1-5. Pictorial wiring diagram for home construction of high-fidelity amplifier. Courtesy Heath Company.

photographs, outline drawings, or cutaway drawings. Examples of these are shown in later chapters.

CONCLUSION

Of all the types of diagrams mentioned in this chapter, the *schematic diagram* is by far the most important and the most useful. Because of the universal acceptance of this form of presenting information, it is the only type that is *always* supplied by manufacturers of electrical or electronic equipment; in many cases it is the only type of diagram supplied. The reason for this is that many manufacturers are of the opinion that no one should attempt adjustments and repairs of the equipment unless he is capable of accomplishing this with only the assistance of a schematic diagram. Layout and pictorial diagrams, along with labeled photographs, are the most widely accepted devices for indicating the physical layout of the various parts and the required interconnections.

Schematic diagrams are complete symbolic representations of electrical and electronic equipment. To *read* them correctly it is necessary to obtain a knowledge of the various parts, their general appearance and purpose, and the symbols used to represent these parts in a circuit.

To *interpret* schematic diagrams it is necessary to identify the various component symbols in a diagram, to recognize or deduce their functions in the circuit sections and stages, and form valid conclusions concerning the effects of these on the overall operation of the equipment. This requires an understanding of the basic parts and recognition of their symbols. In addition, it is necessary to understand and recognize the basic combinations of these parts, so that the overall functions of more complex arrangements may be determined. For this reason, much of this book is devoted to components and their basic combinations. The remainder is concerned with methods and examples of interpreting complex schematic diagrams and their relationship to the actual equipment.

Charts depicting some of the most frequently used electrical and electronic parts, alongside their schematic symbols and identifying letters, appear on pages v and vi.

Chapter 2

DIRECT-CURRENT CIRCUITS

The electron theory is the most widely accepted and useful theory for explaining all electrical and electronic phenomena. In accordance with this theory, an atom is the smallest particle into which an element may be divided without losing its physical and chemical characteristics. There are more than 100 distinctly different types of atoms, and these correspond to the known elements. Every atom contains a *nucleus*, or core, about which one or more negatively charged particles revolve. In the nucleus are positively charged particles (*protons*), neutral particles (*neutrons*), and other particles (which are still being investigated). The negatively charged particles move in orbits about the nucleus, and are known as *electrons*; in a neutral atom their number is exactly equal to the number of protons in the nucleus. Their orbits form various rings or shells, and the arrangement and number of electrons in these rings are characteristic of the element. The electrons in the outer ring are the only ones that enter into normal chemical reactions or electrical effects.

There are various methods by which some of the outer electrons can be removed from their atoms and forced to move in a circuit to perform the desired function. The most important of these involve chemical and magnetic action.

DIRECT CURRENT

The production of a flow of electrons by means of chemical action makes possible such devices as the flashlight and the portable radio. In these applications a chemical action takes place in the

battery, and electrons move within the wire and the other electrical components connected to the battery. This "flow" of electrons can be utilized to generate light or heat, or to amplify weak sounds or radio signals. Since the electron flow produced by chemical action is in only one direction, from one battery terminal through the connecting wires and back to the other terminal, this type of electron flow is known as a *direct current* (abbreviated dc).

ALTERNATING CURRENT

A flow of electrons can also be produced by pushing a magnet into a coil of wire. If a zero-center electric meter is connected to the ends of the coil, its pointer will swing in one direction as this is done. When the magnet is pulled out of the coil, the pointer will swing in the opposite direction, indicating that there is a second electron flow in the opposite direction. In cases where the electron flow reverses direction in this manner, the result is known as *alternating current* (abbreviated ac). The electric generators used in power stations are an important example of the production of electron flow by means of magnetism. Through the proper arrangement of parts and electrical connections, it is also possible to construct generators that will produce dc.

D-C SCHEMATIC DIAGRAMS

The components commonly used in d-c equipment include cells and batteries, lamps, switches, fuses, relays, and resistors. These can be connected in a variety of arrangements to make up complete automotive and marine lighting systems, home and farm lighting systems, and many important sections of electronic equipment.

Nearly everyone is acquainted with the most outstanding features of lighting circuits. It is common knowledge that a flashlight containing two or three standard batteries sends out a much more powerful beam of light than a small pen-sized flashlight. Anyone who has ever seen an automobile at night knows that an auto headlamp emits more light than most flashlights, and most have noticed that a 100-watt bulb is much brighter than a 50-watt bulb.

Although a thorough comprehension of the reasons for those observations involves a fairly extensive study of the basic principles of electricity, a brief review of the fundamentals is adequate for an understanding of the schematic diagrams of lighting circuits. The

most important basic concepts in work with electricity and electronics include the phenomena of voltage, current, resistance, and power. The principles of these will be made clear by an investigation of lighting circuits made up of bulbs and batteries.

CELLS, BATTERIES, AND LAMPS

A flow of electrons can be produced by chemical action. All that is required is to place plates or rods (called *electrodes*) of certain

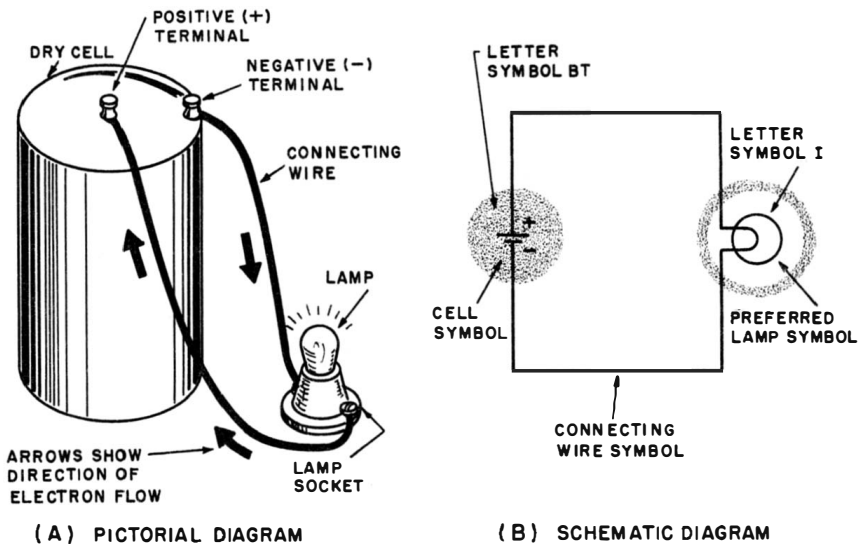


Fig. 2-1. Basic cell and lamp circuit. (A) Pictorial diagram. (B) Schematic diagram.

materials into a container with a fluid or paste (*electrolyte*) that reacts chemically with at least one of the electrodes. The container in which the effect takes place is known as an electric *cell*; when a number of cells are connected together, the complete arrangement is known as a *battery*. Generally speaking, if the cell is permanently sealed so that the paste electrolyte cannot leak out, it is known as a *dry cell*. If the cell is open, or can be opened, and contains a liquid electrolyte, it is a *wet cell*.

Simple cell and lamp schematic diagram. If an electric lamp is connected across the terminals 2-1A, a steady electron flow will take place through the lamp. The

lamp contains a thin wire or *filament* of special material which is heated by the flow of electrons. The electron current causes the filament to become white hot, and light is emitted.

The chemical action causes an excess of electrons to collect on the terminal of one of the electrodes (the *negative* electrode) and also causes a shortage of electrons on the other (*positive*) terminal. Since a definite direction of electron flow is associated with the cell, it is known as a *polarized* device; and the positive and negative terminals are always marked with plus (+) and minus (-) signs. The lamp will give the same light regardless of the direction of electron flow through it, and it is known as an *unpolarized* device.

The schematic diagram for the cell and lamp arrangement is shown in Fig. 2-1B. Notice that the symbols are a fairly pictorial representation of the parts. Connecting wires are shown as lines, and the lamp symbol shows the outline of the glass bulb with a filament inside. The symbol for the cell consists of a short thick line to represent the negative electrode, and a longer thick line to indicate the positive electrode. Standard letter symbols are often used as further identification for all electrical parts. The letter I is used to indicate a lamp, and the letters BT indicate a cell or battery. If a schematic diagram contains several similar symbols, they are further identified with numbers, such as I1, I2, BT1, etc.

A *primary* cell or battery (usually of the dry type) is one that will cease to operate after the chemical action has exhausted some of the materials inside. When this occurs, the cell or battery must be replaced with a new one. A *secondary* cell or battery (usually of the wet type) is one in which the exhausted chemical contents can be restored to their original condition by means of an electric current.

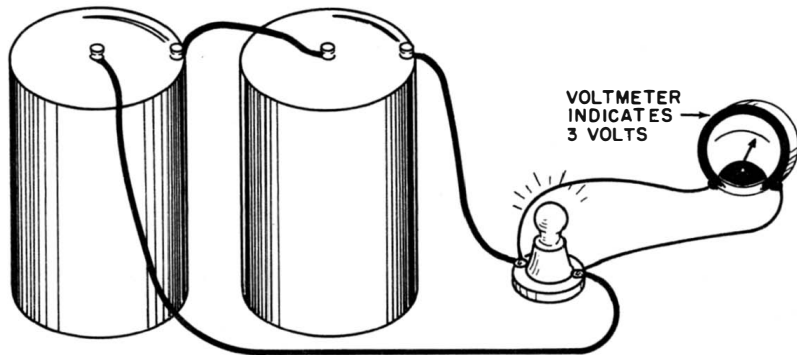
The automobile storage battery usually consists of three or six secondary wet cells, which are capable of being recharged for further use. In the process of recharging, an outside d-c source is used to pass an electron current through the battery, the direction of flow then being opposite to that normally produced by the battery. Although this requires the use of additional components, the procedure is more economical and convenient than replacing the automobile battery.

SERIES LIGHTING CIRCUITS

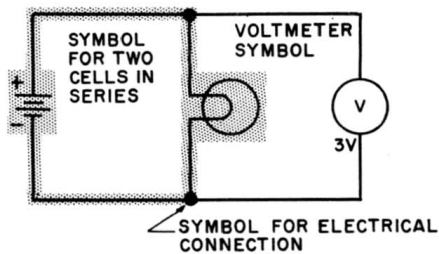
The complete arrangement of parts shown in Fig. 2-1 is known as a *circuit*. In order for an arrangement to be called a circuit, it must contain a source of electricity, plus components capable of

providing a path for the electrons from the negative terminal through at least one component (the *load*) that utilizes the electron flow, and back to the other terminal.

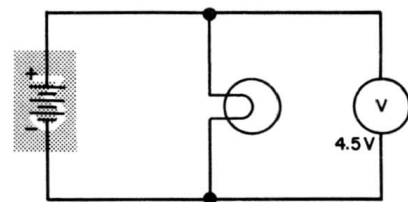
Voltage. Just as it requires physical force to move an object from one location to another, there is a certain type of force required to move electrons through a lamp and the connecting wires. The force



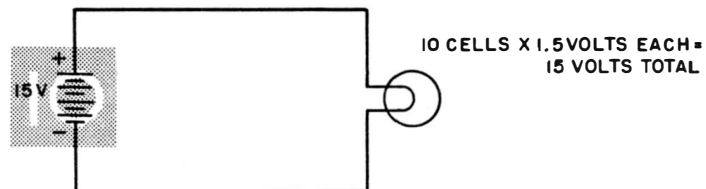
(A) PICTORIAL DIAGRAM OF TWO CELLS IN SERIES, SHOWING VOLTMETER CONNECTION



(B) SCHEMATIC DIAGRAM OF (A)



(C) THREE CELLS IN SERIES



(D) TEN CELLS IN SERIES, SHOWING VOLTAGE CALCULATION

Fig. 2-2. Voltage relationships for cells in series. (A) Pictorial diagram of two cells in series, showing voltmeter connection. (B) Schematic diagram of (A). (C) Three cells in series. (D) Ten cells in series, showing voltage calculation.

that causes electrons to flow is known as *electromotive force* (abbreviated as *emf*). Electromotive force is generated by the chemical action in electric cells. The unit of measuring electromotive force is the *volt*. A flashlight dry cell has an emf of about 1.5 volts, while each cell in an automobile storage battery produces an emf of about 2 volts. The type of electric meter used to measure emf is known as a *voltmeter*, and it is always connected as shown in Fig. 2-2.

Series connections. If two dry cells are connected to a lamp in the arrangement shown in Fig. 2-2A, the cells are said to be connected in *series*, since all of the electron current flows through each of the cells. Each cell has an emf of 1.5 volts, but the total voltage across the lamp is 3 volts (note voltmeter connection). The result of this is that the lamp glows much more brightly, since twice as much electromotive force across it causes twice as much current to flow through it. Figure 2-2B shows a schematic diagram of this arrangement of parts, and it can be seen that the battery symbol consists of two cells.

The addition of more cells in series with the lamp is indicated by the schematic arrangement in Fig. 2-2C. As more cells are added, it is common practice to draw only three or four cells and to write down the total emf, as shown in Fig. 2-2D. The total voltage of cells connected in series is equal to the emf of one cell multiplied by the number of cells in the battery.

Current. The amount of current is a unit called the *ampere*. One ampere is equal to the flow of 6.3×10^{18} (6,300,000,000,000,000) electrons per second past any selected point in the series circuit. When it is necessary to measure the current flow, an electrical meter called an *ammeter* is used. This meter is always connected in series with the flow of electrons. Connecting an ammeter into the lighting circuit indicates that, as more cells are connected in series with a lamp, the current through the filament doubles and triples to correspond with the total battery voltage. This effect is shown in Fig. 2-3A. Note that identical current flows through all portions of a series circuit.

A reverse effect occurs if the number of cells in a battery is kept constant, but additional lamps are connected in series with the battery. Figure 2-3B shows that under such conditions the current drops in direct proportion to the number of bulbs used. In addition, a measurement of the voltage across each of the bulbs indicates that only part of the total voltage appears across each of the lamps, although the total of all these voltages equals that of the battery. The reason for this decrease in current is that the material

of the bulb filament impedes or resists the flow of electrons. This quality is known as *resistance*.

Resistance. Any object resists the flow of electrons through it. The resistance offered is determined, as shown in Fig. 2-4, by the material, by its length, and by the area of its cross section. Metals, in general, are good conductors of electricity; of these copper and silver are among the best. Materials like rubber, glass, and baked clay are very poor conductors of electric current and are known as *insulators*. As far as the length and cross-sectional area of a material are concerned, it may be said that resistance increases as length increases, but resistance decreases as diameter increases.

The unit of resistance measurement is the *ohm* and the meter designed to measure resistance is known as an *ohmmeter*. An object has a resistance of 1 ohm if it conducts 1 ampere of current when 1 volt of emf is connected across it. The relationship between voltage, current, and resistance is expressed by Ohm's Law, which states that:

$$\text{Current (amperes)} = \frac{\text{electromotive force (volts)}}{\text{resistance (ohms)}}$$

Example: For a lamp with a resistance of 6 ohms connected across a 1.5-volt cell, the current is:

$$\frac{1.5 \text{ (volts)}}{6 \text{ (ohms)}} = 0.25 \text{ ampere}$$

These definitions and relationships explain the previous statements about the various effects observed in the lighting circuit. The battery is the source of emf, and the lamp is the major resistance in the circuit. Since the filament in the lamp is made of a very thin wire of a metal (tungsten) that has poor conductivity, the resistance of the filament is high compared to that of the connecting wires. In spite of their long length the connecting wires are much thicker than the filament and are made of a material (copper) that is an excellent conductor. Consequently, the major resistance in the circuit is that of the lamp.

It can be seen from Ohm's Law that if the number of cells in a circuit is kept constant, doubling the number of bulbs in series will effectively double the resistance and reduce the current to half (Fig. 2-3B). It is also clear that if the number of bulbs is kept constant, the current can be doubled by doubling the number of cells in series (Fig. 2-3A).

Power. Power is the rate of doing work. Whenever a force moves

an object, *work* is accomplished. Electromotive force causes electrons to move against the resistance in the circuit. Electric power is the rate at which this work is done, and the unit of power meas-

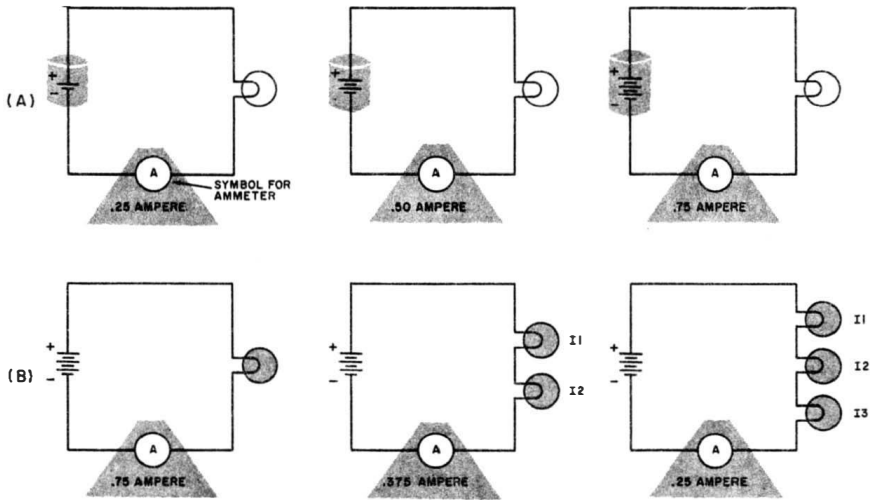


Fig. 2-3. Current relationships for cells and lamps in series.

urement is the *watt*. One watt of power is expended when 1 volt of emf causes 1 ampere of direct current to flow. Since 1 ampere is equal to a definite number of electrons flowing in 1 second past any one point in the circuit, it can be seen that watts of electric power are equivalent to work done in 1 second.

Power is calculated by multiplying the voltage times the current.

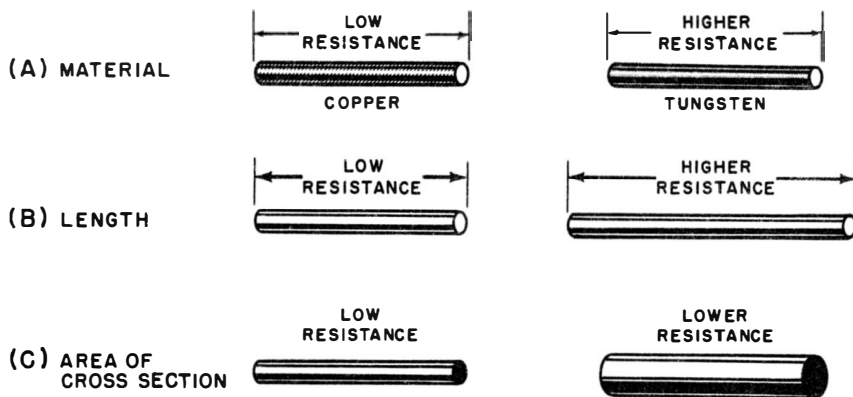
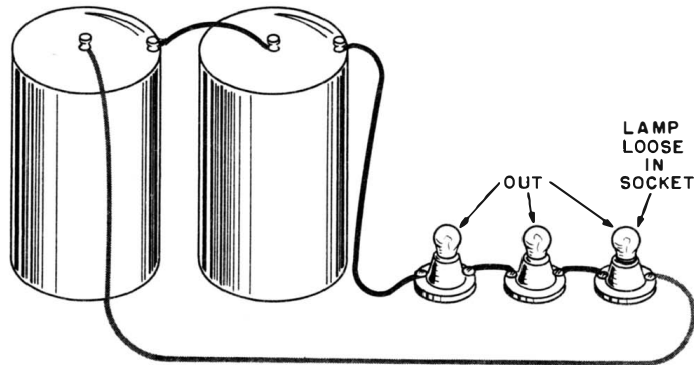
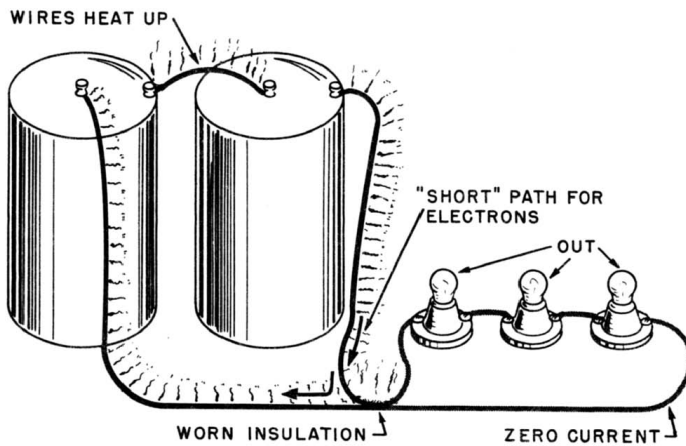


Fig. 2-4. Factors affecting resistance.

If 0.2 ampere flows through a lamp when an emf of 1.5 volts is applied across that lamp, the power expended is 0.3 watt. Electric



(A) OPEN CIRCUIT



(B) SHORT CIRCUIT

Fig. 2-5. Short circuit permits excessive current flow.

light bulbs are usually marked with voltage and power ratings. If a bulb is marked 110V 50W, this means that its resistance is such that it will consume 50 watts of power when connected across a source of 110 volts.

Open and short circuits. In a series circuit all the electric current flows through all the components in sequence. If one of the connections becomes disengaged or if one of the bulbs burns out, all

flow of current ceases, and all of the lights go out. This condition, in which there is an incomplete path for the electric current, is

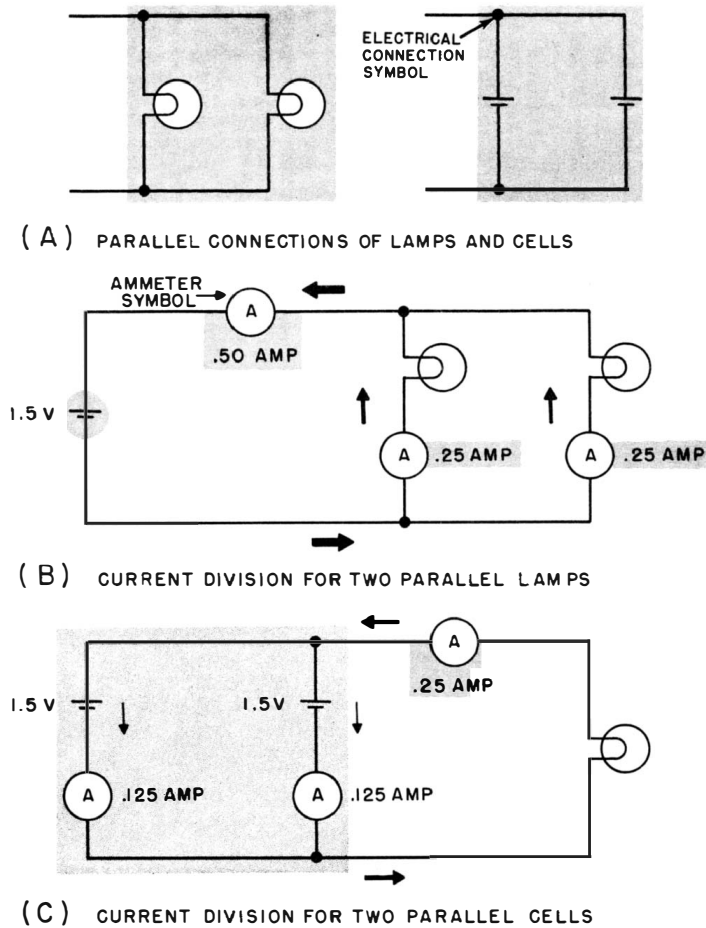


Fig. 2-6. (A) Parallel connections of lamps and cells. (B) Current division for two parallel lamps. (C) Current division for two parallel cells.

known as an *open circuit* (see Fig. 2-5A). A *short circuit* is a condition in which worn insulation, physical damage, or foreign objects provide a direct connection between the voltage source terminals, permitting the current to bypass the load. In this case, as shown in Fig. 2-5B, the electron current is no longer limited by the resistance in the circuit, since there is a “short” path between the

terminals of the voltage source. When a short occurs, the current flow is limited only by the very low resistances of the connecting wires and the internal resistance of the voltage source itself. Large currents develop heat, and severe damage usually results.

PARALLEL AND SERIES-PARALLEL CIRCUITS

Parallel circuits. Series circuits are by no means the only ones used in electrical and electronic equipment. When components are

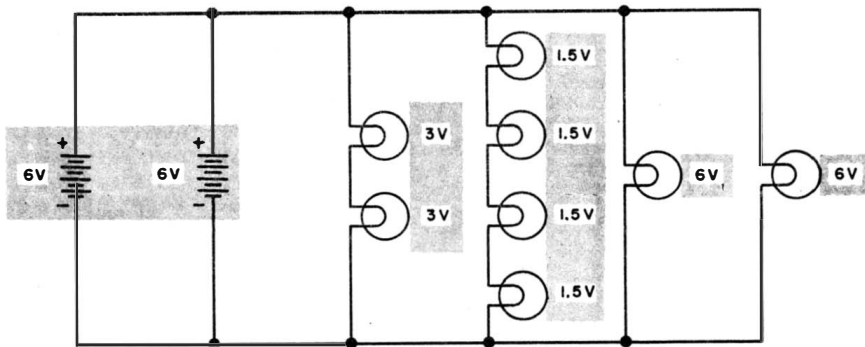


Fig. 2-7. Series-parallel circuit of lamps and batteries. All lamps operating at correct voltage ratings, as indicated.

attached side by side, as shown in Fig. 2-6A, they are said to be *parallel-connected*. If two lamps of equal resistance are connected in parallel across a dry cell (Fig. 2-6B), the total current through the cell divides equally between the lamps. In the event that the lamps have different resistances, the current division will be unequal, with the larger portion of the total current flowing through the lower resistance.

The current through the individual lamps may be calculated from Ohm's Law, and the total current through the cell equals the sum of the currents through the individual loads. Figure 2-6C shows what happens if two cells of the same voltage are connected in parallel with a single lamp. In this type of connection the total voltage of the two cells is the same as for a single cell, but twice as much current is supplied without placing an excessive strain on the individual cells.

Series-parallel circuits. A series-parallel circuit is one containing parts connected in series and parts connected in parallel. Cells are connected in series to obtain higher voltages. When a large amount

of current must be supplied without increasing the voltage, the cells are connected in parallel.

Figure 2-7 shows the various voltages in a circuit containing both cells and lamps connected in a series-parallel arrangement. The illustration shows a method of making use of 1.5-volt, 3-volt, and 6-volt lamps. Connecting several of these batteries in parallel minimizes the current drain on the individual cells. To make use of the 6-volt source thus obtained, two 3-volt lamps or four 1.5-volt lamps can be connected in series across the line. If a 6-volt lamp burns out or is removed, the remaining lamps will be unaffected. In the event that any one of the series-connected lamps burns out, only the others in series with it will also go out.

SWITCHES

Purpose. To turn off a lamp in any of the circuits considered previously, it would be necessary to remove the lamp from its socket or to disconnect a wire from one lamp terminal. Doing this in a series circuit turns out all the lights (the same result can be obtained by making a disconnection anywhere in the circuit). In a circuit containing a number of light bulbs in parallel, disconnecting a wire from a specific lamp terminal will turn off only that particular bulb. Of course, it is impractical to turn off lights by removing bulbs or disconnecting wires. A switch provides a much better method.

Construction. A switch is the most convenient and most widely used method of opening and closing a circuit. The construction of the basic form of a switch is shown in Fig. 2-8A. This type is known as a *single-pole, single-throw knife switch* (spst knife switch). When the handle is pulled up, the blade pivots on the fixed pin, the free end is pulled from between the spring contacts, and the circuit is opened. The circuit is closed when the handle is pushed down. The symbol for this type of switch is shown in Fig. 2-8B. The standard letter symbol is S, and different switches in a diagram are identified as S1, S2, etc.

This type of switch is useful for making or breaking a single connection. Since its open construction shows how it operates, it is most often used in primary power lines and in classroom demonstrations where low-voltage circuits are generally used. This construction is dangerous, however, when high voltages are used, and completely enclosed switches, such as shown in C and D of Fig. 2-8, are generally used. The basic operation of all of these types is identical. A handle or push button presses the metal blade between

spring contacts, and the circuit is closed. When the metal blade is pulled out from between the contacts, the circuit is open.

Switch terminology and symbols. The terminal of the metal blade (together with the blade itself) is known as the *pole*. When

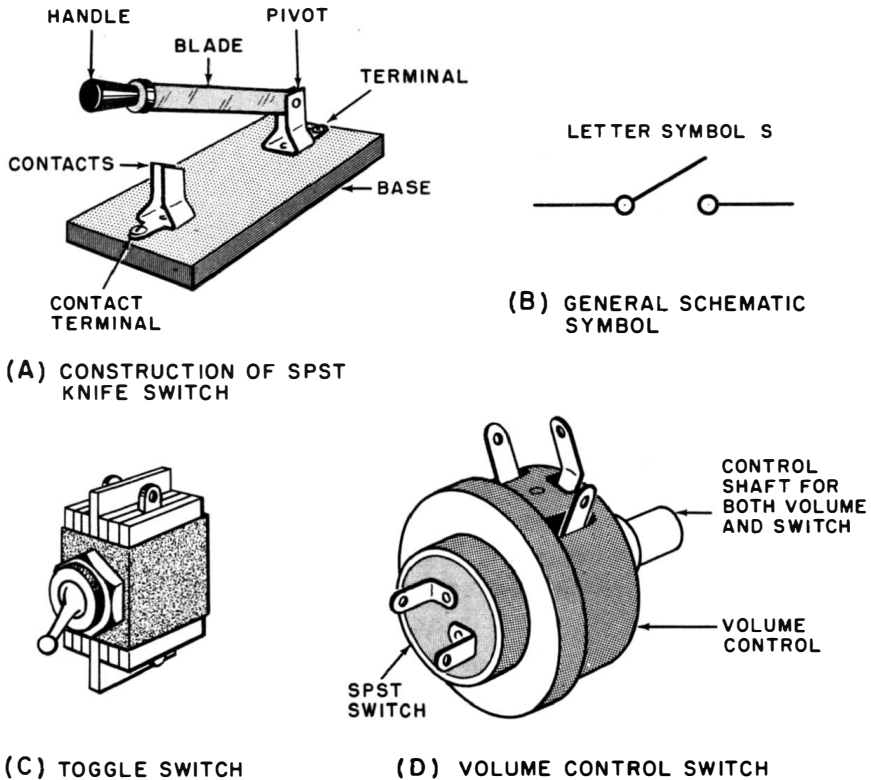


Fig. 2-8. Single-pole single-throw switch. (A) Construction of spst knife switch. (B) General schematic symbol. (C) Toggle switch. (D) Radio volume control switch.

only one blade is used, the device is known as a *single-pole switch*. When there is only one set of contacts for the free end of the blade to go to, the device is a *single-throw switch*.

In the event that a switch must function in two circuits, opening one whenever it closes the other, a switch with two pairs of contacts is used; this is known as a *single-pole double-throw* (spdt) switch.

Switches are available with three or more sets of contacts for connections to the pole. Although the previous terminology might

be extended to these, they are more simply described as *selector* switches and classified as three-position single-pole, four-position single-pole, etc.

When a number of circuits are used together, it is often con-

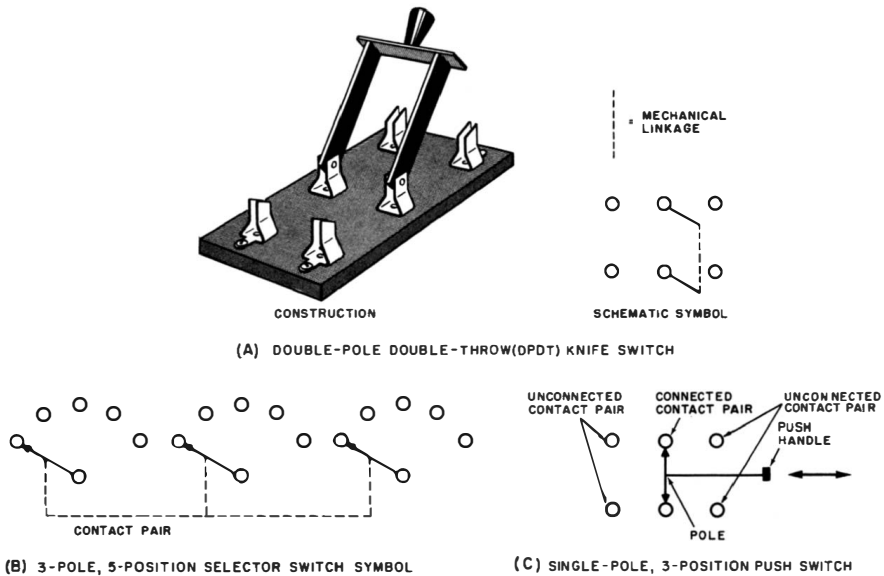


Fig. 2-9. (A) Double-pole, double-throw knife switch construction and schematic symbol. (B) Three-pole, five-position selector switch symbol. (C) Single-pole, three-position push symbol.

venient to activate them with a single switch. In such cases the switch has a single handle which is used to move two, three or more contact blades (poles) to any desired number of positions (see Fig. 2-9). A switch with two blades, each having two sets of contacts (Fig. 2-9A) is known as a *double-pole double-throw* (dpdt) switch. The type shown in B is described as a three pole, five-position selector switch.

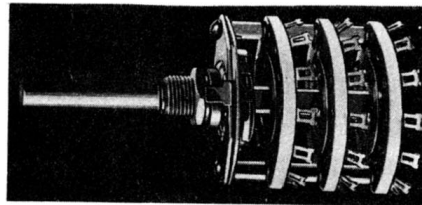
Another type of switch worthy of mention is the push switch. This type has one or more pairs of separated contacts, and the movable pole is pushed between the pair to be connected. The example shown in Fig. 2-9C is, in effect, a single-pole, three-position selector switch. In most electrical equipment it is unusual to find anything more complex than a dpdt switch. However, complex switching arrangements are fairly common in electronic equipment, and examples are presented in Chapter 6.

WAFER SWITCHES

In some electronic equipment it is often necessary to perform a number of complex switching functions with a single control knob. Such switches are often constructed in the form of a rotary switch, which may consist of from one to six, or more, elements known as

Fig. 2-9D.

Typical three-gang wafer rotary switch. Courtesy Centralab.



A THREE-GANG ROTARY SWITCH
(D)

wafers. When a number of wafers are mounted on the same frame, so that they are under the control of a single shaft and knob, the result is a ganged construction of wafer elements.

A typical three-gang rotary (wafer) switch is shown in Fig. 2-9 (D). Each wafer assembly consists of an outer and inner insulating disc, as shown in Fig. 2-9 (E). A number of miniature spring contacts,

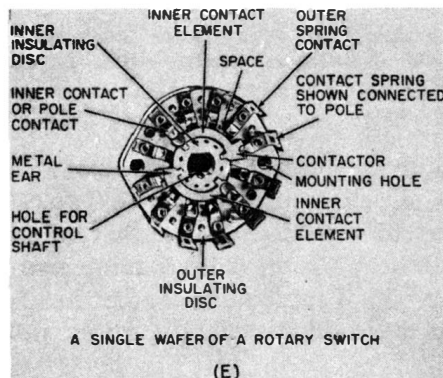


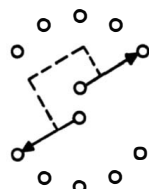
Fig. 2-9E.

Detail of a single wafer of a rotary switch.

usually a dozen or less, are mounted around the outer disc. From one to four metal contact elements are mounted upon the inner disc, each with a single projecting metal ear. Each of these central elements corresponds to a switch arm. The outer disc is held stationary by the switch frame, while the control shaft turns the inner disc. The wafer assembly shown in Fig. 2-9 (E) has two pole contacts, each of which has five associated spring contacts. The result

is a two-pole, five-position selector switch, schematically shown in Fig. 2-9 (F).

The two pole contacts are longer than the spring contacts. Their metal ears always press against one of the five inner contact elements. The other, shorter contacts can only touch the ear when it is turned so as to make such a connection possible. Thus, there is



SCHEMATIC REPRESENTATION
OF A TWO-POLE
FIVE-POSITION SELECTOR
SWITCH
(F)

Fig. 2-9F.

Schematic of a two-pole,
five-position selector switch.

an electrical connection between each pole and the spring contact touching its ear on the inner contact elements. By turning the control shaft a connection can be made between each pole and any one of its five associated contacts. Mechanical stop mechanisms permit the control shaft to be set only to the five associated contacts. There are other mechanical arrangements of the wafer construction, but the effect is always the same.

RELAYS

Purpose. There are many applications in which it is extremely inconvenient to close a switch by the method of directly moving the activating handle. In those cases the activation is accomplished by an electric current, and a switch that is capable of such operation is known as a *relay*. A relay is a switch constructed in such a manner that the blade is moved by magnetic action.

Construction and symbols. Figure 2-10A is a simplified mechanical construction diagram of a relay, and Fig. 2-10B shows three forms of the schematic symbol. When an electric current flows through a coil of wire, a magnetic field is formed, and this field is concentrated by the iron core inside the coil. The magnetic field attracts the iron armature and moves it on its pivot against the force of the spring. The motion of the armature closes the switch contacts of the relay, and the relay circuit is closed. Operation of the circuit connected through the contacts continues as

long as current flows through the coil. When this current is interrupted, the magnetic field disappears, the spring pulls the armature away from the core, the contacts open, and the circuit is

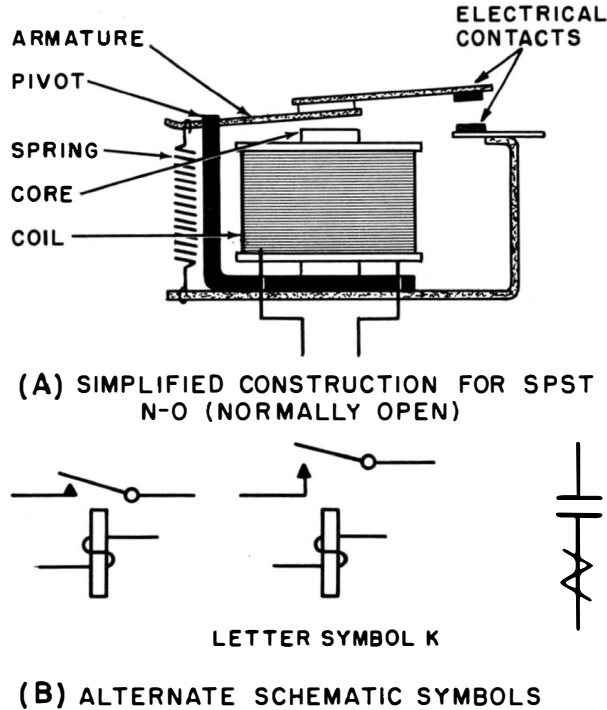


Fig. 2-10. The single-pole single-throw relay with normally-open contacts. (A) Simplified construction diagram. (B) Alternate schematic symbols.

turned off. An example of the use of a relay will be considered later, in connection with an automobile starter.

Types. Relays, like switches, may take many complex forms. The example considered previously is a single-pole, single-throw relay that is normally in the open position when the coil is not energized. This type may be described as a spst, N-O (normally-open) relay. A simple reversal of the contact arrangement, as shown in Fig. 2-11A, makes it possible to have a relay that is normally-closed (N-C) when the coil is not energized. In this case the circuit will be opened when the current flows through the relay coil.

Also available are relays with two sets of contacts, as shown in Fig. 2-11B. Such an arrangement connects a voltage source to one circuit when the coil is not energized and to a second circuit when

the coil is energized. This is a spdt relay. Since additional sets of contacts may be attached to the armature, there are available relays with two, three, or more poles, each of which may have N-O, N-C, or double-throw contacts. Figure 2-11C shows the schematic

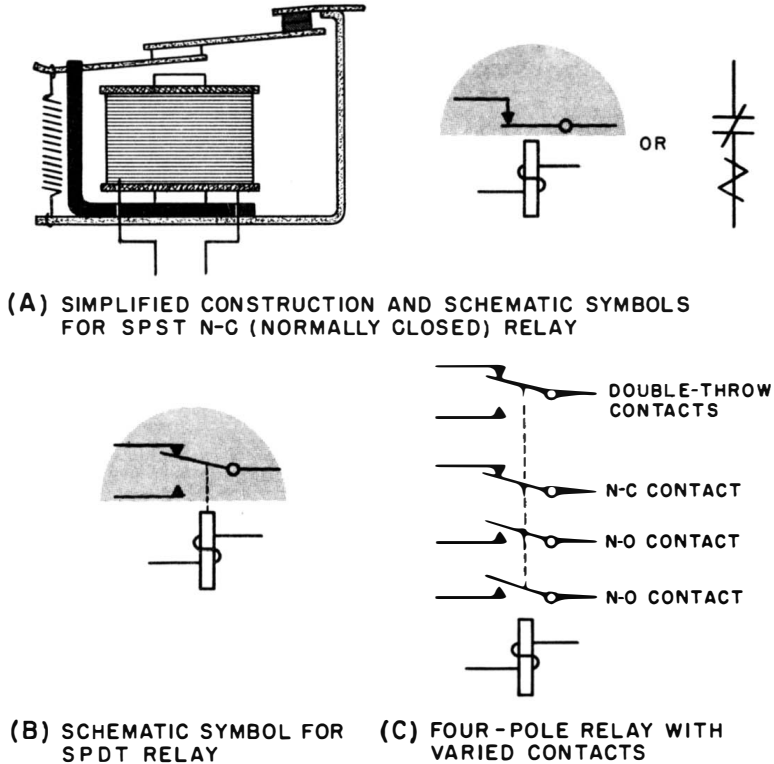


Fig. 2-11. Miscellaneous types of relays. (A) Simplified construction and schematic symbols for spst n-c relay. (B) Schematic symbols for spdt relay. (C) Four-pole relay with varied contacts.

symbol for a relay with four poles and all of the basic contact arrangements.

FUSES

Purpose and construction. Heat is generated when an electric current flows through the resistance in a conductor. As the current becomes larger, more heat is generated and the temperature of the conductor rises.

When a short circuit develops, there is only a very low resistance

across the voltage source, and a very large current flows through the connecting wires. The heat developed may be sufficient to burn the insulation off the connecting wires and start a fire in nearby inflammable objects. Damage is also done to the voltage source, since it is designed to provide only a limited amount of current.

Short circuits are not the only cause of damage to electrical equipment. Overloads can also occur. Connecting too many light bulbs or other electric appliances across a voltage source will result in excessive current flow for the size of wire and/or the voltage source being used. If an electric motor stalls because of too large a mechanical load (overload), large currents flow and the motor is soon damaged by the heat.

Although the heat developed by excessive currents destroys electrical equipment, that same heating effect is used in fuses to provide the simplest method of protecting the equipment against such damage. A *fuse* is simply a holder, with electrical contacts, containing a strip of metal made of a tin-lead alloy that has a low melting point. Figure 2-12A and B shows the construction of two typical fuses; the schematic symbols are shown in Fig. 2-12C.

Applications and connections. Fuses are available in a wide range of current-carrying capacities. If it is determined that the amount of current that may be carried safely in a circuit is 30 amperes, a 30-ampere fuse is connected in series with the voltage source, as shown in Fig. 2-12D. If a short circuit or an overload occurs in the circuit, and the current through the fuse exceeds 30 amperes, the fuse melts or "blows." Once this occurs, there is no longer a path for the electric current through the fuse container, and the circuit is open. After the short circuit has been repaired or the cause of overload removed, a new fuse is placed in the circuit, and normal operation is resumed.

Certain devices (electric motors, radios, television sets, etc.) have much less current carrying ability than the wires connecting them to the voltage source. A short circuit or overload in the device could cause major internal damage without blowing the external fuse. In such cases the equipment is often protected by an additional fuse of lower value, placed between it and the main wires, as shown in Fig. 2-12E. Many types of electronic equipment are supplied with such a protective fuse wired into the internal mechanism. However, since only the more expensive units have an internal protective device, a fuse of the correct size should be installed in the connecting wires.

Thermal-delay fuses. In certain applications, particularly those which make use of motors, it is normal for short-term overloads to

occur during the operation of the equipment. When an electric motor is switched on, the starting current is two or three times the normal running current. In addition, it is quite normal for the current through a motor to double when a mechanical load is

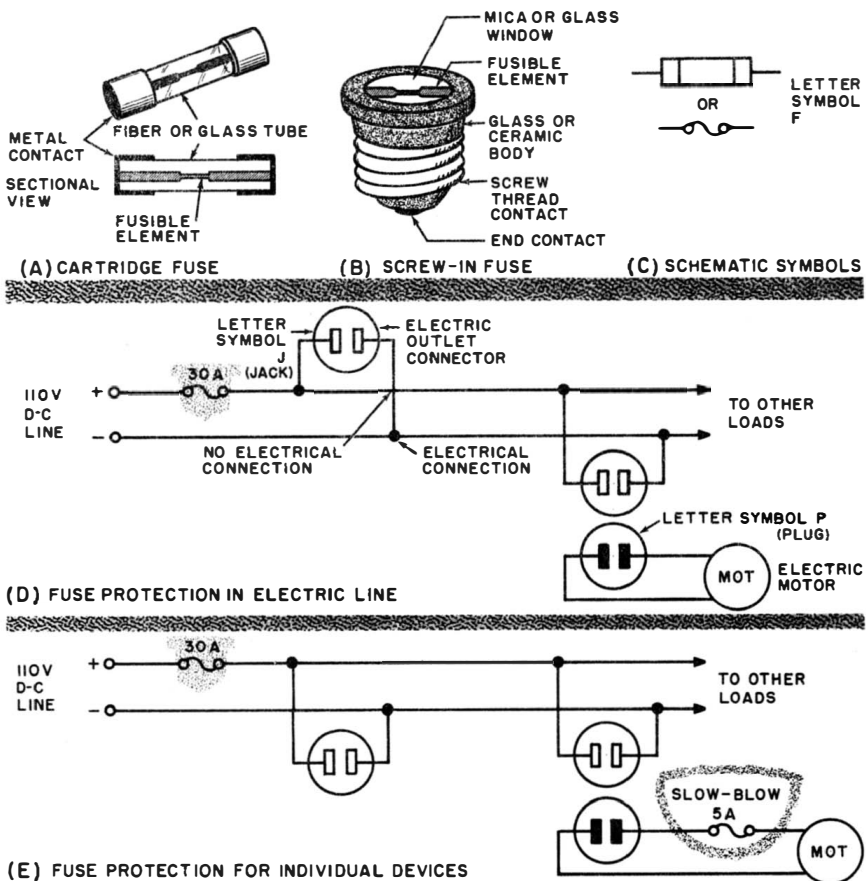


Fig. 2-12. Fuses and their use. (A) Cartridge fuse. (B) Screw-in fuse. (C) Schematic symbols. (D) Fuse protection in electric line. (E) Fuse protection for individual devices.

suddenly applied. Because of these normal short-term effects, electric motor applications pose a special problem. Damage may result if the fuse permits normal running current to be exceeded for more than a few seconds, but a protective fuse rated at this normal current will blow out every time the motor starts.

Thermal delay or "slow-blow" fuses provide one practical solu-

tion to the problem of protecting electric motors against overload. A fuse of this type will permit overloads of two or three times the

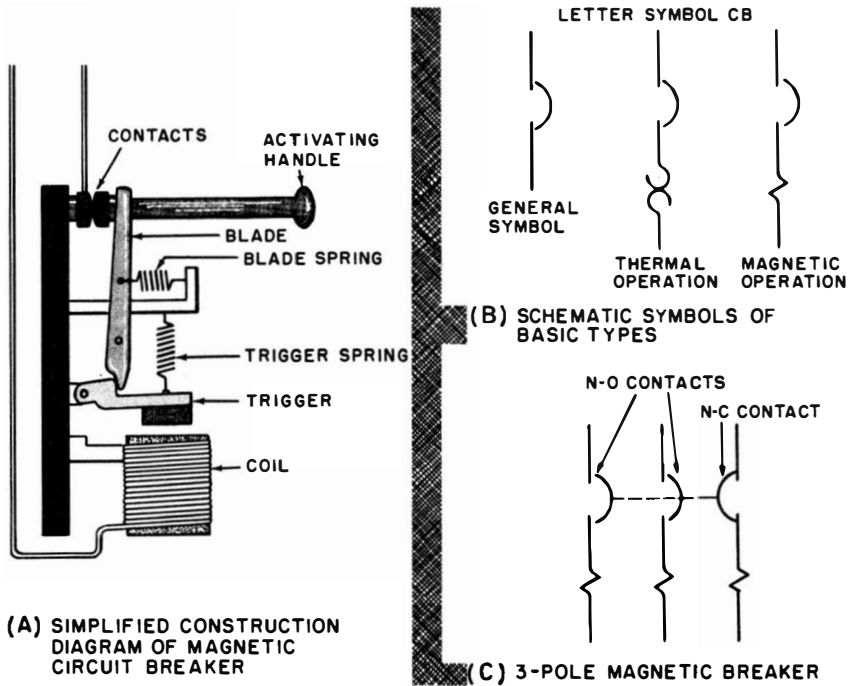


Fig. 2-13. Circuit breakers. (A) Simplified construction diagram of magnetic circuit breaker. (B) Schematic symbols of basic types. (C) Three-pole magnetic breaker.

rated value for short periods of time. Blowout occurs if the overload continues.

CIRCUIT BREAKERS

Function. A circuit breaker is a special type of relay that combines the functions of a fuse and a switch. When a fuse blows out, it must be replaced with a new one, but a circuit breaker does not require replacement after an overload situation. Returning the switch handle to its normal position closes the circuit, and the same unit provides the required protection over and over again.

Construction and symbols. Figure 2-13 is a simplified construction diagram (A) and several schematic symbols (B) of a type of

circuit breaker that finds wide application. The arrangement of parts is very similar to that of the relays considered previously, except for the spring and trigger arrangement. When the activating handle is moved, the free end of the blade enters the contact, and the circuit is closed. The free end of the blade is held to the contacts by the trigger. The spring exerts a force that tends to remove the blades from the contacts, but this force is completely overcome by the trigger. Circuit current flows through the coil, but the magnetic field generated by the rated current is not strong enough to pull back the trigger.

If an overload occurs, the strength of the magnetic field increases, and the trigger is pulled down. The blade spring then pulls the free end of the blade away from the contacts, and the circuit is broken. The blade can be reset to the closed position by means of the handle. In addition, the handle can be used to release the trigger and open the circuit at any desired time.

Recognizing types. Circuit breakers are normally single-throw devices with one, two, or three poles. There are a few double-throw types; with these the second set of contacts is generally used to sound an alarm when the trigger is released (see Fig. 2-13C). Special types are available with additional coils, which can be used to open or close the contacts from a remote point.

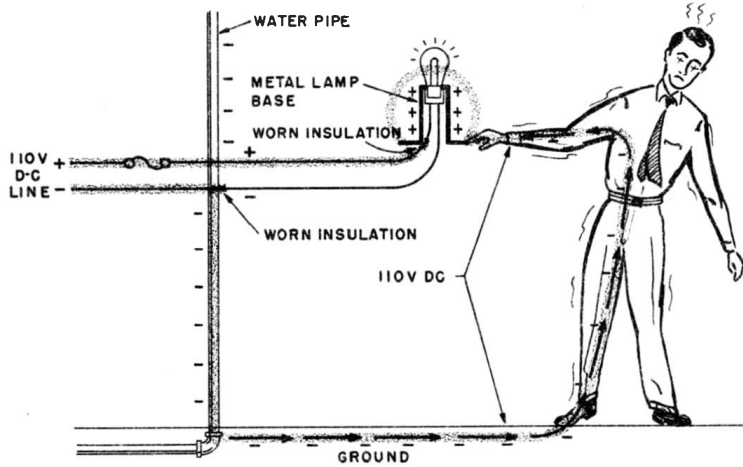
In addition, there are a number of special arrangements for obtaining a wide range of time delays between the beginning of the overload and the pulling out of the trigger. There is a *thermal overload* type of circuit breaker in which the trigger mechanism is released by the melting of fusible material inside a small container. The material solidifies upon cooling, permitting the breaker to be reset. The schematic symbol of this type is shown in Fig. 2-13B.

GROUNDING CONNECTIONS

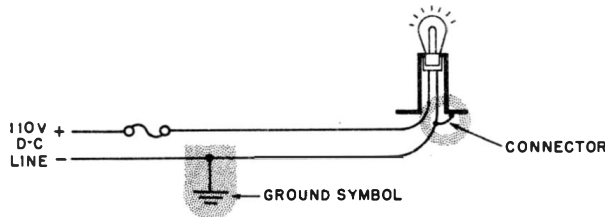
It has been seen that uncontrolled electricity can be a source of property damage. Electric shock can also be dangerous to human life. Voltages present in domestic and industrial appliances (110 to 120 volts) have often caused fatal shocks. The notion that it is necessary to touch a bare electric wire before one can get a shock is a mistake. Figure 2-14A shows how frayed insulation can place a fatal voltage on a lamp base, electric drill, or any appliance with a metal framework. Note that *the fuse does not blow*, since there is no short circuit.

Electricity can be conducted through damp earth, water pipes, gas pipes, and any metal framework in a building. If a person is in

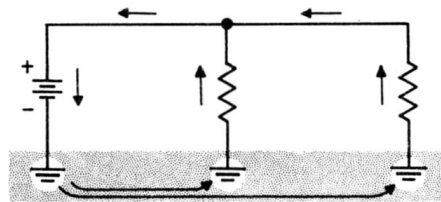
contact with any of these when he touches the charged appliance, he will receive a dangerous shock. Since electric wires must pass



(A) DANGERS OF ACCIDENTAL GROUNDING



(B) PROTECTION FROM ACCIDENTAL GROUNDING



(C) ELECTRON FLOW THROUGH GROUND

Fig. 2-14. Grounding. (A) Dangers of accidental grounding. (B) Protection from accidental grounding. (C) Electron flow through ground.

through walls and ceilings, there is no way to know when or where the fraying takes place.

Safety can be achieved by the method of grounding shown in Fig. 2-14B. This method requires that one of the power lines (the

negative line in d-c systems) shall be electrically connected to a water pipe that passes through the ground or to a metal rod driven deeply into damp ground. It also requires that any appliance with a metal framework shall have that framework connected either to the grounded electric line or to a separate wire attached to ground.

Under these conditions any dangerous fraying of the insulation of the positive or ungrounded wire would cause a short circuit that would immediately blow the fuse. The dangerous voltages cannot appear on appliance frames, and the fraying must be repaired before replacement fuses will stop blowing.

In electronic equipment it is quite common to connect one side (usually the negative) of all d-c voltage lines to the metal chassis or framework of the equipment. In many cases advantage is taken of this by connecting the corresponding negative side of all components directly to the chassis. Current flow will then take place through the chassis, as shown in Fig. 2-14C, and the wiring is simplified by the elimination of all return leads.

RESISTORS AND RESISTOR CIRCUITS

In the review of lighting circuits earlier in this chapter, it was seen that the resistance of the lamp filaments determines the various voltages and currents found in different portions of the circuit. The ability to determine voltages and currents is of major importance in many electrical and all electronic circuits. While electric light bulbs could be used for this purpose, they require too much space, and there is available a wide variety of *resistors* which have more desirable characteristics.

A resistor is an electrical component designed to provide a fixed amount of electrical resistance in a single compact unit. They are available in a wide variety of types, sizes, and wattage ratings. Some examples are shown in Fig. 2-15, and others will be seen in later chapters. Regardless of their other important characteristics, all of these units have a resistance which is either fixed or variable.

Fixed resistors. Figure 2-15A shows some forms of *fixed resistors* (so called because they contain no means of varying their resistance). All of these are tubular in shape and have a wire lead or terminal at each end. The carbon type contains carbon composition pressed into the form of a rod. The manufacturer determines the amount of resistance by controlling the proportion of conducting and insulating materials in the composition. Wirewound, fixed resistors consist of a core upon which is wound a wire of predetermined material, length, and diameter. Fixed resistors are

available in a wide range of standard sizes marked with numerals or a color code to indicate their resistance, wattage, and the accu-

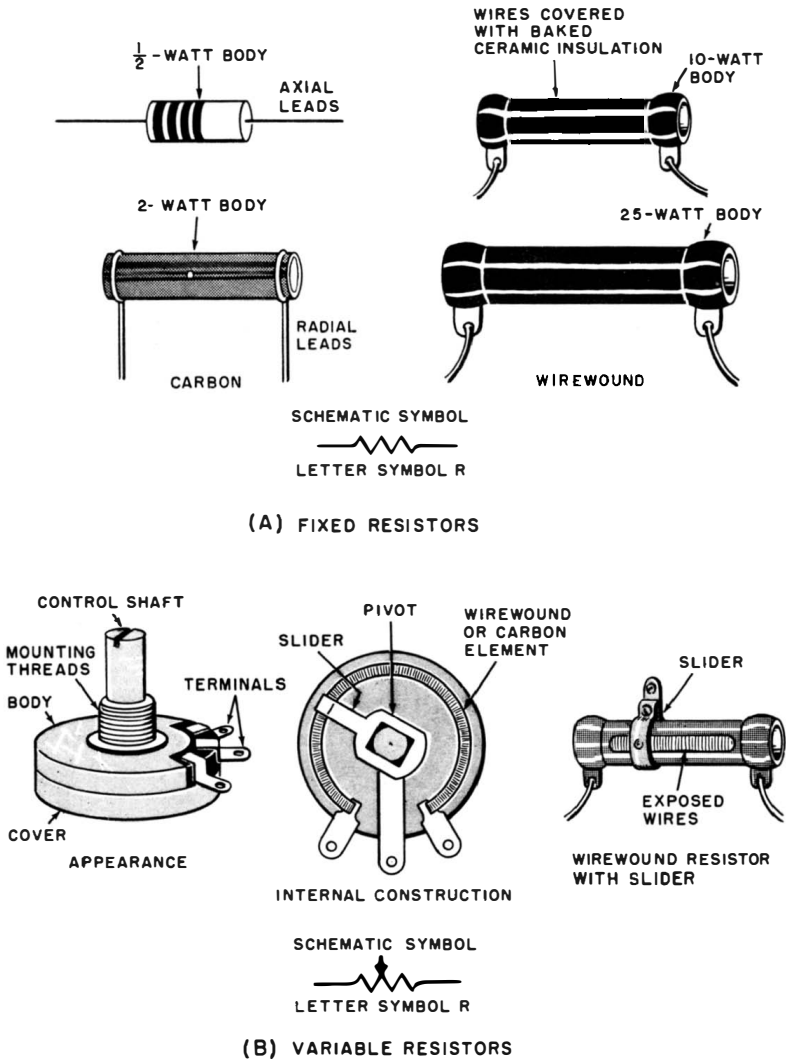
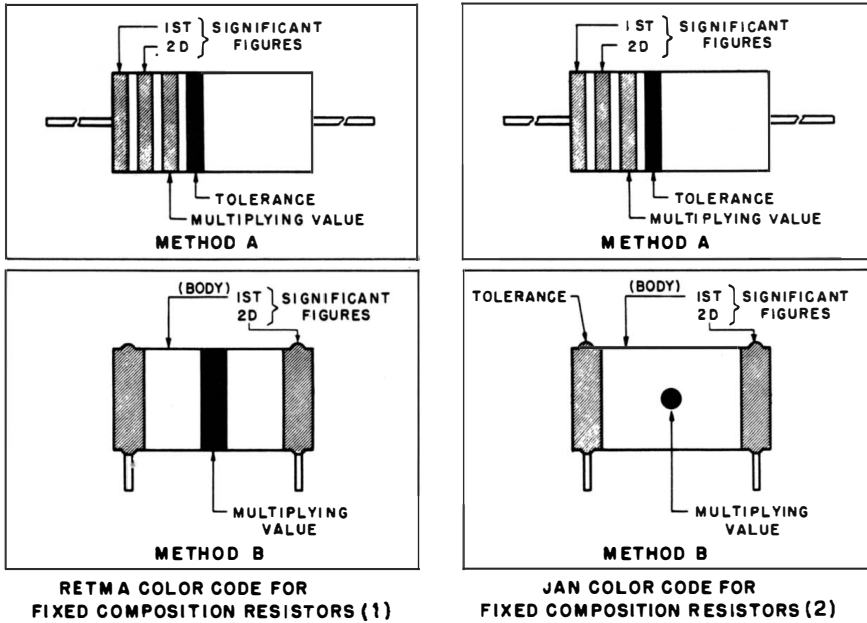


Fig. 2-15. (A) Fixed resistors. (B) Variable resistors.

racy of the resistance rating. The color code and examples of its use are shown in Fig. 2-16.

To determine the resistance of a color-coded resistor observe the first three colors. The first color indicates a significant digit as shown in the color-code chart. The second color indicates a second



RETMA COLOR CODE FOR FIXED COMPOSITION RESISTORS (1)

JAN COLOR CODE FOR FIXED COMPOSITION RESISTORS (2)

¹Insulated fixed composition resistors with axial lead are designated by a natural tan background color. Noninsulated fixed composition resistors with axial leads are designated by a black background.

²Resistors with axial leads are insulated. Resistors with radial leads are noninsulated. RETMA: Radio-Electronics-Television Manufacturers Association, now EIA—Electronic Industries Association.

JAN: Joint Army-Navy.

COLOR	SIGNIFICANT FIGURE	MULTIPLYING VALUE	TOLERANCE (%)
BLACK	0	1	± -
BROWN	1	10	± 1
RED	2	100	± 2
ORANGE	3	1,000	± 3
YELLOW	4	10,000	± 4
GREEN	5	100,000	± 5
BLUE	6	1,000,000	± 6
VIOLET	7	10,000,000	± 7
GREY	8	100,000,000	± 8
WHITE	9	1,000,000,000	± 9
GOLD	-	0.1	± 5
SILVER	-	0.01	± 10
NO COLOR	-	-	± 20

Fig. 2-16. Resistor color codes giving all resistance values in ohms.

significant digit as shown in the chart. The third color indicates the number of zeros that follow the two digits. Thus, a resistor

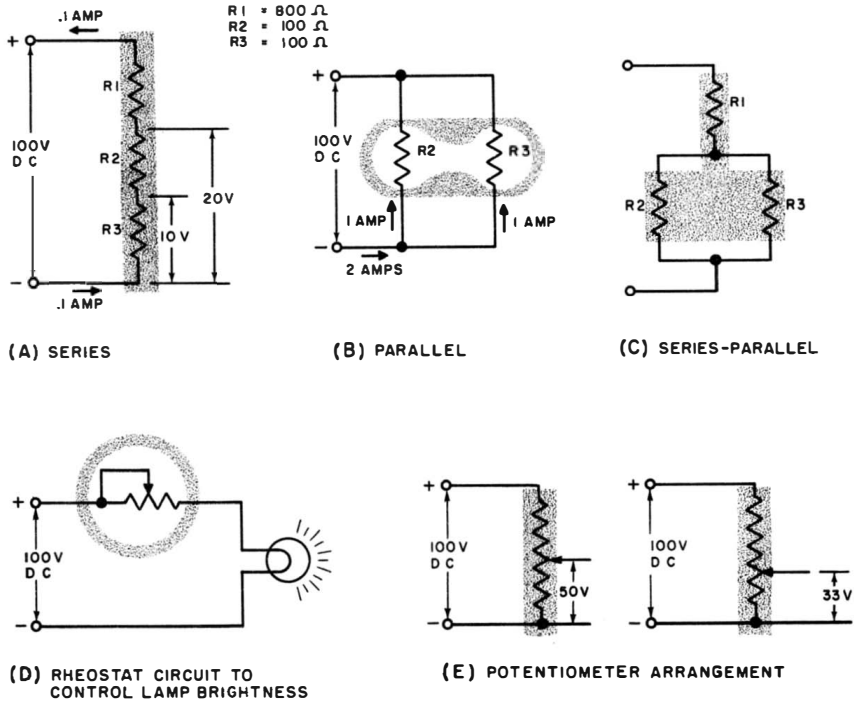


Fig. 2-17. Typical resistor networks. (A) Series. (B) Parallel. (C) Series-parallel. (D) Rheostat circuit to control lamp brightness. (E) Potentiometer arrangement.

having three bands of orange would indicate a 3, another 3, and then three zeros. The number would be 33,000 ohms.

In addition to resistance color code, a resistor may have a fourth color indicating tolerance. Gold indicates 5% tolerance, silver 10%, and the absence of a fourth color, 20%. Thus, a resistor of 100,000 ohms having a silver band may have a resistance value of anywhere from 90,000 ohms to 110,000 ohms.

Variable resistors. Figure 2-15B shows some forms of variable resistors. The resistance element consists either of a carbon composition coating on a special form, or of a similar form wound with resistance wire. A sliding contact is provided in all variable resistors. While the resistance across the two outside terminals is always the same, the resistance between the sliding contact terminal and either end terminal can be adjusted as desired.

Typical resistor circuits. Resistors may be arranged in series, parallel, and series-parallel circuits, as shown in A, B, and C respectively, of Fig. 2-17. The diagrams indicate the voltage and current distribution in these circuits; the laws governing this distribution are identical to those previously described for lamp circuits.

There are two general methods of connecting variable resistors. The *rheostat* connection shown in Fig. 2-17D places part of the resistance of the unit in series with the load, while shorting out the unwanted part. Adjusting the sliding contact thus changes the voltage across the load and, consequently, provides a means of regulating the current through it. The connection that shorts out the unwanted portion of the resistor may be eliminated without altering the operation. The shorting connection has the advantage of maintaining some voltage across the load in the event that the sliding contact becomes worn and sometimes fails to make contact while being moved.

A typical *potentiometer* arrangement is shown in Fig. 2-17E. The entire 100 volts dc is applied across the total resistance of the potentiometer. The center slider arm contacts the resistance of the potentiometer. The proportion of the total resistance between slider arm and either end of the potentiometer determines the proportion of the total voltage that will appear between these two points. Thus, with the slider arm in the center, half the total voltage will be read. With the arm about one-third the total resistance away from one end, approximately 33 volts will be read between these two points.

INTERPRETATION OF AUTOMOBILE WIRING DIAGRAM

Basic procedure. The basic purpose of the analysis that follows is not to teach the principles of automobile operation, but to indicate the procedure for breaking down a complex diagram into several fairly simple subsystem diagrams. These techniques will be very useful in the detailed analysis of electronic equipment in Chapters 4, 5, and 6.

Figure 2-18A is a complete wiring diagram for an automobile. The arrangement is typical of diagrams supplied for many present-day motorcars, and while it is known as a wiring diagram to the trade, it is actually a combination wiring and schematic diagram since it includes both schematic and outline symbols.

Unless the reader has prior knowledge of the contents and arrangement of a complex diagram, the most straightforward method

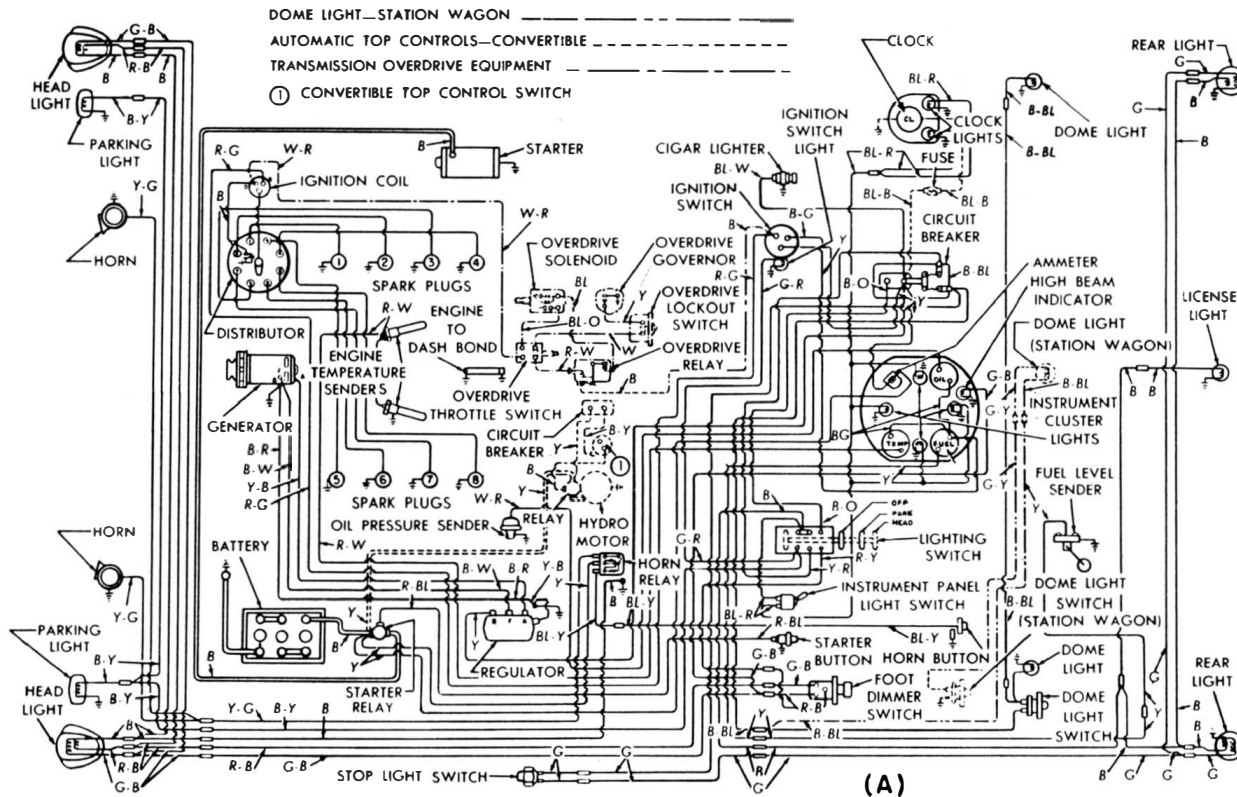


Fig. 2-18A. Complete automobile electrical system. Courtesy Floyd Clymer's "Ford Owner's Handbook"

of making an analysis is to redraw the system in the form of several simplified schematic diagrams. In doing this, note that the wiring diagram symbols (regulator, foot dimmer switch, etc.) do not have to show any internal wiring; their functions cannot be determined by means of the wiring diagram alone. Such parts will be described briefly in the text. Additional explanations of this type will not be necessary in the interpretation of the true schematic diagram of the electronic equipment presented later in this book.

The method of breaking the complex wiring diagram down into simplified schematic diagrams is to begin with the primary source of electric power in the system—the storage battery—and to trace out the connections between it and one particular type of component. Thus one diagram could include the battery and all the lights, another, the battery and all the accessories (cigarette lighter, instruments, horn, etc.), another the battery and the starter motor and generator, and still another the battery and the ignition system. The first of these subsystems will be considered here, and the others will be interpreted in Chapter 3. The technique of locating parts in the equipment itself by reference to the schematic diagram, and vice versa, will be discussed in the last three chapters.

Lighting system diagram. The first step in drawing a schematic diagram of the lighting system is to locate in Fig. 2-18A the storage battery and each of the lamps. Using a colored pencil, mark each lamp and the wires leading from it back to the battery. (Letter symbols next to the wires on a practical diagram will indicate the color with which the actual insulation is marked for identification.) Also mark each switch or other component encountered in the path back to the battery. Then take a separate sheet of paper and draw these marked components and their connections in schematic diagram form. The wires from most of the lamps will have small rectangles marked upon them close to the lamps. These rectangles are wiring diagram symbols for connectors that permit the entire lamp assembly to be disconnected quickly for repair or replacement.

When your diagram is complete, it should contain the same information as that presented in Fig. 2-18B. It can be seen that all the lamps are connected in parallel across the battery, and that all lights, except the dome, (interior lighting), and stoplight, are controlled by a three-position push switch. This switch is used to place the lighting system in the off, park, or headlight position.

The stop (rear) lights are independent of this switch, but are controlled by the stop light switch, which is activated by pressure on the brake pedal. Note that the rear lights have two filaments. One of these is activated by the brake pedal, as just described, and

the other is on when either the park or headlight position is selected on the push switch.

Also note that the headlights have two filaments. A foot dimmer switch is used to select one or the other of these filaments. One of these, the *high-beam* filament, is positioned at the focal point of

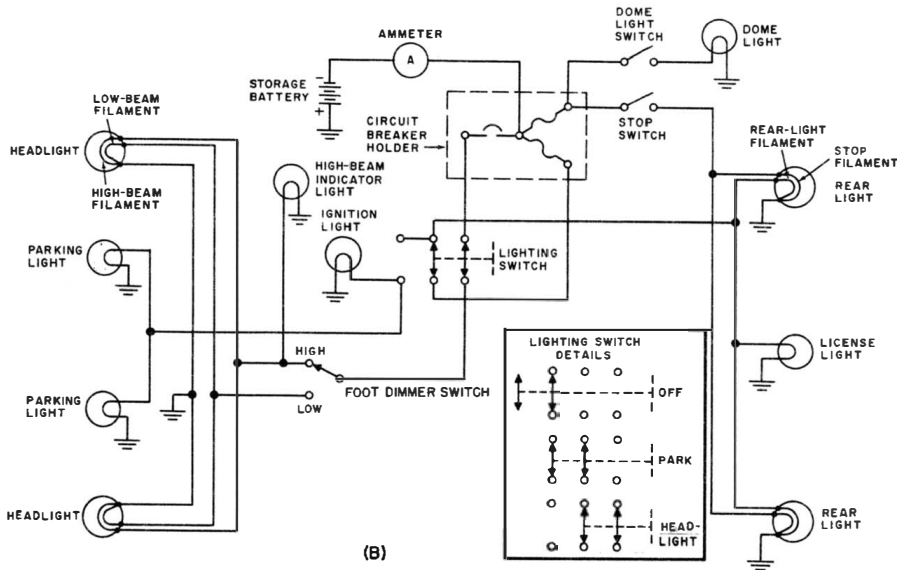


Fig. 2-18B. Automobile lighting system.

the headlight reflector; when it is on, the headlight beam is directed straight ahead. The other, the *low-beam* filament, is positioned slightly away from the focal point of the reflector; when it is on, the headlight beam is directed downward toward the road.

One battery terminal (the positive terminal) is grounded to the frame of the automobile. None of the lamps or accessories has a direct connection to this side of the battery. Instead every component that draws current has one of its terminals grounded, and the current flow path is completed through the automobile frame. There is an engine-to-dash bond, which assures the continuity of the ground connection between the engine and the control panel. Not only does this grounding system assure that high voltage from the ignition system cannot cause shock when the frame or body of the automobile is touched, but it also permits a saving in the number of wires running to the various lights and accessories that are remote from the control panel. More of the automobile wiring diagram will be analyzed in Chapter 3.

Chapter 3

ALTERNATING-CURRENT CIRCUITS

As explained in the previous chapter, alternating current flows first in one direction and then in the opposite direction. When a light bulb is connected across an a-c outlet, both the voltage and the current rise from zero to a maximum, decrease to zero, reach a maximum in the opposite direction of current flow, decrease back to zero, and repeat the cycle over and over again (see Fig. 3-1).

When the voltage or current is plotted on a graph, this curve is called a *sine wave*. The number of positive peaks that occur in one second is called the *frequency* of the sine wave, and the distance between these peaks is called the *wavelength*. Frequency is always measured in cycles per second (cps), while wavelength may be measured in meters or centimeters, depending upon the particular application. Most of the electrical power supplied for industrial and domestic use in the U.S. is at either 110 to 120 or 220 to 240 volts, and at 60 cycles. On many diagrams the value is very often shown as 117 volts.

TRANSFORMERS AND THEIR CONNECTIONS

Basic characteristics. Transformers provide the most practical means for increasing or decreasing a-c voltages to meet the requirements of a-c equipment. When direct current flows through a coil of wire, a fixed magnetic field is formed around the coil. If alternating current is used as shown in Fig. 3-2A, the magnetic field is initially zero, then increases to a maximum strength in one direction, decreases to zero, increases in the opposite direction, and decreases to zero, repeating this cycle continuously.

If a second coil of wire is placed in close proximity to the one just described, as shown in Fig. 3-2B, an alternating voltage appears across the terminals of this second coil. This voltage can be used to

light an electric lamp or energize electrical and electronic equipment. Depending upon the ratio of the number of turns of wire in the two coils, the voltage at the terminals of the second coil may be higher or lower than that applied across the terminals of the first.

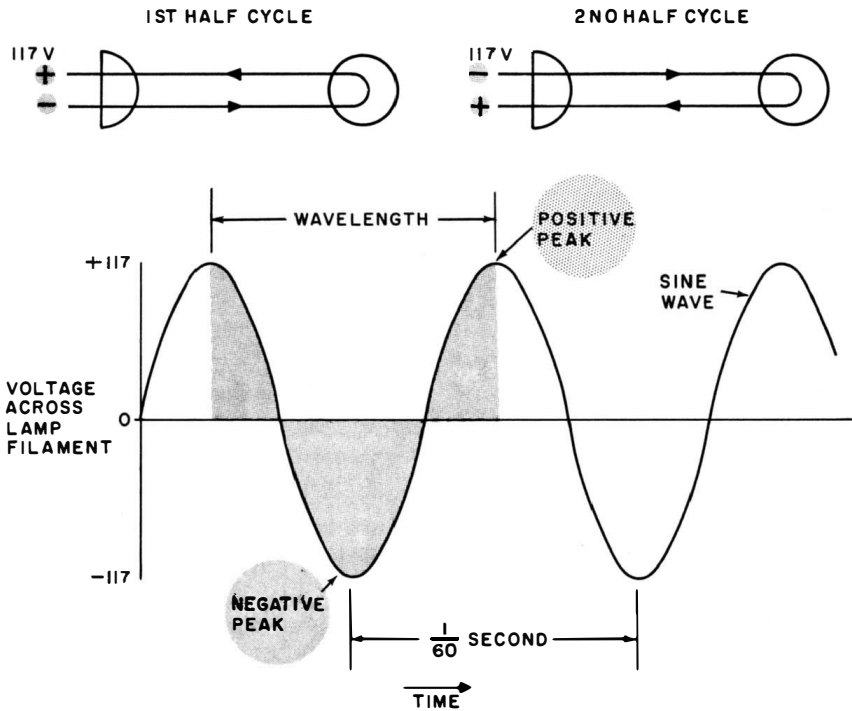


Fig. 3-1. Basic nature of alternating current.

The combination of coils is known as a *transformer*, and the basic parts are known as the *primary* and *secondary* windings.

Transformer voltage and power. If the transformer is constructed so that the entire magnetic field of the primary winding goes through the secondary winding (100% efficiency), there is a simple relationship between the input and output voltages:

$$\frac{\text{secondary voltage}}{\text{primary voltage}} = \frac{\text{number of turns in secondary winding}}{\text{number of turns in primary winding}}$$

Figure 3-3A shows an example of the calculation in which 117-volt ac is connected to the primary winding consisting of 1,000 turns of

wire, and it is desired to determine the voltage across the secondary winding consisting of 100 turns. A voltmeter will show that this calculation (11.7 volts) is correct. This arrangement is known as a *step-down* transformer, because the input voltage is decreased. If

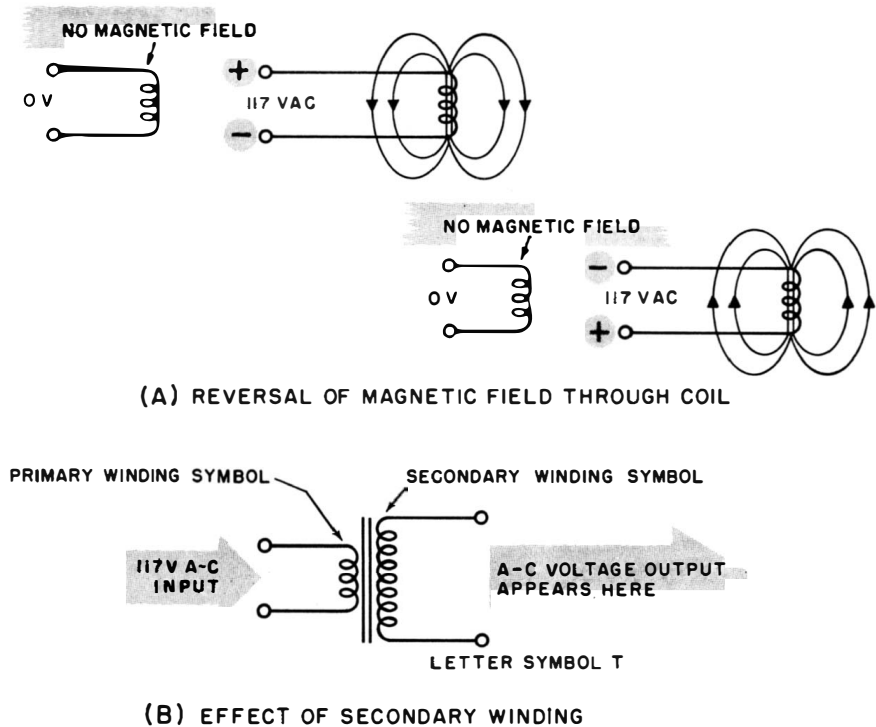


Fig. 3-2. Basic transformer operation. (A) Reversal of magnetic field through coil. (B) Effect of secondary winding.

there are more turns of wire in the secondary winding than in the primary, as shown in Fig. 3-3B, the secondary voltage is higher than the input voltage, and the result is a *step-up* transformer.

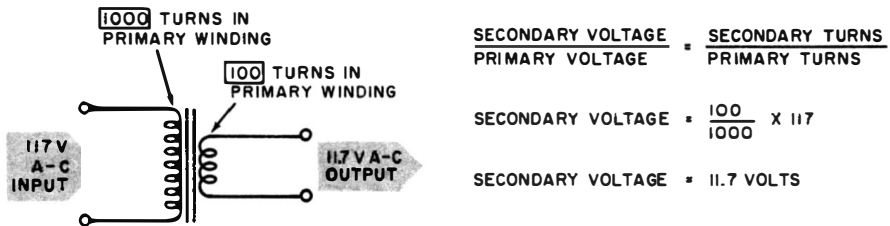
The fact that an increase or decrease in voltage can be accomplished by means of a transformer does not mean that any electric power is gained or lost. In a perfect transformer the input and output power would be exactly equal and the following relationship would exist:

$$\text{primary voltage} \times \text{primary current} = \text{secondary voltage} \times \text{secondary current}$$

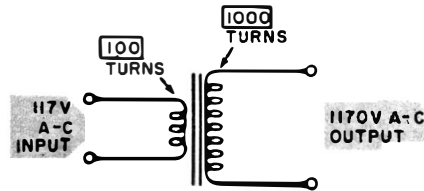
Thus, in the step-down transformer shown in Fig. 3-3A, a primary

current of 1 ampere would enable a current of 10 amperes to be drawn from the secondary, but the input power and output power would both be 117 watts. Actually, no transformer is 100% efficient, and the output is generally only slightly more than 90% of the input power.

The physical construction of a transformer varies with the frequency of the alternating current to be supplied to it, and with



(A) STEP-DOWN TRANSFORMER AND SAMPLE CALCULATION



(B) STEP-UP TRANSFORMER

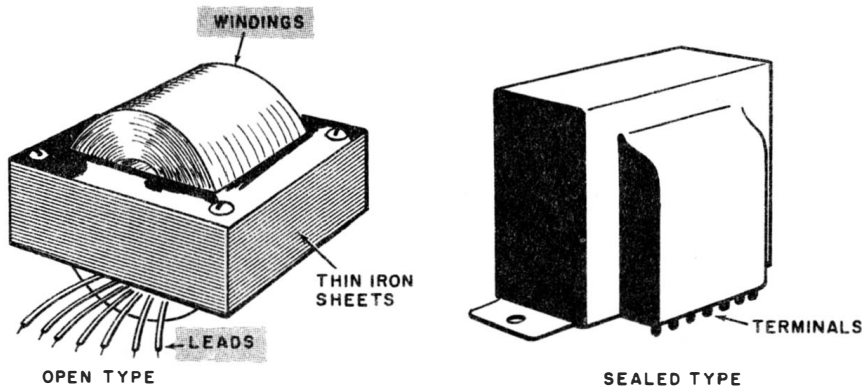
Fig. 3-3. Transformers. (A) Step-down transformer and sample calculation. (B) Step-up transformer.

the particular use for which it is intended. We shall consider different basic types of transformers.

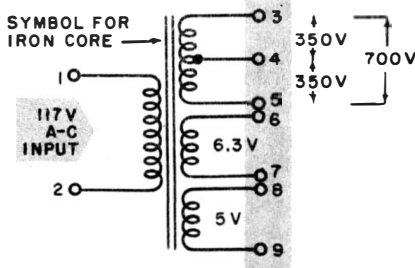
Power transformers. Power transformers are used to supply basic electric a-c power at desired operating voltages. The input to such a transformer is alternating current at the voltage and frequency supplied by the power line (generally 110 to 120 volts at 60 cycles). The output is the voltage required for the intended application, and is always at the same frequency. Figure 3-4 shows typical power transformers used in electronic equipment. The primary and secondary windings are wound around a core consisting of many layers of thin iron sheets stamped into the required shape. Figure 3-4A shows simplified construction diagrams of the transformer.

Since several different secondary voltages are generally required,

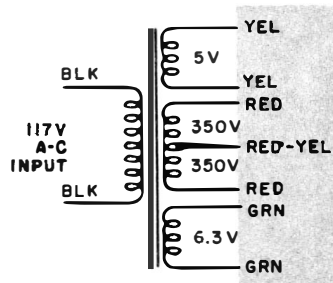
these are obtained by including one secondary coil for each output voltage required. The greater the current to be drawn from a particular winding, the larger must be the diameter of the wire used (to prevent overheating). Note that a connection called a



(A) SIMPLIFIED CONSTRUCTION



(B) TERMINAL IDENTIFICATION DIAGRAM



(C) TRANSFORMER LEAD COLOR IDENTIFICATION

Fig. 3-4. Power transformers. (A) Simplified construction. (B) Terminal identification diagram. (C) Transformer lead color identification.

centertap may be made to the center of a secondary winding. The voltage from the centertap to either end of that secondary winding is equal to one-half the voltage across the two ends (Fig. 3-4B). A centertap is usually provided in the high-voltage secondary winding, and examples of its use will be seen in Chapter 4.

A number of different wires come out of the transformer, and they must be clearly identified. One method of identification is to have numbered terminals on the base of the transformer, and to print a schematic diagram (such as that shown in Fig. 3-4B) on the case. The most widely used method of identification involves trans-

former leads with insulation of different colors; a standard color code is used to identify the different windings. Figure 3-4C is a schematic diagram for a transformer of this type. (Examples of the use of the various colors will be found in Chapter 4.)

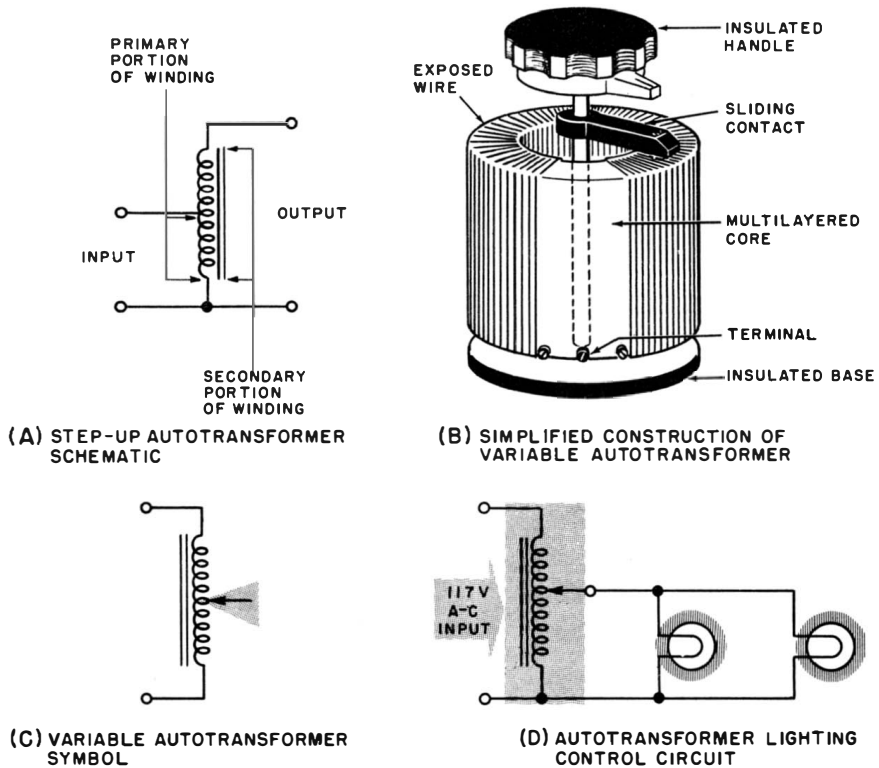


Fig. 3-5. Power autotransformers. (A) Step-up autotransformer schematic. (B) Simplified construction of variable autotransformer. (C) Variable autotransformer symbol. (D) Autotransformer lighting control circuit.

Autotransformers. An autotransformer has only one winding to which connections are made for the input and output voltages. Figure 3-5A shows the schematic symbol for an autotransformer and the relationship between the various parts. Principles of operation and voltage, and current calculations, are identical to those described for the power transformers considered previously. The only difference is that a portion of the single coil is common to both the primary and the secondary windings.

One advantage of this type of transformer is that some savings in the cost of construction are effected by the use of a single winding.

Another, is that if a sliding contact is provided, there is an economical method of obtaining a secondary voltage that may be adjusted as required. This second advantage is shown in Fig. 3-5B, a simplified construction diagram of the variable autotransformer.

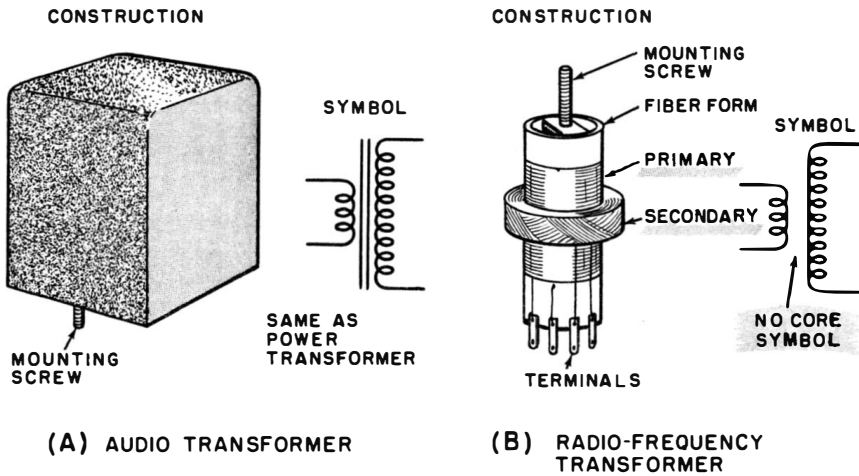


Fig. 3-6. (A) Audio transformer. (B) Radio-frequency transformer.

The schematic symbol is shown in Fig. 3-5C, and Fig. 3-5D shows how different output voltages can be obtained by moving the contact, which varies the number of turns in the secondary portion of the winding.

Adjustable autotransformers are used in laboratory work to provide a simple method of checking the effects of different a-c voltages upon circuits under test. Another application is to provide a means of controlling the brightness of the lamps in a-c lighting circuits (Fig. 3-5D).

Recognizing other transformer types. Other types of transformers are distinguished mainly by the frequency of the current flowing through them. Some transformers are designed for a-c voltages at sound frequencies; these are called *audio* transformers. They have the same appearance and schematic symbol as power transformers, although they are generally smaller (see Fig. 3-6A).

In certain portions of an A-M radio receiver the radio signal voltage is at a frequency of 456 kc (kilocycles; 1 kc = 1,000 cycles). In other sections of the receiver the frequencies may vary from 550 to 1,600 kc. In television receivers the signals may be at frequencies in the order of hundreds of megacycles (mc; 1 mc =

1,000,000 cycles). Transformers that operate within these frequency ranges are known as *radio-frequency* (r-f) transformers or *intermediate-frequency* (i-f) transformers.

When they consist of coils containing many turns of fine wire, as shown in Fig. 3-6B, the coils are wound on a fibre or plastic form. If there are only a few turns of heavy wire, no central form

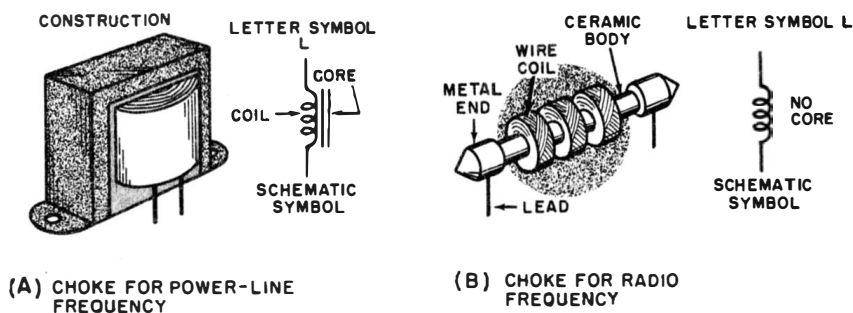


Fig. 3-7. (A) Choke for power-line frequency, and (B), for radio frequency.

is used, although there is usually a support for the terminals. Depending upon the application, r-f transformers may or may not be enclosed within a container. Applications of the various types will be presented in Chapters 5 and 6.

CHOKES

Appearance. In appearance, a choke is very much like a transformer. Different forms of chokes are made for operation at power-line or radio frequencies, and the appearance and schematic symbols of these are shown in Fig. 3-7A and B respectively. A choke contains only a single winding of wire with many turns. Its effect in an a-c circuit superficially resembles that of resistance in a d-c circuit, but there are differences that must be considered.

Inductance and inductive "resistance." When an alternating current flows through a choke it produces a magnetic field, which behaves in the manner described for the primary winding of a transformer. The increase, decrease and reversal of the magnetic field acts upon the voltage and current through the single coil producing this field, and the result is similar to the effects obtained in a transformer secondary circuit. The alternating magnetic field of the choke winding induces an alternating voltage across this winding. This induced voltage opposes the changes in the original cur-

rent. This property of a coil is known as *inductance*; it is symbolized by the letter *L* and is measured in *henrys*. Since the induced voltage opposes all *changes* in current flow, the choke presents a "resistance" to alternating currents. This type of "resistance" is known more properly as *inductive reactance*.

Example of inductive reactance. Although a thorough under-

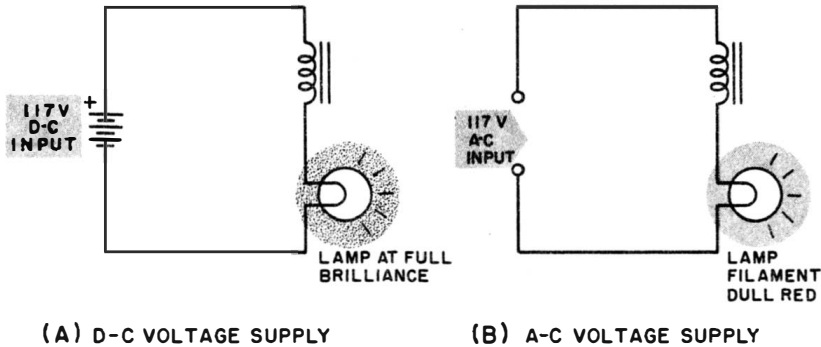


Fig. 3-8. Effects of inductive reactance. (A) D-C voltage supply. (B) A-C voltage supply.

standing of the nature of inductive reactance involves an extensive mathematical analysis of the physical factors involved, the effects can be seen very quickly and clearly by examining the operation of a circuit consisting of a choke and a lamp connected across the voltage source. When the voltage source is a battery, as in Fig. 3-8A, the current through the circuit can be determined by application of Ohm's Law. The total resistance is equal to the sum of the lamp resistance and the choke resistance. Since the choke winding consists of copper wire, its resistance may be negligible, although some chokes present a d-c resistance on the order of 500 ohms. Almost the full rated current flows through the lamp, and it lights at almost its normal brilliance.

When an a-c voltage is connected across the circuit, as in Fig. 3-8B, the lamp filament gives off only a dull red glow. Measuring the a-c voltage across first the lamp and then the choke, reveals that most of the input voltage appears across the choke. The inductive reactance opposes any change in current, and consequently greatly reduces the flow of a-c current through the choke.

Inductive reactance (X_L) is measured in ohms and is equal to:
 $2\pi \times \text{frequency of the input voltage} \times \text{inductance (in henrys)}$.

For a 10-henry choke with an applied voltage at power-line frequency (60 cycles):

$$X_L = 2\pi \times 60 \times 10 = 6.28 \times 60 \times 10 = 3,768 \text{ ohms.}$$

It can be seen from these relationships that inductive reactance

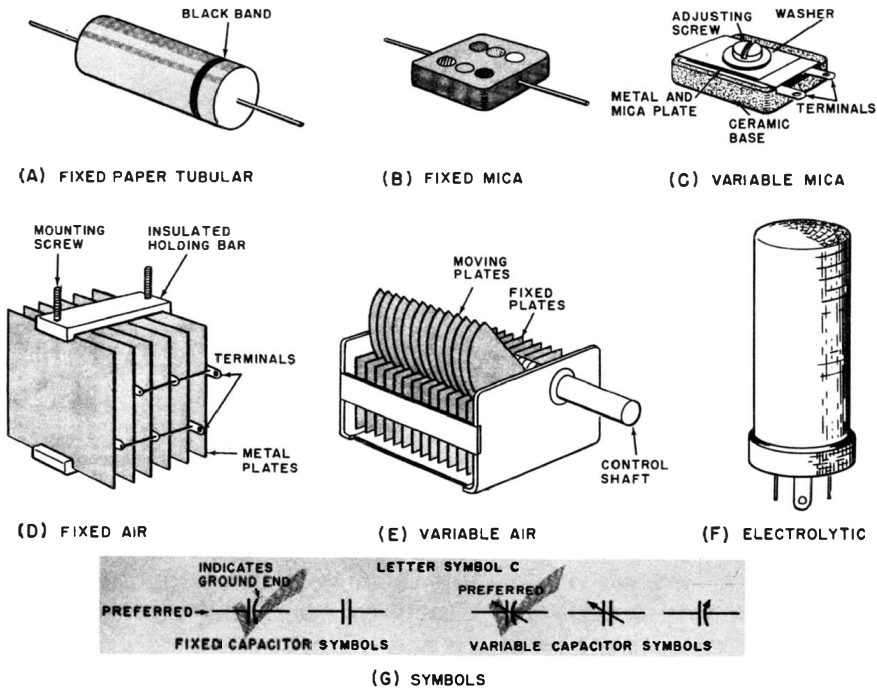


Fig. 3-9. Capacitors. (A) Fixed paper tubular. (B) Fixed mica. (C) Variable mica. (D) Fixed air. (E) Variable air. (F) Electrolytic. (G) Symbols.

is zero for direct current, and that for alternating current it increases with the frequency of the applied voltage.

CAPACITORS

Construction and symbols. A capacitor, popularly known as a "condenser," consists of two or more metal plates separated by an insulating material called *dielectric*. The metal plates usually consist of aluminum foil, and the most common dielectrics are waxed paper, mica, oil, air, and special electrolyte liquids and pastes. The electrical effects of a capacitor increase as the area of the plates

increases, as the plates are brought closer together, and as more effective dielectric materials are used.

Capacitors are available in a large variety of types, and those in most widespread use include fixed paper, fixed mica, variable mica, fixed air, variable air, and fixed electrolytic capacitors. All of these are shown with their appropriate schematic symbols in Fig. 3-9. They are usually marked with numerals or a color code to indicate their capacitance and voltage rating. The color code and notes for its use are shown in Fig. 3-10.

Capacitive reactance. The electrical effect associated with a capacitor is called *capacitance*; it is symbolized by the letter C and measured in farads. (Usually, the smaller unit *microfarad* is used.) When an electric circuit contains a capacitor, the capacitance *opposes any change in voltage* across itself. This effect is in contrast to inductance, which *opposes any change in current*.

The theoretical aspects of capacitance are fairly complex, but the practical effects can be described simply. Connecting a lamp

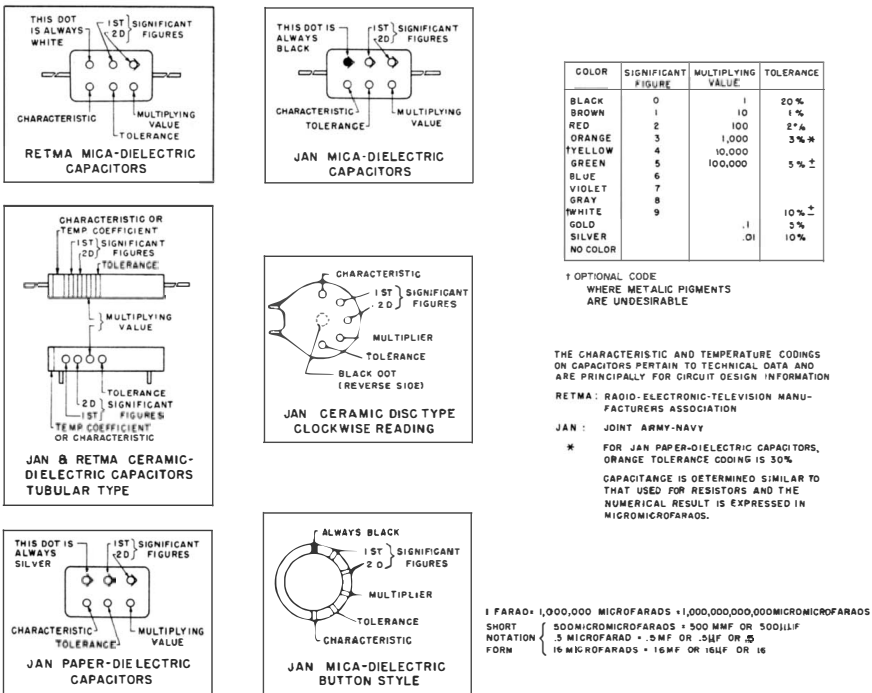


Fig. 3-10. Capacitor color code.

and a capacitor in series across a source of constant voltage, but of variable frequency (Fig. 3-11), demonstrates one important effect. If the frequency is zero (direct current), no current flows through the lamp. The full source voltage can be measured across the capacitor, with a zero voltage reading across the lamp. As the frequency of the source voltage is increased, the voltage across the capacitor becomes lower, and an increasingly higher voltage is developed

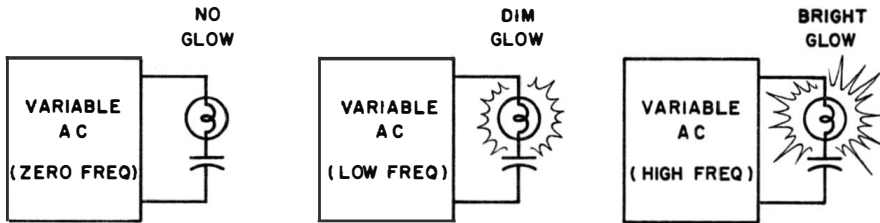


Fig. 3-11 Effect of capacitance in a basic circuit.

across the lamp. The full source voltage can be developed across the lamp (and a voltage close to zero across the capacitor) by increasing either the frequency or the capacitance, or both.

The opposition that a capacitor offers to a voltage change across itself is known as *capacitive reactance* (X_C). This quantity is measured in ohms according to the relationship:

$$X_C \text{ (ohms)} = \frac{1}{2\pi \times \text{frequency} \times \text{capacitance (farads)}}$$

It can be seen from this that capacitive reactance is infinitely large for dc and decreases as either frequency or capacitance is increased.

IDENTIFYING BASIC FILTER CIRCUITS

The reactance characteristics of chokes and capacitors makes it possible to construct circuits that will oppose unwanted frequencies, to pass more desirable frequencies. Circuits of this type are known as *filter circuits*. In circuits containing any combination of resistance, inductance, and capacitance, the combined opposition to current flow is known as *impedance* (Z) and is measured in ohms.

Many types of filter circuits are used in electronic equipment; their purpose is always to remove unwanted frequencies while permitting the desired frequencies to pass. Filters are used in radio and TV sets, record players, and tape recorders to remove undesirable

humming sounds, resulting from the a-c power-line voltages, to prevent interference from unwanted broadcast and TV stations, to remove noises caused by nearby electrical equipment, to remove scratch noise in old disc recordings, and to separate the low-frequency and high-frequency sounds in multispeaker hi-fi systems. The most basic types will be reviewed now, and more complex forms will be considered later. Examples of these filters will be seen in the equipment diagrams in later chapters.

High-pass filter circuits. Suppose a signal that is constant in voltage but ranging in frequency from 0 to 20,000 cycles is being fed into a certain section of an electronic equipment. If the frequency were plotted in graph form against the voltage, the result would be the straight line shown in Fig. 3-12A. To remove the low frequencies and permit only the high frequencies to get through, we employ a circuit called a *high-pass filter*, consisting of resistors and capacitors arranged as shown in Fig. 3-12B. The operation of this filter may be explained by the fact that the capacitor has low reactance to the higher frequencies, thus permitting them to get through with only slight opposition.

Another viewpoint is that the circuit is a voltage divider. For voltage variations at 10,000 cycles per second the capacitive reactance, measured in ohms, may be only one-tenth that of the resistor. This means that 90% of the voltage appears at the output. However, at 100 cycles the capacitive reactance is 100 times higher than previously, making it approximately 10 times larger than the resistance. Thus at 100 cycles only about 10% of the voltage gets through to the output.

The final effect of this filter is that frequencies higher than 10,000 cycles per second get through virtually unaffected, while the lower frequencies are reduced or *attenuated* rapidly. If the capacitance is reduced by half, only the frequencies above 20,000 cycles will go through, with an attenuation of less than 10%. If the capacitance is doubled, frequencies above 5,000 cycles will get through with less than 10% attenuation.

Although the R-C filter just considered is economical, there are many applications for which the undesired frequencies would not be reduced rapidly enough. The filtering effect may be improved greatly by replacing the resistor with a choke, resulting in the L-C filter shown in Fig. 3-12C. The inductance of the choke is selected to be high for the desired output frequencies, and low for the undesired output frequencies. Now the voltage divider is greatly improved, since both capacitive and inductive reactance change with frequency. For any specified frequency the values of L and C

can be selected to allow all higher frequencies to pass through virtually unaffected, while all lower frequencies are sharply reduced.

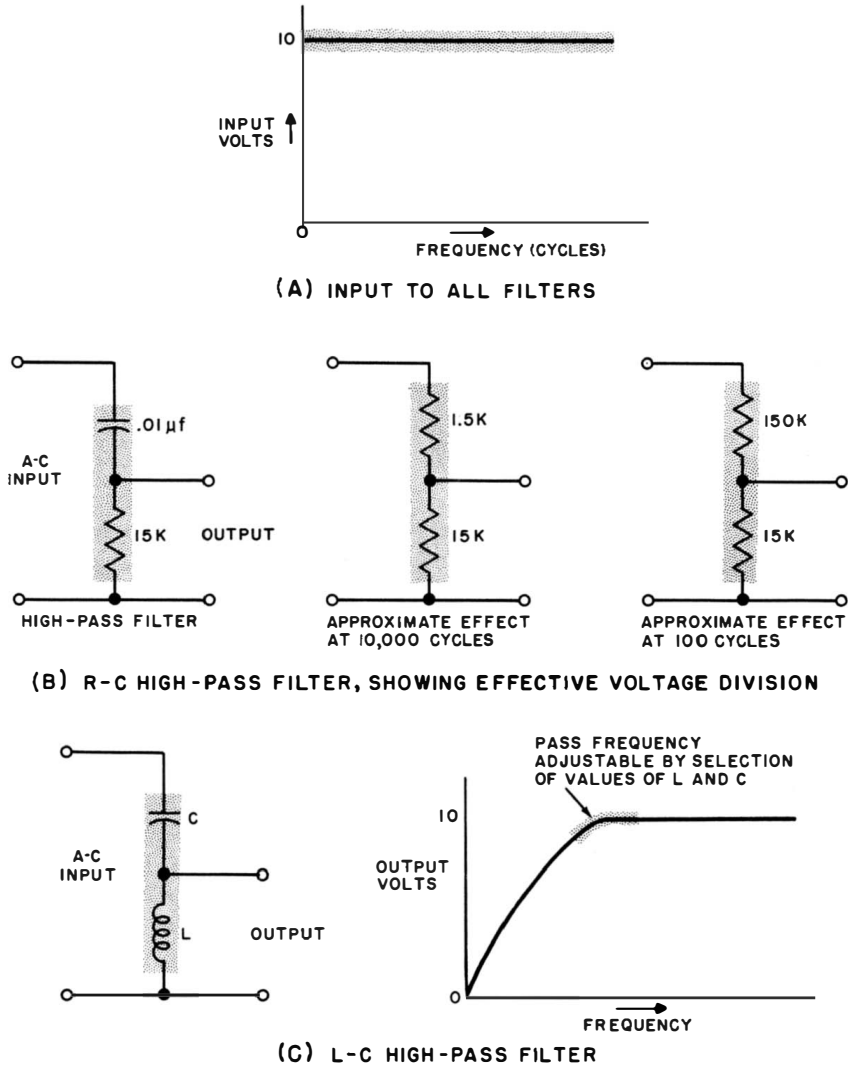
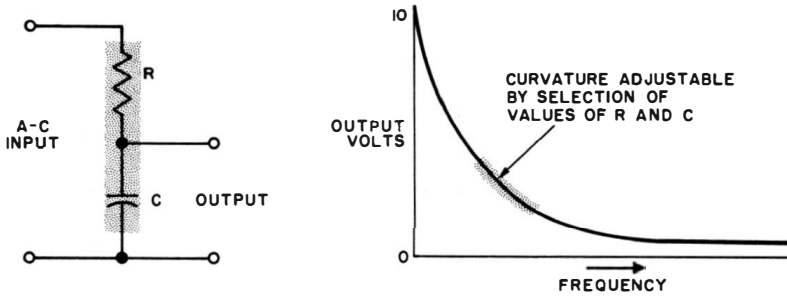


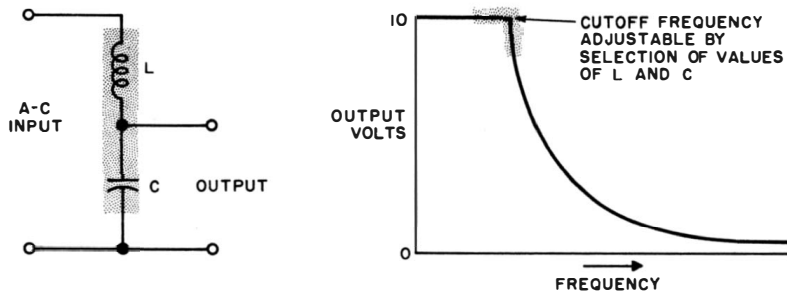
Fig. 3-12. (Above) Basic filters and their characteristics. (A) Input to all filters. (B) R-C high-pass filter, showing effective voltage division. (C) L-C high-pass filter. (Opposite) (D) R-C low-pass filter. (E) L-C low-pass filter. (F) Multisect filter.

Low-pass filter circuits. In many applications the reverse effect is desired; that is, at a specified frequency all higher frequencies

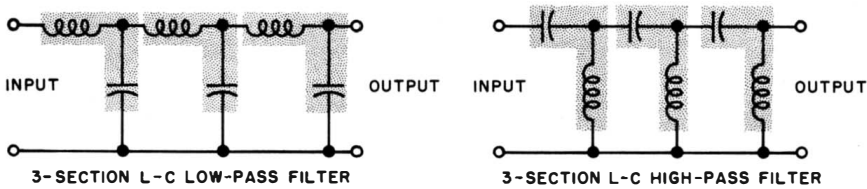
are to be removed and only the lower frequencies allowed to pass through unaffected. This can be accomplished by either R-C or



(D) R-C LOW-PASS FILTER



(E) L-C LOW-PASS FILTER



(F) MULTISECT FILTERS

L-C low-pass filters, as shown in Fig. 3-12 D and E respectively. In these examples the voltage-dividing effect is exactly the reverse of that described for high-pass filters. The effect of increasing R, L, and C is to lower the frequency above which voltage variations are reduced rapidly.

Multisection filters. The operation of either high-pass or low-pass filters can be improved by using several of the sections considered previously. Examples of such multisection filters are shown in Fig.

3-12F. In filters of this type, the percentage by which the unwanted frequencies are attenuated increases with the number of sections used.

Power supply filters. Low-pass filters have an application of extreme importance in all electronic equipments that are energized

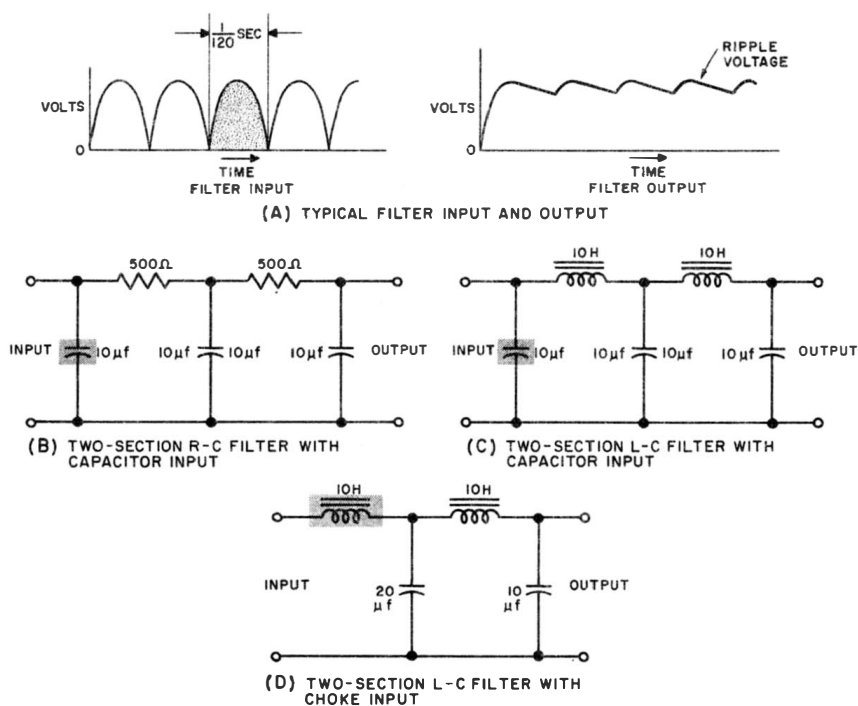


Fig. 3-13. Power supply filters. (A) Typical filter input and output. (B) Two-section R-C filter with capacitor input. (C) Two-section L-C filter with capacitor input. (D) Two-section L-C filter with choke input.

by a-c power lines. In these applications certain circuits require d-c voltages, and these voltages must be derived from the a-c voltages delivered by the power line. This can be accomplished partially by means of the rectifier circuits to be considered in Chapter 4. The output of these circuits is not steady dc, but a unidirectional current which rises and falls in voltage at frequencies of either 60 or 120 cycles, depending upon the type of circuit used.

Examination of the output of a widely used type of rectifier, as shown in Fig. 3-13A, shows that it rises to a maximum positive

value and falls back to zero at a frequency of 120 cycles. Mathematical analysis of that waveform indicates that it contains both a-c and d-c voltage components. The object is to attenuate all frequencies above zero cycles, allowing only the d-c voltage component to appear at the output.

Low-pass filters are used for this purpose. An R-C type of filter with typical values is shown in Fig. 3-13B. Although the 120-cycle a-c voltage appearing at the output (called *ripple* output), may be reduced through the use of higher values of resistance, the current flow through these resistors also causes a drop in the d-c output voltage. The first capacitor at the input charges each time the input voltage reaches a peak, and helps offset the voltage drop caused by the resistors. This is known as a *capacitor-input filter*.

A more efficient form of this filter is obtained by replacing the resistors with high-inductance chokes, as shown in Fig. 3-13C. This type is used mainly for applications in which only nominal amounts of dc are required. If larger amounts of dc are required, the *choke-input filter* shown in Fig. 3-13D is employed. Because there is no input capacitor, the output voltage is slightly lower and the filtering action less effective than for the capacitor-input type. However, when large amounts of dc are required, the choke-input type places less strain on the rectifier circuit, and there is less voltage variation with changing load currents.

RECOGNIZING RESONANT CIRCUITS

It has been seen in the review of inductive reactance that this quantity becomes larger as frequency increases. It was also seen that capacitive reactance becomes lower as frequency increases. Consequently, when chokes and capacitors are used in the same circuit, there is always one specific frequency at which inductive and capacitive reactance are equal.

An important electrical effect results from the opposition of inductive reactance to current changes, and of capacitive reactance to voltage changes. This effect is known as *resonance*. There are two basic circuits of interest; in one the two reactances are connected in series, and in the other they are connected in parallel. In both types the frequency at which resonance takes place can be adjusted or "tuned" by varying the values of C and/or L. Because of this, resonant circuits are often known as *tuned circuits*.

Series resonance circuits. In this type of circuit the coil and capacitor are connected in series, as shown in Fig. 3-14A, and voltages of varying frequency are applied across the two. At frequen-

cies above the *resonant frequency*, the circuit has high reactance because of the inductance in the coil, and at lower frequencies the capacitor causes a high reactance. At the resonant frequency, inductive and capacitive reactances are equal, and—due to their

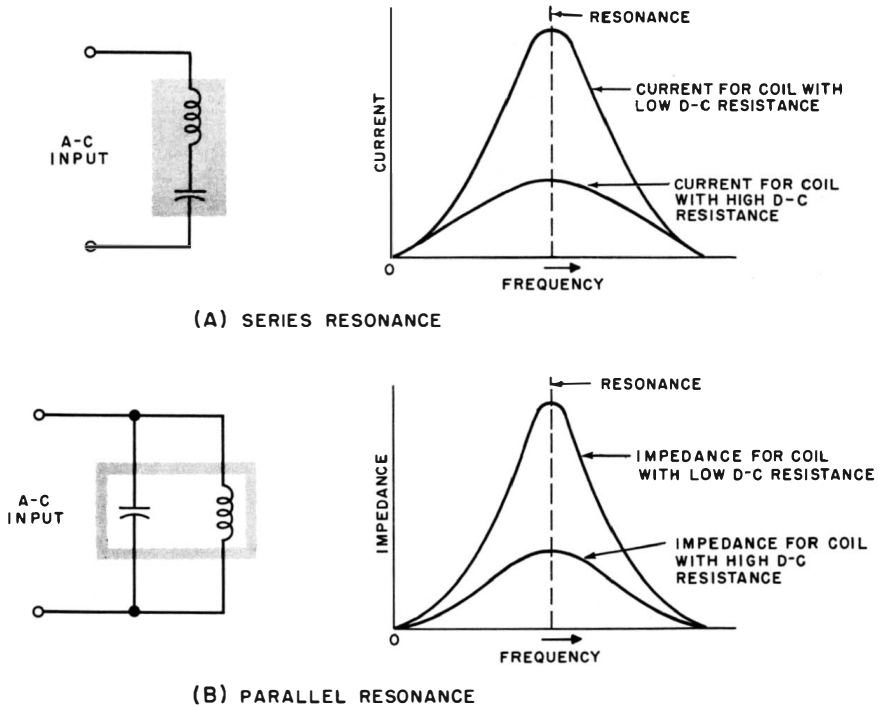


Fig. 3-14. Resonant circuits. (A) Series resonance. (B) Parallel resonance.

opposite effects, cancel completely. The total impedance of the circuit is zero, and only the very small resistance of the wire in the coil retards the current flow. Thus the circuit acts as a very high resistance for nonresonant frequencies.

When the current flow through the coil is plotted against the frequency of the applied voltage, the curve shown in Fig. 3-14A results. The sharpness of the peak increases as the resistance of the coil decreases. Resonant circuits of this type are important in connecting radio and TV antennas to their receivers (as will be seen in Chapter 5) and in certain resonant filters, to be described later in this chapter.

Parallel resonance circuits. In this type of circuit the coil and capacitor are connected in parallel, as shown in Fig. 3-14B. The

circuit has little impedance at low frequencies, because of the low reactance of the coil, and little impedance at high frequencies, because of the low reactance of the capacitor. At resonance, however, the two reactances combine in an unusual manner to give the effect of a high value of impedance.

Impedances of 10,000 ohms or higher are not unusual. The impedance increases as the resistance of the wire in the coil decreases; when the impedance is plotted against the frequency of the applied voltage, the resulting curve has the sharp peak shown in Fig. 3-14B. Resonant circuits of this type are very important in radio-frequency transformers (as will be seen in Chapter 6) and in resonant filters.

MOTORS AND GENERATORS

Purpose. Electric motors and generators have the same general appearance. As shown in Fig. 3-15A, either is contained in a housing or frame that is generally cylindrical in shape, with a shaft

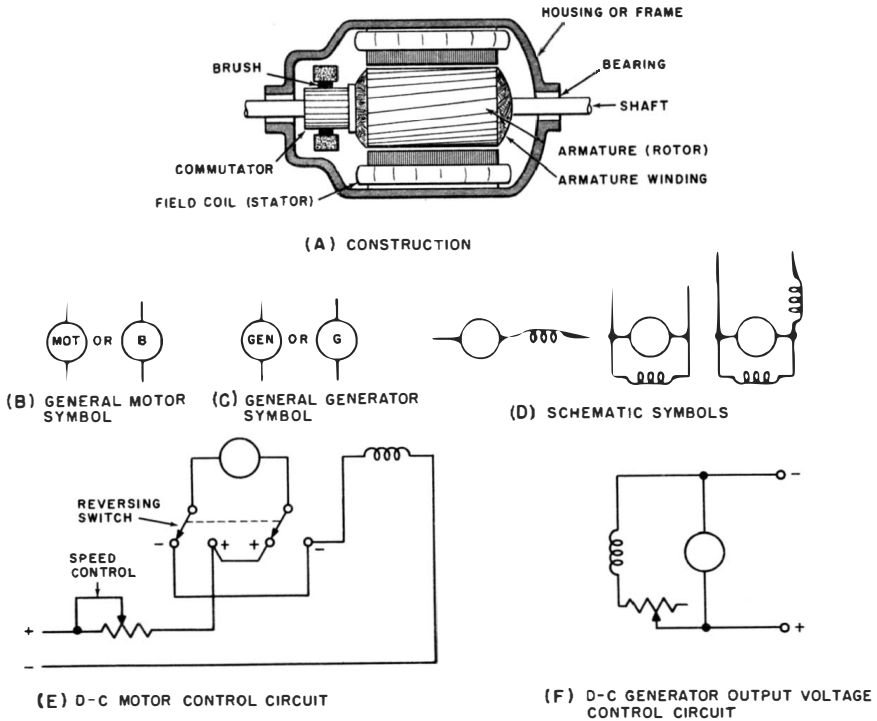


Fig. 3-15. Motors and generators. (A) Construction. (B) General motor symbol. (C) General generator symbol. (D) Schematic symbols. (E) D-C motor control circuit. (F) D-C generator output voltage control circuit.

protruding from one or both ends. Two or more terminals or wires are provided to make electrical connections.

When the terminals of an electric motor are connected to a suitable source of electricity, the shaft turns. This turning shaft can be used to drive a concrete mixer, a saw, a refrigerator, elevator, and a variety of household, industrial, and military devices. An electric motor is *a device for converting electrical power into mechanical power.*

An electric generator performs the opposite function. When its shaft is turned by a steam, gasoline, or diesel engine, or by the force of falling water, a voltage is generated at the terminals of the generator. This voltage can then be used to drive electric motors or to energize electrical or electronic equipment. Thus, an electric generator is *a device for converting mechanical energy into electrical energy.*

The design of all electric motors is based on the fact that a magnetic field is formed when an electric current flows through a coil of wire. This magnetic field can exert a strong force which is converted to torque. All electric generators operate on the principle that when a coil of wire is rotated in a stationary magnetic field (or the wire is stationary and the field revolves) an alternating current can be made to flow in the coil; the current flow continues as long as the rotation is maintained. In all motors and generators ac must exist; in d-c machines, a rectifying device called a *commutator* changes ac into dc for a generator and dc into ac for a motor.

Construction. Depending upon their construction, motors and generators are used with direct current or with alternating current. Some types of machines can be used as either motors or generators. The general construction of a d-c motor or generator is shown in Fig. 3-15A. Inside the housing, and mounted to it, are a number of coils of wire wound on cores consisting of layers of soft iron. The assembly containing these stationary windings is known as the *stator*, and the windings themselves are often known as the *field* coils.

The rotating shaft is mounted in bearings that allow it to turn freely. A number of coils of wire are wound around soft iron cores attached to the shaft. Each end of each coil is electrically connected to a metal strip or segment mounted on, but insulated from, the shaft. All of these strips are insulated from each other, and the complete segment assembly is the *commutator*. Electrical connections to the coils on the shaft are made by means of two or more stationary contacts or *brushes*, which press against the commutator and successively contact the various segments as the shaft turns.

The entire rotating section of the motor or generator is known as the *rotor*.

Although all d-c motors and generators have commutators and brushes, this is not the case with a-c motors and generators, since the required effects can be produced solely by alternating magnetic fields.

Symbols. While there are a number of different types of motors and generators with a wide variety of operating characteristics, the distinction between types is rarely indicated in schematic diagrams. A parts list, and the manufacturer's model number, should provide all the information required. The generalized schematic symbol is a circle with the letter symbol B, or the abbreviation MOT, for motor, and the letter symbol G, or the abbreviation GEN, for a generator. These symbols are shown in B and C of Fig. 3-15.

In some schematic diagrams the symbol is shown as a circle, representing the complete rotor, and one or more coil symbols, representing the different stator windings, as shown in Fig. 3-15D. The method by which the circle and coils are connected to each other and to the outside circuit indicates the basic type of motor or generator.

For example, if the coil is shown in series with the circle, a *series-wound* type of motor or generator is indicated; this means that the armature and field coils are connected in series. If the coil is shown in parallel (or "shunt") with the circle, a *shunt-wound* type of motor or generator is indicated; this means that the armature is connected in parallel with field coils. Each type of machine has certain special advantages for certain uses.

There are also *compound-wound* machines which afford the advantages of both the series-wound and shunt-wound types. Although the schematic symbol contains nothing resembling brushes or a commutator, it should be understood that these exist in any connection made to the circle part of the symbol for a d-c machine.

In d-c motors the speed of rotation can be controlled by varying the voltage supplied to either or both the rotor and stator windings. Direction of rotation can be changed by reversing the connections to either, but not both, of these two windings. Figure 3-15E shows a motor circuit with provisions for both of these types of control. In general, the speed and direction of rotation of a-c motors is determined by their basic design and construction, and there is no simple method of changing these operating characteristics. Generator output voltage can be increased by driving the shaft at higher speed or by providing a higher voltage to the generator field coils (see Fig. 3-15F).

INTERPRETATION OF AUTOMOBILE WIRING DIAGRAM: IGNITION, STARTER AND CHARGING SYSTEM

General arrangement. The automobile wiring diagram to be analyzed here is the one shown in Fig. 2-18A. The lighting subsystem was analyzed in Chapter 2; the ignition system and the

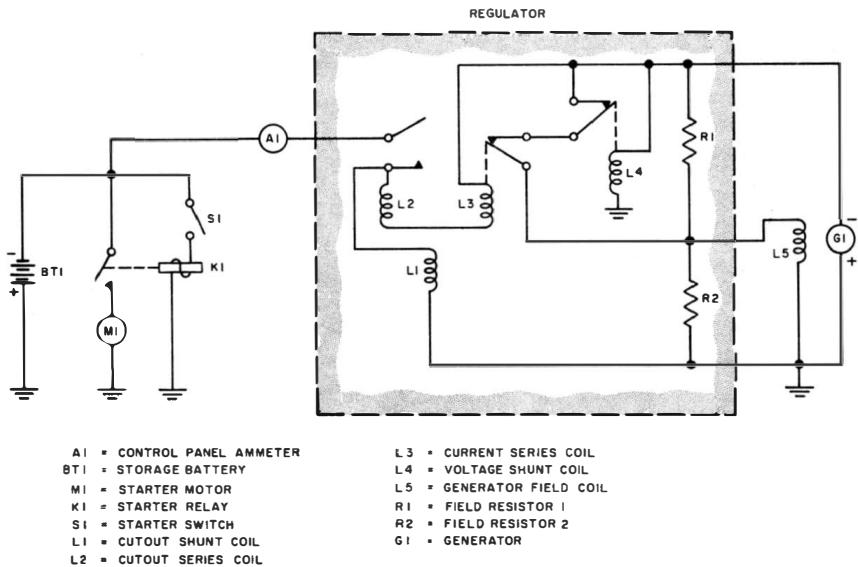


Fig. 3-16. Automobile starting and battery charger system.

starter and battery charger will be considered now. (The accessory system will not be analyzed at all because it contains many special components that cannot be described without extensive explanations of automobile instrumentation and special drive systems.) The methods of analysis used in Chapter 2 also apply here.

Starter and battery charger. The drive shaft of a gasoline engine must be rotated before the engine can begin to operate. The turning of the engine shaft draws a gasoline and air mixture into the cylinders, compresses this mixture and supplies the spark required to ignite it. Almost every automobile uses an electric starter motor to turn the crankshaft until the engine begins to operate under its own power. Since the automobile storage battery must supply power to the starter motor, lights, and accessories, it must be kept re-

charged to be ready for use. A d-c generator is supplied for this purpose, and is turned by the engine.

Simplified schematic. The procedure for drawing a simplified schematic of the starter and battery charger system is the same as for the lighting system. Using a pencil of a different color than that used previously, trace out all of the connections between the battery, starter motor, and generator. Then draw these connections in schematic-diagram form on a separate sheet of paper. The result should contain the information shown in Fig. 3-16. The only information that cannot be obtained from the wiring diagram concerns the internal connections of the regulator; these will be explained shortly.

The battery in Fig. 3-16 is connected through a heavy-duty relay to the starter motor. The relay is necessary because an electric current of hundreds of amperes is required to supply the starter motor with sufficient power to turn the engine shaft. The insulated copper wire used to carry this current is approximately $\frac{1}{2}$ -inch thick; very heavy switch contacts are also required. Since there is little space behind the control panel for such a bulky arrangement, it is much more convenient to use a small switch with thin connecting wires behind the control panel, and to mount the heavy-duty relay in the engine compartment. Closing the switch energizes the relay coil, closing the relay contacts and thereby connecting the battery to the starter motor.

The d-c generator is turned by the engine while the engine is running. Since the battery can be damaged by overcharging, a regulator is used to keep the voltage and current applied to the battery within safe limits. The regulator is a specialized device that is of interest in automotive systems, but a schematic diagram of a typical unit is shown in the portion of Fig. 3-16 outlined in dashed lines; a simplified explanation follows.

Interpretation of the schematic. The regulator consists essentially of three relays: a voltage relay, a current relay, and a cutout relay. While the engine is not running, the voltage and current relays are normally closed, and the cutout relay is normally open. The purpose of the voltage relay is to prevent excessive generator voltage from being applied to the battery at high engine speeds. Since the coil of the voltage relay is connected across the generator terminals, a rise in generator voltage increases the current through this coil, and the contacts open.

With the contacts closed, the field resistor is shorted out of the circuit; full generator output voltage then is applied to the field coil, and the generator continues to develop its full output. With

the voltage relay contacts open, the field resistor is unshorted, and the field and absorbing resistors act as a voltage divider for the voltage delivered to the field coil. Less current now flows through the generator coil and there is a decrease in the generator voltage

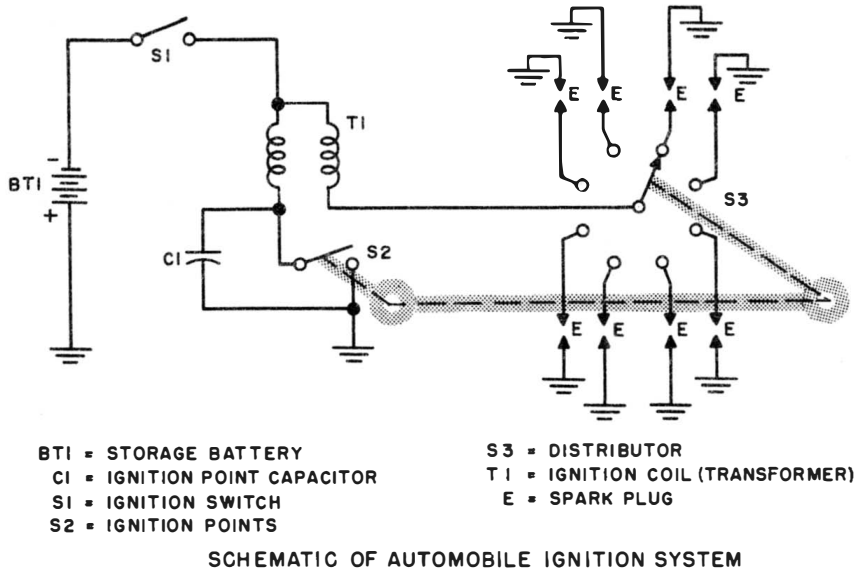


Fig. 3-17. Automobile ignition system.

output. Under normal running conditions, the voltage relay contacts vibrate rapidly, and the average voltage delivered to the battery is the safe voltage required to charge it.

The operation of the current relay is identical to that described for the voltage relay, except that the current relay coil is in series with the generator current output to the battery. As a result of the operation of this relay, the battery charging current is limited to a safe value.

When the gasoline engine turns very slowly or stops, the battery voltage is higher than that of the generator; without the cutout, the battery would discharge through the generator. The cutout prevents this by opening its contacts and interrupting the reverse current flow. These contacts close when the generator output can charge the battery; they open when reverse current begins to flow.

Ignition system. The ignition system in an automobile is the electrical arrangement that provides a surge of high voltage to the

spark plug to explode the gasoline-air mixture in the cylinder. Consequently, to draw a simplified schematic of the ignition system all the connections and components between the spark plugs and the battery must be traced out. When the schematic diagram is complete, it should contain all of the information shown in Fig. 3-17. The only information that cannot be obtained from the wiring diagram is the fact that the ignition coil is a step-up transformer.

Interpreting the schematic. It can be seen from the schematic diagram in Fig. 3-17 that the main parts in the ignition system are the battery, ignition coil, and distributor (which in an 8-cylinder engine contains an 8-position selector switch, the pole or *rotor* of which is rapidly rotated by mechanical connections to the engine). Also contained in the distributor is a single-pole single-throw switch (commonly known as the *points*), which is rapidly opened and closed by the mechanism that drives the rotor. A capacitor is connected across the points.

As the engine turns, a surge of high voltage must be supplied to the right spark plug at the right time. The spark plug is essentially a conductor with a very small break or *gap*, and the ignition voltage surge causes a hot spark to jump across the gap. This spark explodes the gasoline-air mixture in the cylinder; the force of the explosion moves the piston in the cylinder, turning the main engine shaft. The distributor connects the high-voltage surge to one spark plug after another.

The distributor drive mechanism closes and reopens the points eight times during one complete turn of the rotor. For the brief period during which the points are closed, a surge of battery current flows through the transformer primary winding. This current surge has the same effect as a half-cycle of a-c current. As a result, a surge of several thousand volts appears across the transformer secondary winding. The rotor connects this surge of high voltage to the selected spark plug.

If there were no capacitor across the ignition points, the rapid collapse of the magnetic fields in the ignition coil windings would generate a high-voltage surge across the points. This would cause a spark to jump across the points as they open. Not only would this spark interfere with normal point operation (effectively causing conduction between the points when they were separated) but the high temperature developed by the spark would quickly burn away the contacting surface of the points. Since a capacitor has the effect of opposing voltage change, the voltage appearing across the opening point contacts is limited to a level below that required to form a hot spark.

Chapter 4

ELECTRONIC EQUIPMENT POWER SUPPLY CIRCUITS

Almost every piece of electronic equipment requires several different a-c and d-c voltages for the operation of its internal circuits; the group of components used to supply these voltages is known as the power supply. The type of power supply used for any equipment depends not only upon the voltages and currents required, but upon the cost, the weight and space requirements, and the availability of a suitable source of primary electric power. It can be seen that there are few weight, space, cost, and power-source restrictions placed upon a commercial radio transmitter based on land, but each of these factors is greatly restricted when an efficient transmitter or receiver must be placed in an automobile, small boat, or airplane.

IDENTIFYING TYPES OF POWER SUPPLIES

As a result of these considerations, there are several basic types of power supplies in use today. These range from the simple, low-cost types used in table-model radio receivers through the more complex and costly types used in high-fidelity sound systems; those which must operate from an automobile storage battery, and those which must operate while being carried on a man's back.

A general-purpose power supply, involving no serious space, weight, or cost restrictions usually contains a transformer, a rectifier, and a filter circuit. Such a power supply operates from the a-c power line and supplies low-voltage a-c and high-voltage d-c to the equipment circuits. The purpose of the transformer is to take the 117-volt, 60-cycle input and transform this to whatever high and low voltages are required. Since all electronic equipment requires

high-voltage dc, a rectifier circuit is used to change the high-voltage ac at the transformer secondary, to an equivalent high-voltage dc. The filter circuit smoothes out the voltage variations in the rectifier output, so that pure dc will be supplied to the equipment circuits.

If the equipment contains precision circuits that must have a

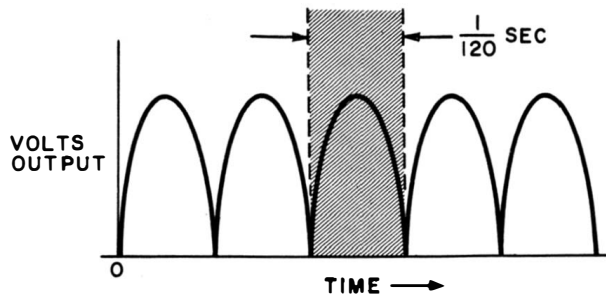


Fig. 4-1. Output voltage of a full-wave rectifier with no filter.

steady d-c voltage input, a voltage regulator is used. If only a storage battery is available to activate the power supply, a vibrator is generally used to interrupt the low-voltage dc for conversion to higher-voltage ac. The latter voltage is then used to operate the rectifier. Some circumstances permit the complete elimination of the rectifier tube or the transformer. There are also many other variations.

RECOGNIZING RECTIFIER CIRCUITS

Purpose. The purpose of a rectifier is to change an a-c voltage to a d-c voltage. In most power supplies the rectifier is used to supply d-c voltages on the order of 350 volts at currents of 50 to 100 milliamperes (ma). (1000 milliamperes=1 ampere.) A rectifier does not change its input voltage into a steady and unvarying d-c output voltage. As shown in Fig. 4-1 (which is the output of a full-wave rectifier), the output varies in voltage from zero to a maximum and back to zero without reversing in polarity. Filter circuits (such as those reviewed in Chapter 3) are then used to smooth this rectifier output to a fairly stable voltage in which the ripple voltage is only a few percent (or less) of the total voltage. The most common rectifier circuits make use of either vacuum tubes or dry-metal rectifiers.

Rectifier tubes and schematic symbols. A rectifier tube consists of a glass or metal envelope containing a *filament* (or *heater*), one

or two *plates*, and sometimes a *cathode-shell* surrounding the filament. Air is evacuated from the envelope, leaving a "high vacuum"

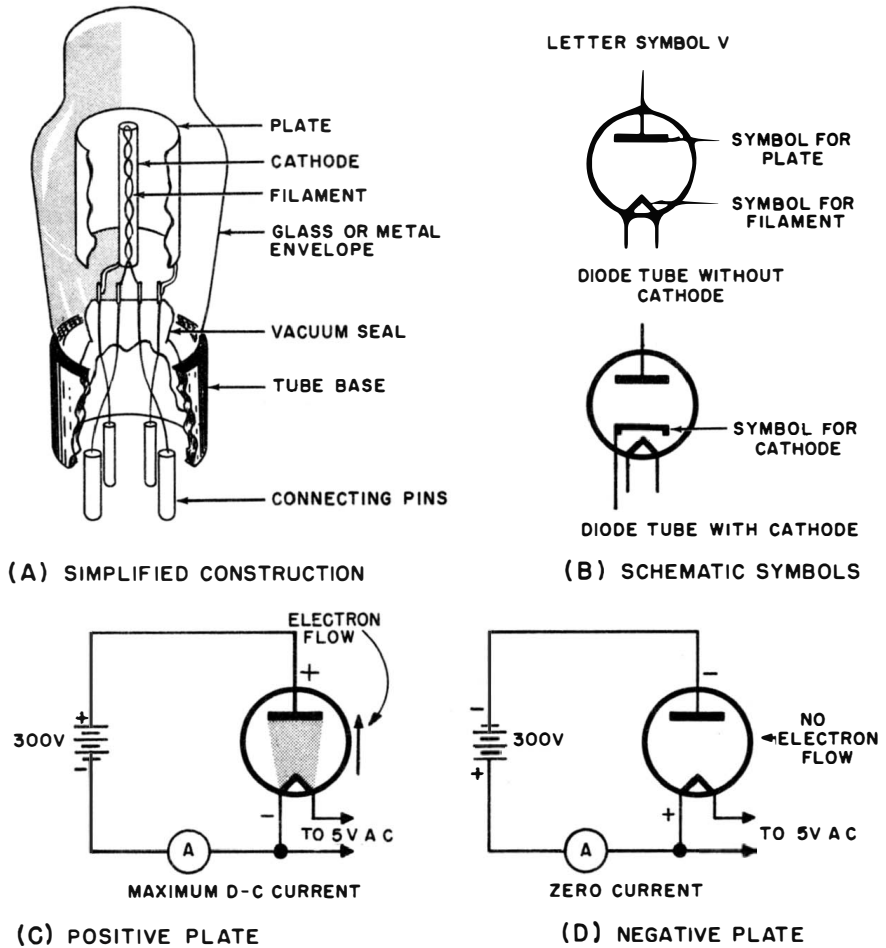


Fig. 4-2. Single-diode rectifier tube. (A) Simplified construction. (B) Schematic symbols. (C) Positive plate. (D) Negative plate.

inside. The construction and schematic symbols of two typical rectifier tubes are shown in A and B of Fig. 4-2.

Figure 4-2C shows the operation of a rectifier tube consisting only of a filament and a single plate. The filament is heated by connecting it to a source of low-voltage alternating current. Heat causes electrons to be emitted from the surface of the filament and they collect in a cloud around it. If a voltage source is connected across

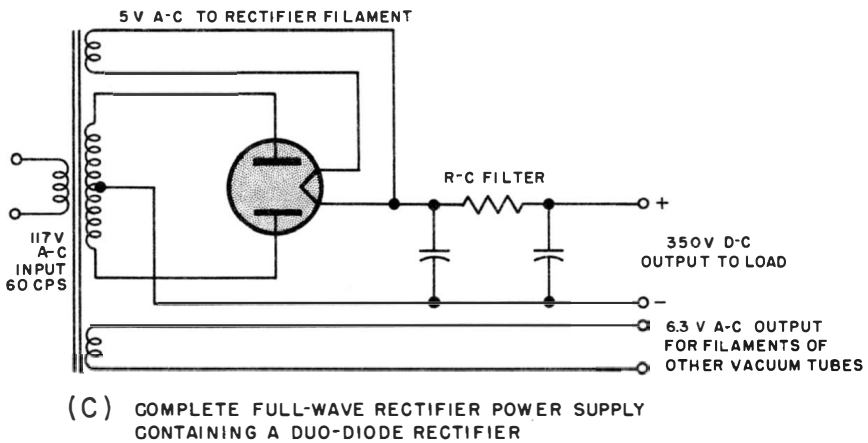
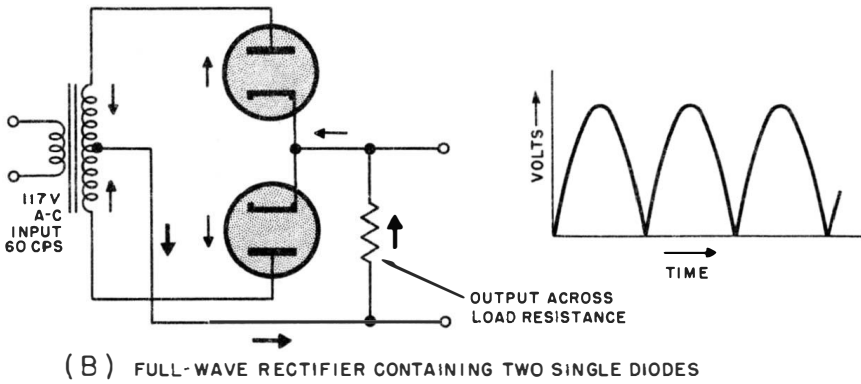
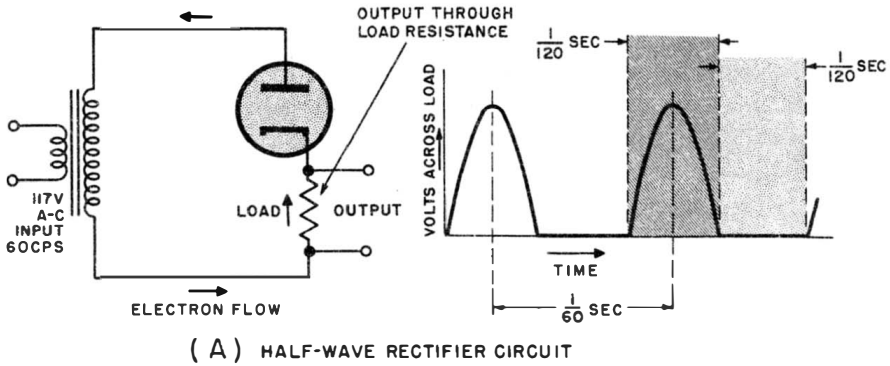
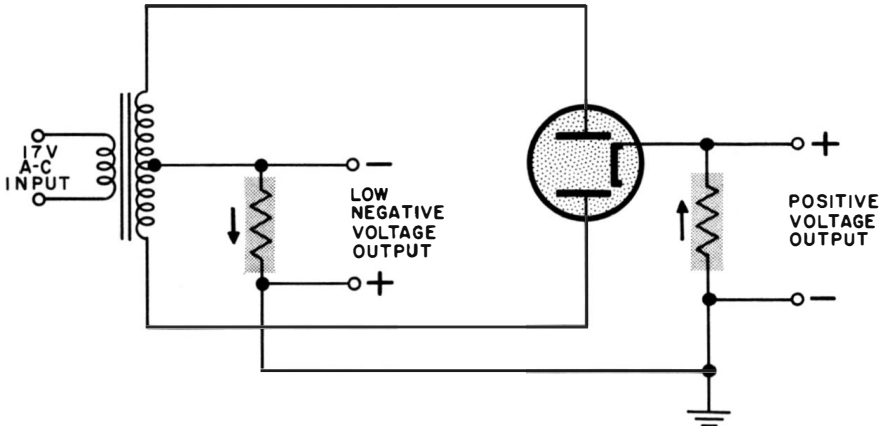


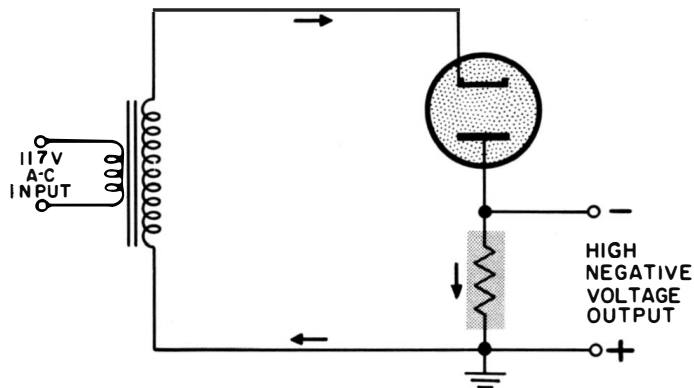
Fig. 4-3. Basic transformer-type rectifier circuits. (A) Half-wave rectifier circuit. (B) Full-wave rectifier containing two single diodes. (C) Complete full-wave rectifier power supply containing a duo-diode rectifier.

the tube, making the plate positive and the filament negative, the electrons will be attracted to the plate. This filament-to-plate current flow and the external connections, form a complete circuit.

If the polarity of the voltage source is reversed, as shown in Fig. 4-2D, the plate becomes negative; no electrons are attracted to it,



(A) RESISTOR IN SERIES WITH TRANSFORMER CENTERTAP



(B) REVERSAL OF RECTIFIER TUBE CONNECTIONS

Fig. 4-4. Negative voltage rectifier circuits. (A) Resistor in series with transformer centertap. (B) Reversal of rectifier tube connection.

and no current flows through the outside circuit. Since the tube contains only two elements directly associated with flow of electrons, it is called a *diode* (two-element) tube.

If a cathode is placed in the tube (see the lower part of Fig 4-2B),

it is heated by the filament, and the cathode emits the electrons. This type of tube is also a diode because here again there are only two active elements, the filament serving only as a means of heating the cathode. When the tube contains a cathode, the filament symbol is often eliminated from the main part of the schematic diagram for purposes of simplification. When the tube has no separate cathode, the filament element is used and functions as the cathode.

VACUUM-TUBE RECTIFIERS

Half-wave rectifier circuits. The simplest rectifier circuit consists of a tube with a single plate and cathode connected across the secondary winding of a transformer, as shown in Fig. 4-3A. Since the tube conducts current only when the diode plate is positive, only one *half* of the sine-wave input produces a useful output. For this reason the circuit is known as a *half-wave rectifier*. Although there is zero output voltage for 1/120 of a second, a filter circuit can be used to smooth out the variations and give a fairly stable output voltage.

Full-wave rectifier circuits. The unused portion of the input sine-wave can be utilized by two half-wave rectifier tubes. This arrangement is shown in Fig. 4-3B and is known as a *full-wave rectifier*. In this case the transformer secondary winding has a center tap. When the input voltage is such that the upper diode plate is positive with respect to its cathode, that diode conducts, delivering a half-cycle of positive voltage to the load. When the input voltage reverses, the lower diode plate is positive with respect to its cathode, and that diode conducts, delivering another half-cycle of positive voltage to the load. Thus a half-cycle of output voltage is obtained for each of the two halves of the cycle.

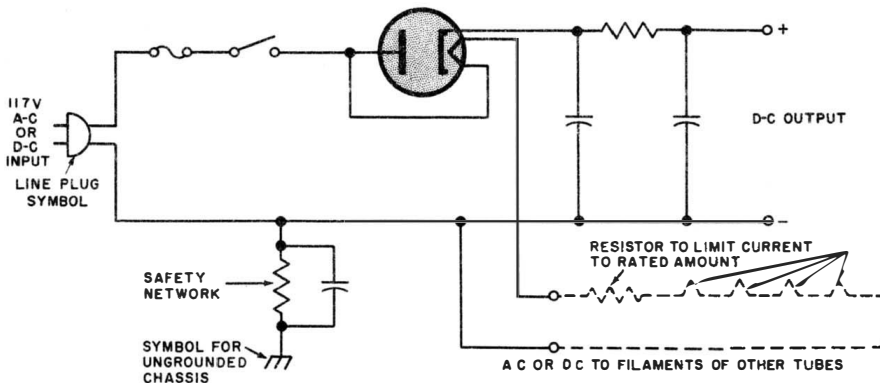
Single-tube full-wave rectifier circuits. Instead of using two half-wave rectifier tubes, a single tube with two plates can be used, as shown in Fig. 4-3C. Operation is identical to that of the previous circuit.

Negative-voltage supplies. If low negative voltages are required they can be obtained by placing a resistor in the transformer center-tap connection, as shown in Fig. 4-4A. The higher the resistance value used, the higher will be the negative voltage obtained, but this amount of voltage is subtracted from the overall voltage output of the rectifier.

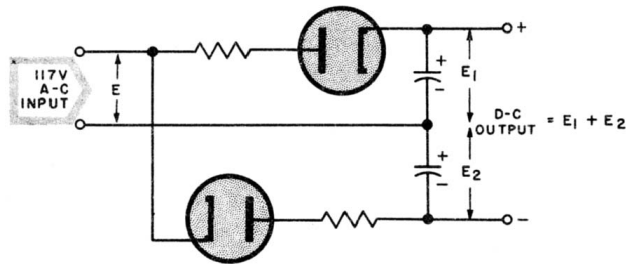
If high negative voltages are required, they may be obtained by the circuit arrangement shown in Fig. 4-4B. This circuit is identical

to that of the half-wave rectifier considered previously (Fig 4-3A), except that the connections of the plate and cathode are reversed. The tube will only conduct when the plate is positive, but the connection to the load resistor gives a negative output.

Transformerless rectifier circuits. When weight or cost is a limiting factor, it is often possible to eliminate the use of the transform-



(A) COMPLETE A C OR D C TRANSFORMERLESS POWER SUPPLY WITH HALF-WAVE RECTIFIER



(B) FULL-WAVE VOLTAGE DOUBLER

Fig. 4-5. (A) Complete a-c or d-c transformerless power supply with half-wave rectifier. (B) Full-wave voltage doubler.

er. In this case the rectifier tube may be connected directly to the power line, as shown in Fig. 4-5A. In this type of circuit the maximum no-load output voltage obtainable is the peak voltage of the a-c line input minus the voltage drop in the rectifier tube. Output voltage drops rapidly with increasing loads. Operation is identical to that of the half-wave rectifier considered previously.

This type of rectifier can be operated from a d-c line, but the connection must be made so that the plate is positive. When operated from a d-c line, the rectifier tube conducts continuously. This is the

most common type of transformerless power supply used in a-c/d-c radios. (Note that *neither* side of the power input can be connected to the chassis because reversal of the plug would make the chassis "hot," creating a serious shock hazard.) The effects of grounding are obtained by connecting the negative output of the power supply to the chassis through a resistor-capacitor network (Fig. 4-5A).

When higher voltages are desired without a transformer, the voltage-doubler circuits shown in Fig. 4-5B can be used. Each diode conducts during the half-cycle in which its plate is positive, and each

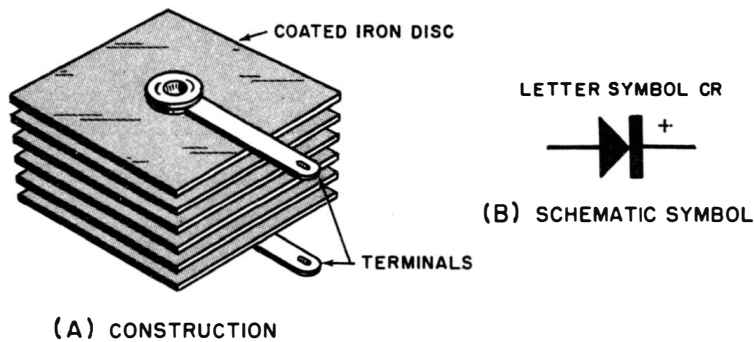


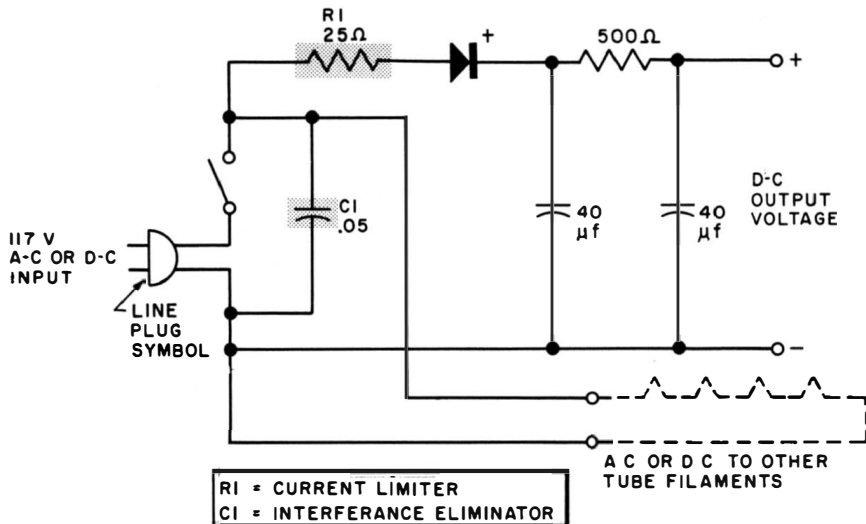
Fig. 4-6. Selenite rectifier. (A) Construction. (B) Schematic symbol.

diode charges its capacitor to peak line voltage. Since the two capacitors are in series, the total voltage across both of them is at approximately twice the peak line voltage. The voltage-doubling action takes place only when the input is an a-c voltage.

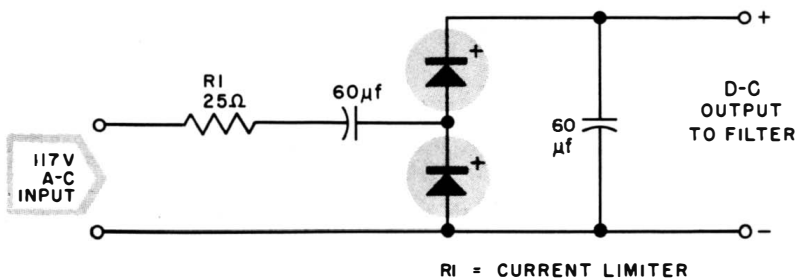
Dry-metal rectifiers. In recent years a new type of rectifier has been perfected. These units consist of copper discs coated on one side with copper oxide or iron discs coated on one side with selenium. When these discs are stacked with metal spacers, the unit allows a much greater current flow in one direction than in the other, making it useful as a rectifier. Simplified construction details and the schematic symbol are shown in Fig. 4-6. Copper-oxide rectifiers are used mainly in such instruments as a-c voltmeters. Selenium rectifiers are used mainly where a moderate to large amount of power must be supplied to the load.

Dry-metal rectifiers are rugged, give long-term service, and do not have to be heated in order to operate. No chemical reactions are involved in their operation, and there is nothing to be used up or worn out. The main drawback to their use in power supplies has been their relatively large size. This difficulty has been resolved

to a large extent, and selenium units are now widely used in a-c/d-c rectifier circuits. They are also used in special equipments requiring separate sources of low-voltage dc. In these applications the units



(A) COMPLETE HALF-WAVE POWER SUPPLY



(B) HALF-WAVE VOLTAGE DOUBLER

Fig. 4-7. Typical selenium rectifier circuits. (A) Complete half-wave power supply. (B) Half-wave voltage doubler.

are much smaller than vacuum tubes and can supply many times more current.

Typical circuits. Dry-metal rectifiers can be used in all of the circuits previously described for vacuum-tube rectifiers. To change any of these schematics to an equivalent dry-metal rectifier circuit, simply substitute the arrow and bar symbol for the vacuum tube symbol. Examples of a half-wave power supply and a half-wave

voltage-doubler circuit are shown in A and B respectively, of Fig. 4-7. Note that the direction of electron flow is opposite to the direction of the arrow in the rectifier symbol.

VIBRATORS AND VIBRATOR RECTIFIERS

In a number of applications, a power supply must deliver a high-voltage d-c output, but only a storage battery or a 117-volt

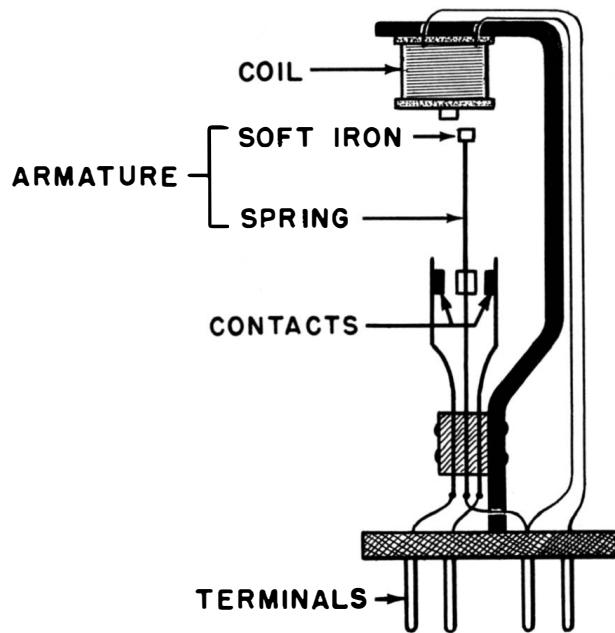


Fig. 4-8. Vibrator, simplified construction diagram.

d-c line is available as a power source. For example, the only source of power for an automobile radio is a 6-volt or 12-volt storage battery. Under these conditions a vibrator and transformer can be used to change the d-c voltage to high-voltage ac. If a rectifier tube is not to be used, certain types of vibrators are capable of both interrupting the low-voltage d-c and rectifying the resulting ac.

Vibrator construction. Figure 4-8 shows a simplified construction diagram of a vibrator. The schematic symbol appears in Fig. 4-9. It can be seen from these diagrams that the vibrator is simply a variation of a relay in which the armature consists of a flexible

spring with a soft-iron end. The spring is adjusted so that, if tapped lightly, it will vibrate naturally at frequencies of from 50 to 100 times a second. When the coil is energized and de-energized at these same frequencies, the resulting spurts of magnetism supply just the right impetus to the armature to keep it vibrating contin-

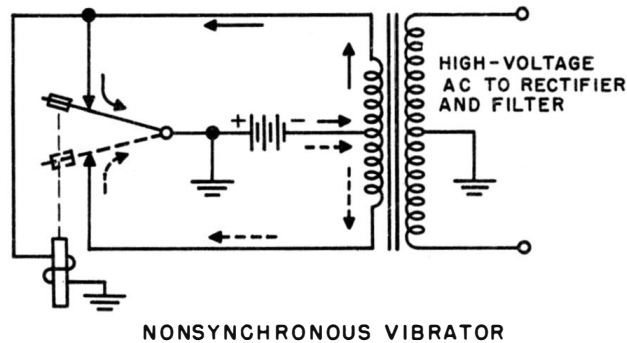


Fig. 4-9. Nonsynchronous vibrator, in an automobile radio system.

uously. With each back and forth swing, the armature closes and opens the contacts on either side of it.

Nonsynchronous vibrator circuits. Figure 4-9 shows a simplified schematic diagram of the vibrator connections in an automobile radio system. As the armature vibrates between the contacts, it has the effect of rapidly reversing the direction of current flow through the transformer primary winding. When the armature touches the upper contact the electrons flow only through the upper part of the primary winding, in the direction shown by the solid arrows. When the armature touches the lower contact the electrons flow only through the lower part of the primary winding, in the direction shown by the dotted arrows.

The result is equivalent to an a-c current flow through the transformer primary, even though the variations are not as smooth as when a sine-wave voltage is applied. As a result, high-voltage ac emerges from the transformer secondary, and this voltage may be connected to any of the rectifier and filter systems considered previously. A vibrator of this type is known as a *nonsynchronous vibrator*.

Synchronous vibrator. If the vibrator is made with a second pair of contacts, shown schematically and marked A and B in Fig. 4-10, the second set of contacts can be used to rectify the transformer output — and the rectifier can be eliminated. Since the armature

completes circuits simultaneously with the two contacts on either side, the vibrator is known as the *synchronous* type.

Operation of the circuit connected to the transformer primary is identical to that of the vibrator considered previously; therefore, only the effects in the secondary winding circuit will be considered now. When the armature touches the upper contact (A), the current flows only through the upper part of the secondary winding, and through the load in the direction shown by the solid arrows. When the armature touches the lower contact (B), the current flows only through the lower part of the secondary winding, and through the load in the direction shown by the dashed-line arrows.

Since the current always flows through the load in the same direction, direct current is obtained and a d-c voltage is impressed across the load resistance. The result is identical to that obtained by means of a vacuum tube or dry-metal rectifier. The output can be smoothed out to pure dc by a suitable filter circuit.

ELECTRONIC EQUIPMENT WIRING TECHNIQUES

The universally accepted method of constructing electronic equipment is to mount the various components upon a metal box or

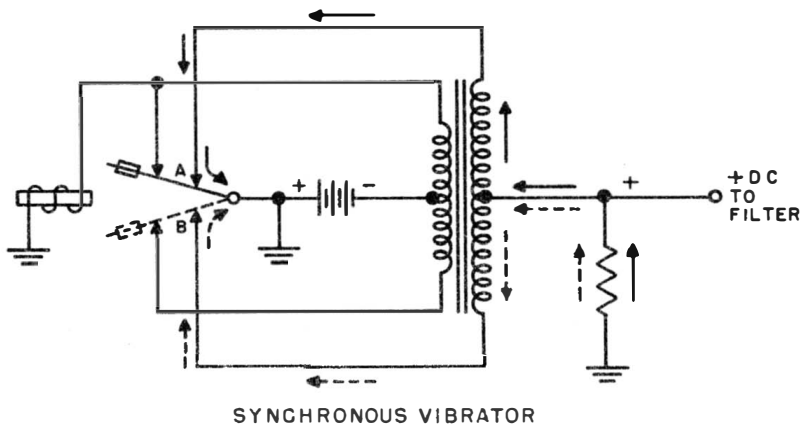
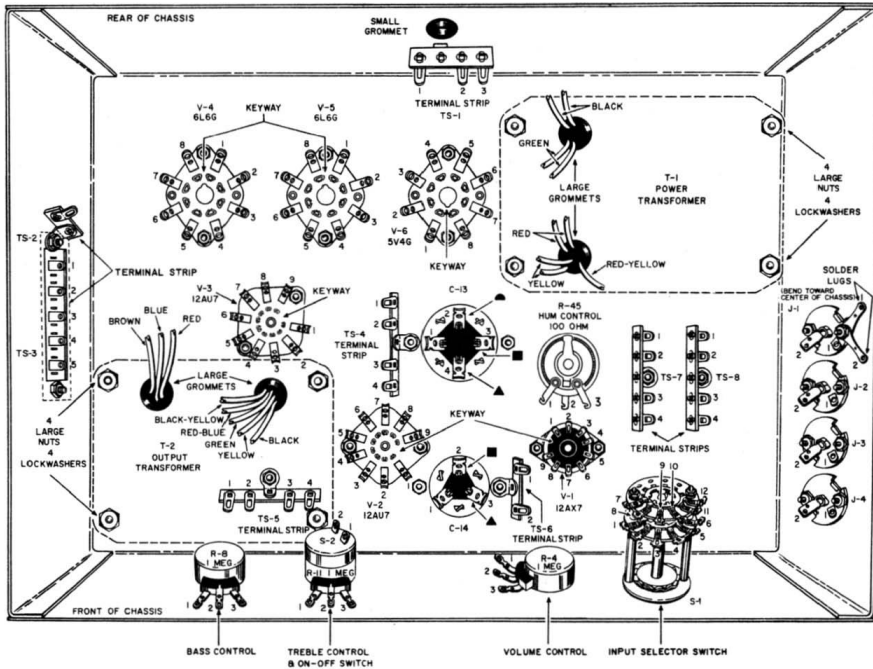


Fig. 4-10. Synchronous vibrator.

framework known as the *chassis*. In small units all the components are mounted on a single chassis, which is generally placed in a protective cabinet. When the equipment requires more parts than can be placed on one chassis of convenient size, two or more chassis

are used. These chassis may be placed in individual protective cabinets, stacked vertically in a framework called a *rack*, or mounted in a desk-type cabinet that provides maximum convenience for the operator and is called a *console*.

Mounting large parts. The larger circuit components (transformers, chokes, tubes, and the larger resistors and capacitors) are



Courtesy Allied Radio Corporation.

Fig. 4-11. Chassis underside with major parts mounted but not wired.

fastened directly to the top of the chassis or to brackets fixed to the chassis. Holes are cut through the top of the chassis, making terminals of the components accessible from the bottom. Figure 4-11 shows a pictorial diagram of the underside of a hi-fi amplifier chassis with the major parts mounted, but not wired. Note that sockets are used to mount tubes and some electrolytic capacitors to permit easy replacement.

Most of the wiring is done underneath; it is unusual for more than a few wires to appear on top. This procedure keeps the top free of dangerous voltages, permitting inexperienced persons to replace tubes without danger of electric shock. When space requirements result in the presence of high voltages on the upper part

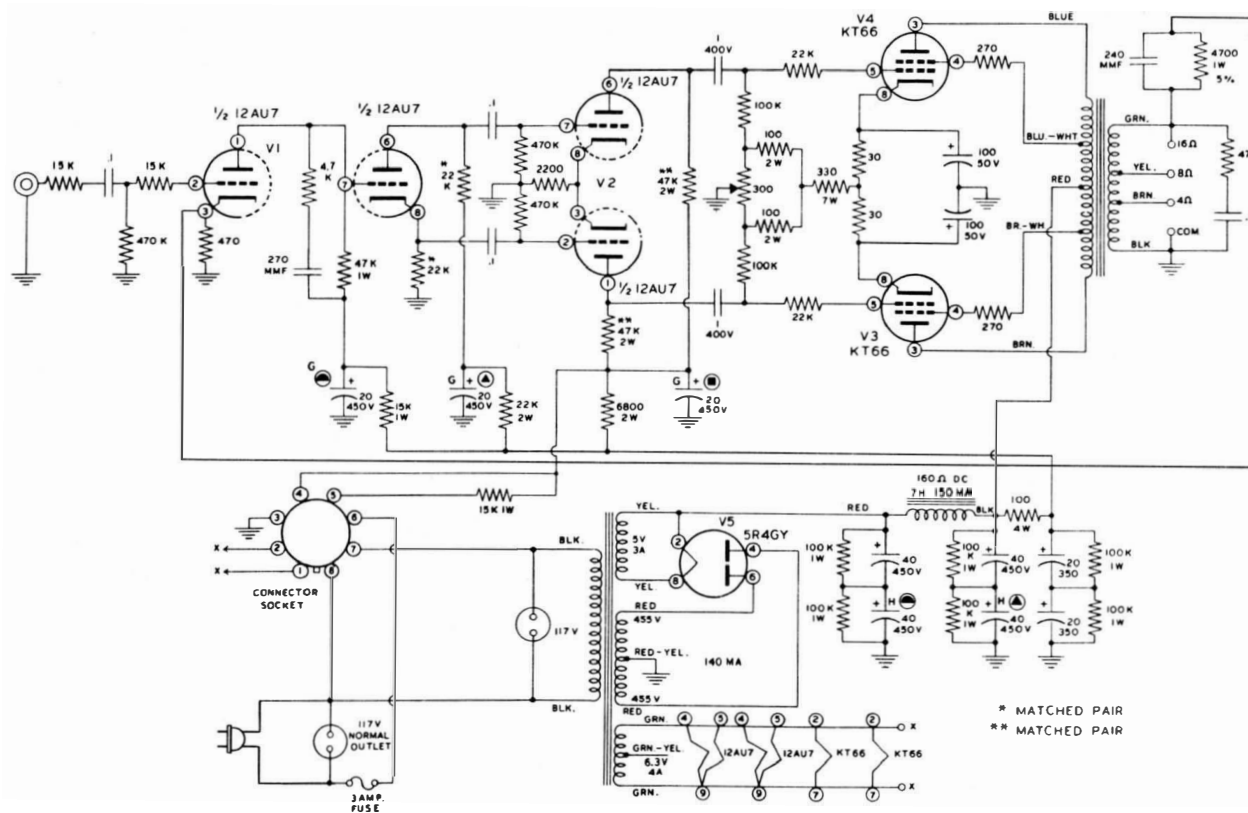


Fig. 4-12. High-fidelity audio amplifier schematic, showing power supply in lower half of diagram. Courtesy Heath Company.

of the chassis (as is the case with most television sets) special devices disconnect the power when the back is removed from the cabinet.

Identification of connections. When a part has several leads or terminals, these leads are identified by insulation of different colors, numbers stamped next to the terminals, or special markings (squares, circles, triangles) stamped or painted next to the terminals or leads. Standardization has been attempted, but no single system has been universally accepted. The schematic diagram is often marked to indicate the colors of wires and the numbers or symbols of the terminals that appear on the part itself. Figure 4-12 is an example of such a schematic. If there is no marking on the schematic diagram to identify a connection, it can be assumed that the part itself is marked so clearly that identification on the schematic is unnecessary.

Fixed resistors and chokes are *unpolarized*; either of the output leads may be used to make either of the two connections indicated in the schematic diagram. In the case of variable resistors with unmarked terminals, the sliding contact is always the center of the three terminals. The black band on paper tubular capacitors marks the end that should be connected closest to ground. The special requirements of other parts will be considered later.

The method of identifying tube socket terminals requires special consideration. Tubes are made with the pins spaced so that the tube cannot be put into its socket unless the pins are seated in the correct holes. Many tubes have a ridged cylindrical projection at the center of the base (see Fig. 4-13A). This *key* fits into a notch (called a *keyway*) at the edge of a round hole in the tube socket (see Fig. 4-13B). This arrangement permits the tube pins to be aligned and inserted into the proper holes in the socket with a minimum of attention. To identify the terminal numbers on a tube socket, examine it from the underside of the chassis and count in a clockwise direction, from the blank space or keyway (see Fig. 4-13B).

Methods of wiring. There are several methods of mounting the small components on the chassis and making the required electrical connections. The method that was used almost universally until the early fifties is called *point-to-point* wiring.

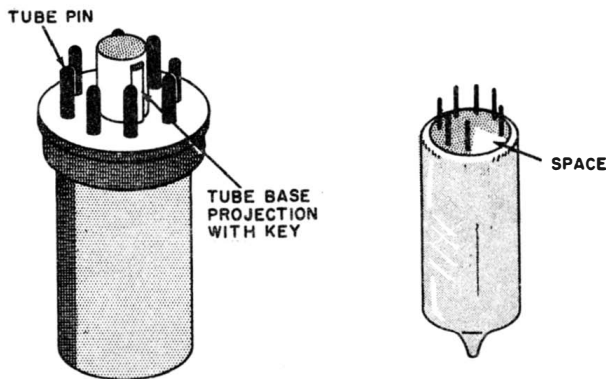
In point-to-point wiring most parts are connected directly between the points indicated on the schematic diagram. For an example of this type of wiring see Fig. 1-5. Large parts are mounted either directly on the chassis or on brackets attached to the chassis, and their leads are also connected directly to the points indicated on the schematic. Parts that are not in close proximity

may be wired through intermediate terminal strips. Terminal strips are readily evident in Fig. 4-11; see also Fig. 1-5.

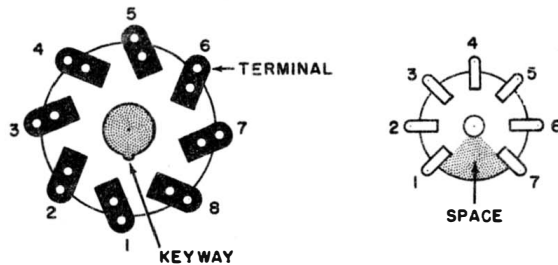
This method of wiring does not give a very neat appearance to the underside of the chassis, but it usually provides the shortest possible leads—a desirable condition for best operation and to prevent circuit interaction. In addition, the stiffness of resistor and capacitor leads is usually sufficient to hold the body of the part suspended in the air, so that no other method of mounting is required. (Other construction methods are discussed later in this chapter and in Chapter 6.)

EXAMPLE OF POWER SUPPLY WIRING

Figure 4-12 is the schematic diagram for a high-fidelity amplifier for use in home music systems. Only the power supply is of inter-



(A) TYPICAL TUBE BASES



(B) TYPICAL TUBE SOCKETS

Fig. 4-13. Tube socket terminal identification. (A) Typical tube bases. (B) Typical tube sockets.

est at the present time; the amplifier portion will be considered in the next chapter. Figure 1-5 shows the underside of the chassis with the point-to-point wiring completed.

The power supply is shown in the lower half of the schematic diagram. It should be recognized as a transformer-type containing a full-wave rectifier with a combination of L-C and R-C filtering. The circuit used in this power supply is basically that of Fig. 4-3C; the only significant difference is that a more elaborate filtering system is employed here.

Several features of this power supply are not always found in such circuits. The purpose of the *connector socket* is to supply filament voltage and high-voltage dc to an associated pre-amplifier that does not have a separate power supply. The pre-amplifier also contains a power switch that closes the circuit between terminals 6 and 7 of the connector socket, supplying line voltage to the primary winding of the power transformer. This provides a remote control for turning the power supply on and off. The remote switch also supplies a-c line voltage to the *117-volt switched power outlet*, so that other equipment, such as an f-m tuner or tape recorder, may be turned on and off by means of the single remote switch. A *117-volt normal outlet* is also included for supplying line voltage to additional equipment, such as a turntable motor; this outlet is not controlled by the remote switch or protected by the 3-ampere power supply fuse.

A word of explanation is required concerning the filter capacitors and the 100,000-ohm resistors connected across them. D-c voltages on the order of +500 volts appear at the junction of the filter choke and the 100-ohm resistor, and approximately +470 volts is supplied at the output of the second filter section. These voltages are above the safe voltage ratings for standard electrolytic filter capacitors. An adequate safety factor is achieved by connecting two electrolytic filter capacitors in series, thus doubling the voltage rating.

The 100,000-ohm resistors act as a voltage divider across the capacitors, assuring that equal d-c voltages appear across both of the series capacitors. (These resistors also serve as bleeders, which drain dangerous voltages from the capacitors as soon as the equipment is turned off.) This method gives each of the first two filter capacitor legs a d-c voltage rating of 900 volts, and the third leg a rating of 700 volts.

The major parts of this power supply can be identified in the pictorial diagram of the underside of the chassis (see Fig. 1-5). The power transformer leads, with their colors identified, are seen

coming through holes S and T. Both of the yellow and both of the red leads go directly to the rectifier tube (V5). High-voltage d-c appears at terminal No. 2 of the rectifier tube socket and is connected at terminal strip P to the leads of the filter choke, which come through hole R. The terminals of two-section electrolytic

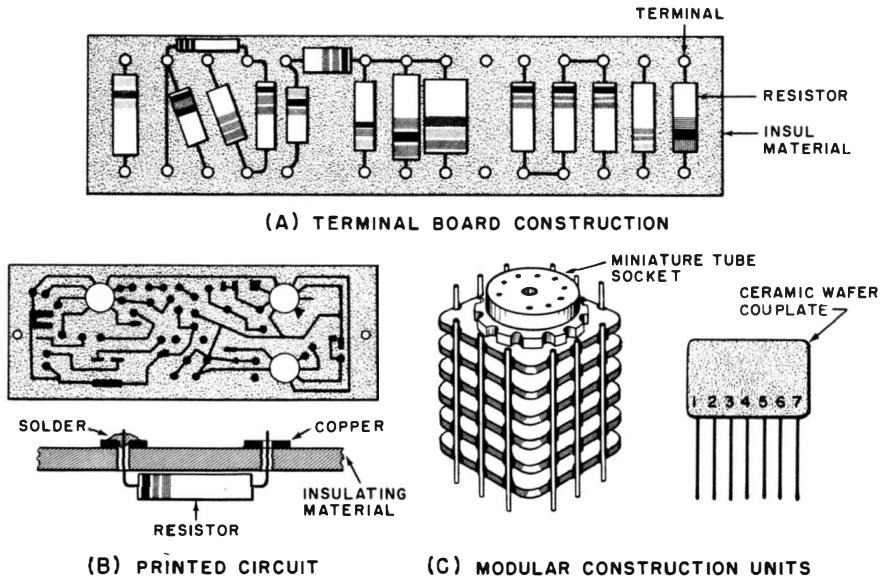


Fig. 4-14. (A) Terminal board construction. (B) Printed circuit. (C) Modular construction units.

capacitor H are identified on this by a semicircle and triangle, and each of its two sections is connected in series with one of the two large tubular electrolytic capacitors mounted to the right. Electrolytic capacitor G is not part of the power supply. The 100-ohm, 4-watt filter resistor is in the upper right-hand corner of the diagram, and the final filter capacitor section is made up of the tubular electrolytic capacitors, which are to the left and right of V5. The 100,000-ohm voltage divider resistors are distributed among the electrolytic filter capacitors.

RECOGNIZING OTHER CONSTRUCTION METHODS

Point-to-point wiring is not the only construction method in use today. *Terminal board*, *printed circuit* and *modular construction*

are gaining in popularity, because such circuits are more compact and rugged, and because they can be assembled by machine. Examples of these will be seen in Chapter 6.

Terminal board. Construction of a terminal board (Fig. 4-14A) involves mounting all or most of the resistors and capacitors in the circuit on a thin board of plastic or other insulating material. The leads of the parts are wound and soldered around metal terminals firmly attached to the board. The board is attached to the chassis, and wires are used to connect the terminals to the tube sockets.

Printed circuit. This construction (Fig. 4-14B) goes a step further than the terminal board method, eliminating wires almost completely. The most common type of printed circuit board consists of a thin sheet of insulating material upon which a very thin sheet of copper is bonded. Photographic or printing methods are used to place upon the copper a network of lines of acid-resisting material. An acid bath is used to etch away all of the unprotected copper, and the copper that remains embodies all the interconnections between the components. Soldering terminals are also etched into the copper and the parts can be soldered directly into the board.

In some circuits connecting wires are run to the tube sockets, but in most recent printed circuits the tube socket is an integral part of the board.

Modular construction. In modular construction certain standardized circuits are made in printed form (including, in many cases, printed resistors and capacitors), and the complete circuit is encased in a wafer of protective insulating material. Only the leads required for external connections are left exposed, and the wafer is sometimes made so that it will interlock with other wafers ("Tinkertoy" construction). Figure 4-14C shows a modular assembly that contains a complete section of an amplifier, including a socket for a miniature tube. Also shown is a ceramic wafer that contains approximately a dozen resistors and capacitors. Selection of the proper module makes it possible to build complex equipment in a minimum of space and in very little time.

Chapter 5

AUDIO AMPLIFIER CIRCUITS

In most electronic equipment, *signals* consisting of very small voltage variations are used to produce sounds, pictures, or mechanical effects. In radio or television receivers, the signal picked up from the transmitter may be as small as a few millionths of a volt, yet this signal must be used to produce audible sound from a loud-speaker or, in the case of television receivers, to form a clear picture on the screen of a cathode-ray tube. In industrial applications equally small voltages must be used to drive heavy machinery. Obviously, something must be done with the small voltages to obtain the power necessary to accomplish the required result. It is done by vacuum tubes (or transistors) which increase the small voltage and current until sufficient power is available to drive the load. This process is known as amplification.

AMPLIFIER STAGES

Almost every piece of electronic equipment consists largely of amplifiers. An ordinary radio contains at least two, and sometimes three, different types of amplifier sections. A television set contains at least five different amplifier sections. The more complex the equipment, the greater the number and kinds of these sections. Each amplifier section may contain one or more vacuum tubes or transistors. Each of these together with the associated parts is known as an *amplifier stage*.

IDENTIFYING TYPES OF AMPLIFIERS

Although there are many methods of classifying amplifiers, one of the most basic and useful is by the frequency of the signals that

must pass through them. Some amplifiers are designed to amplify signal voltages at the frequencies of any sounds audible to the human ear, and are called *audio-frequency* (a-f) amplifiers. The maximum range of human hearing is from 20 to 20,000 cycles, although most of the better high-fidelity amplifiers provide uniform undistorted amplification of signals in a range from 10 cycles

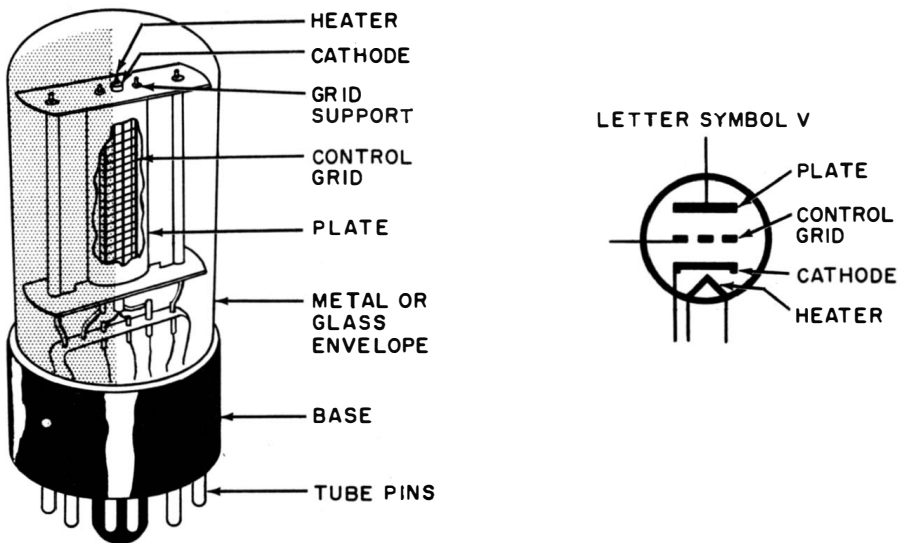


Fig. 5-1. Typical triode tube construction and schematic symbol.

to 100 kc or higher. When the frequency range falls between 30 kc and hundreds of megacycles, the circuit is usually called a *radio-frequency* (r-f) amplifier.

A third common type is the *video* amplifier. This is similar in many ways to the audio amplifiers, but it is used primarily in such applications as television and radar, where the signal eventually activates a picture tube of some type. The frequency range of most television video amplifiers is from 30 cycles to 4 mc, although some types carry even higher frequencies.

AMPLIFIER TUBES AND SCHEMATIC SYMBOLS

Although there are hundreds of types of vacuum tubes available for amplifier applications they all have the same basic type of construction and principles of operation. They are identified by standardized type numbers (6J5, 12SA7, 5Y3, etc.). The digit pre-

ceding the letter is the nominal filament voltage. For the three tubes just mentioned the filament voltages are 6, 12, and 5, respectively. The remainder of the type number gives information concerning the construction of the tube.

Triode amplifier tubes and circuits. The construction and schematic symbol of a simple amplifier tube (rf, af, or video) are

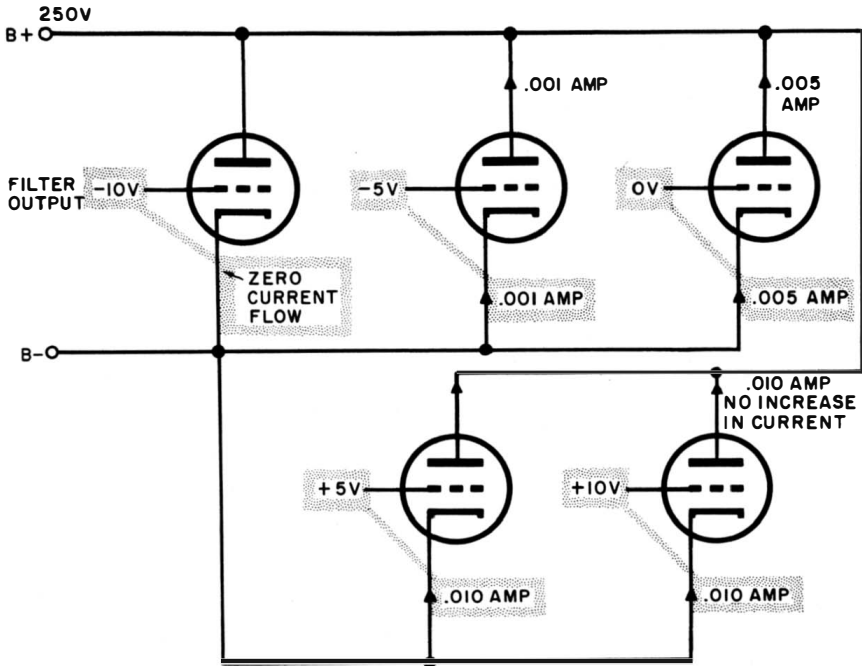


Fig. 5-2. Plate current increase with grid bias increase.

shown in Fig. 5-1. The main differences between this tube and the diode rectifier tube mentioned in Chapter 4 is that a new element, called the *control grid* has been added. Since there are now three elements in the tube that are directly related to the flow of electrons, the tube is known as a *triode*.

Without a control grid, the number of electrons flowing from the cathode to the plate increases as the plate voltage is raised. Up to a maximum current for the tube, a specific amount of current will flow for specific plate voltage.

When the grid is added to the tube, the plate current can be increased or decreased without changing the plate voltage, as shown in Fig. 5-2. Applying a very negative voltage to the grid repels all

the electrons back to the cathode, and none reach the plate. Reducing the negative voltage (known as the grid bias) on the grid permits the plate to attract a few electrons through the tube and the outside circuit. More electrons flow when the grid is made

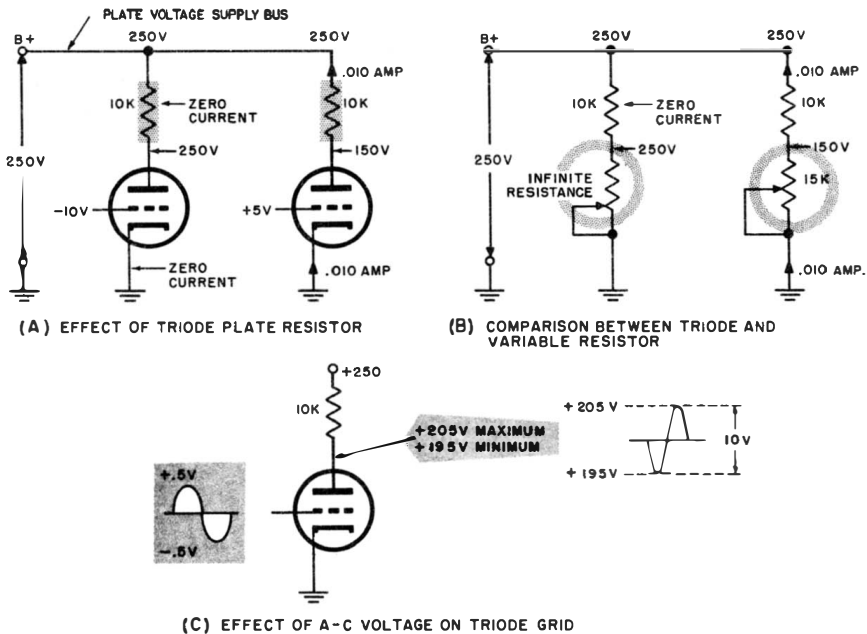


Fig. 5-3. (A) Effect of triode plate resistor. (B) Comparison between triode and variable resistor. (C) Effect of a-c voltage on triode grid.

slightly positive. Eventually there is a maximum positive grid voltage beyond which no further increase in plate current takes place, unless the voltage on the plate is made more positive or the voltage on the cathode is made more negative.

If a resistor is inserted into the plate circuit as the plate "load", as shown in Fig. 5-3A, the voltage at the plate will be a maximum positive value when the grid voltage is a maximum negative, because the higher the negative grid voltage the less the plate current through the resistor and therefore the less the drop in voltage across the resistor. If the negative grid voltage is high enough to prevent plate current flow the voltage drop in the plate resistor is therefore zero, and the voltage at the plate is the same as at the plate voltage supply bus. Conversely, at the maximum positive grid voltage the voltage at the plate will be at a minimum because of the drop in voltage across the plate load resistor. With varying grid

voltage, it is convenient to imagine the tube as a variable resistor with the grid voltage acting as the resistance control, as shown in Fig. 5-3B. The tube and its plate load resistor now act as a voltage-divider circuit in which the tube resistance is variable. With maxi-

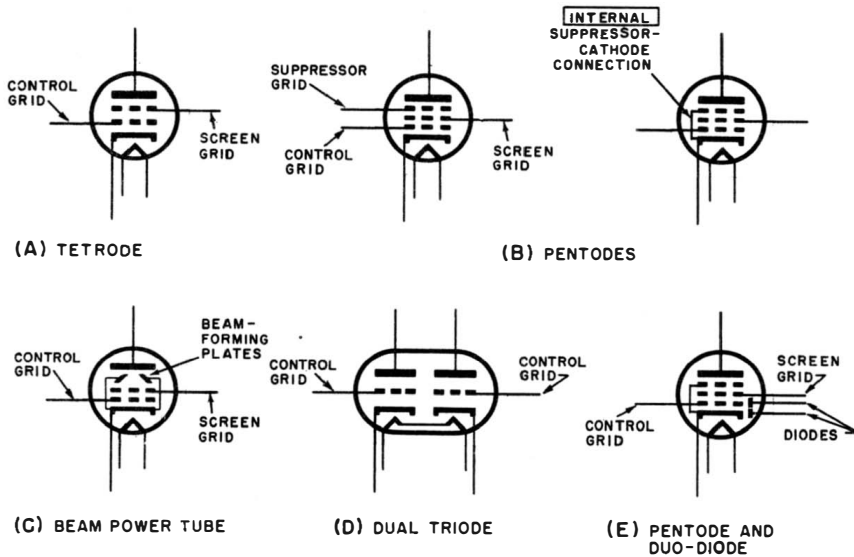


Fig. 5-4. Tetrodes, pentodes, and dual-section vacuum tubes.

imum negative grid voltage, the tube has a maximum internal resistance, and the plate voltage is at a maximum. The fact that a grid voltage change of 1 or 2 volts can cause a plate voltage change of 10 or 20 volts makes amplification possible.

If an a-c voltage of 1 volt peak-to-peak is connected to the grid, as shown in Fig. 5-3C, a corresponding amplified a-c voltage of 10 or more volts peak-to-peak will appear at the plate.

Other types and symbols. Shown in Fig. 5-4 are the schematic symbols for a variety of other types of amplifier tubes. The *tetrode* (A) has four active elements and the *pentode* (B) five. Operation of these tubes is basically the same as for the triode explained previously. The *screen* and *suppressor grids* prevent a number of undesirable secondary effects that occur in triodes, and permit much higher amplifications. Some pentode tubes produce an output signal several hundred times the magnitude of the input.

Figure 5-4C shows the symbol for a beam power tube. This tube has beam-forming plates instead of a suppressor grid, and is used in the final stage in audio amplifiers.

D and E of Fig. 5-4 are the symbols of two types of dual-purpose tubes. The first contain two triodes, the second a pentode and two diodes. A number of other combinations are also available. Such tubes find widespread use in applications where space and weight are at a premium.

The physical appearance of a tube has little to do with its internal structure. Figure 5-5 shows some of the different tube shapes

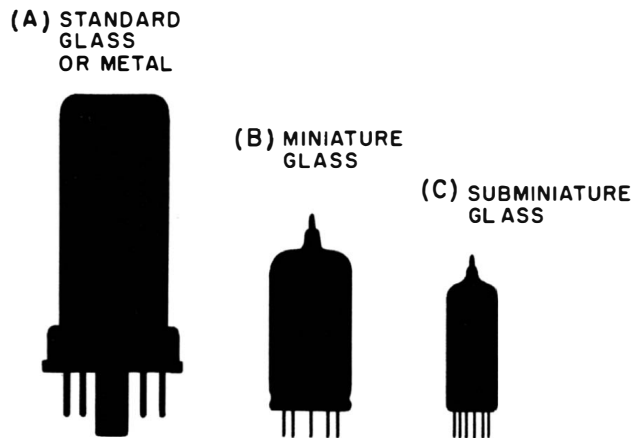


Fig. 5-5. Amplifier tube shapes and sizes.

and sizes that may be found in electronic equipment. Nearly every one of these sizes and shapes is available as a diode, triode, tetrode, pentode or multipurpose tube.

AUDIO AMPLIFIERS

Audio amplifiers are found in record players, tape recorders, motion picture sound systems, radios, television sets and various special instruments. Although many different devices are used to supply the electrical signals going into the amplifier, that signal generally originates ultimately from a microphone. Of the many devices that make use of the signal coming out of the amplifier, the loudspeaker is the most common. This study of audio amplifier schematic diagrams will include a consideration of the basic vacuum-tube circuits employed, and of their relationships to microphones and loudspeakers.

Microphones. Microphones are used to convert sound waves into corresponding electrical signals. Sound is produced by physical

vibrations. Examination of human vocal cords, a violin string, or a train wheel will indicate that they vibrate at frequencies in the range from 20 to 20,000 cycles. These physical vibrations are transmitted by the air and can be detected by a sensitive device, such as the ear or a microphone. The ear produces nerve impulses that are detected by the brain and translated into meaning. The microphone produces an a-c voltage (usually irregular in waveform)

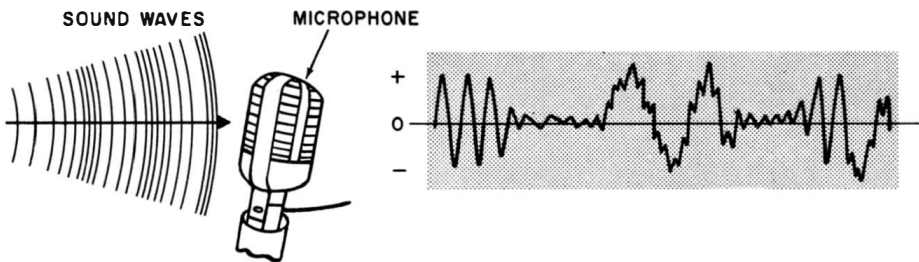


Fig. 5-6. Voltage variations produced by microphone.

that corresponds in frequency and amplitude to the vibrations received from the air. This voltage is known as an audio-frequency or a-f signal. Figure 5-6 shows typical voltage variations produced by a microphone. Although they differ widely in construction and principles of operation, every microphone contains a delicately constructed physical element that can be vibrated easily by the sound coming through the air, plus some means of changing this vibration into an electrical signal.

Recognizing Typical Audio Amplifier Circuits. Audio-amplifier circuits may contain triode, tetrode, and pentode vacuum tubes. The type of tube used depends upon the degree of voltage and power amplification required, the *fidelity* (accuracy) with which the amplified signal must correspond to the input signal, and the convenience with which this particular amplifier may be connected to other circuits in the equipment. The descriptions that follow indicate the basic combinations in which component parts may be connected to make up a vacuum-tube amplifier.

To secure proper operation from a vacuum tube, the various tube elements must be supplied with operating voltages of fairly specific values, and certain definite relationships must exist between these voltages. The voltages are most frequently supplied through resistors, as shown in Fig. 5-7. Although the specific resistances used vary according to tube type, the circuits for triode

(A), tetrode (B), and pentode (C), tubes are essentially the same, except for the additional connections required by the screen and suppressor grids. Since a specific current flows from each tube element for each specific voltage that is applied, the resistances are selected to result in the desired voltages on the elements themselves.

Since the plate and screen currents flow through the cathode resistor, a positive voltage appears at the cathode. No current flows

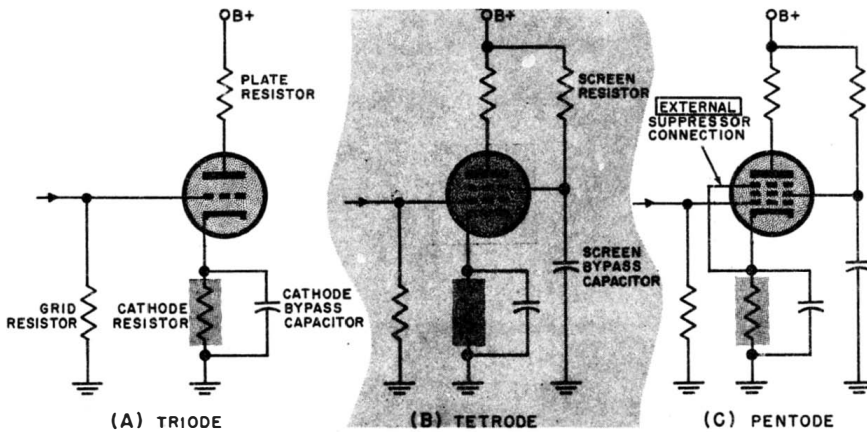


Fig. 5-7. Amplifier tube biasing arrangements. (A) Triode. (B) Tetrode. (C) Pentode.

through the grid resistor, making the d-c voltage on the grid equal to zero, and making the grid negative with respect to the cathode. This method of obtaining a negative bias on the grid is known as the *cathode bias* method, and is the one in most widespread use.

When the amplifier circuit is used, the small input signal voltage is connected to the grid, and the amplified signal voltage is usually obtained at the plate. The purpose of the capacitor connected across the cathode resistor is to provide a low-impedance path for the signal voltage. When this capacitor is omitted, the variations in cathode current caused by the signal cause a signal voltage to be developed at the cathode, lowering the signal voltage at the plate (this process is equivalent to negative feedback, which is explained elsewhere in this book). Because it furnishes a low-impedance path, through which the signal voltage may bypass the cathode resistor, this capacitor is known as the *cathode bypass*.

The screen bypass capacitor serves a similar purpose. Since it provides a low-resistance path for any signal voltage, a constant

d-c screen voltage is maintained, and there are no screen voltage variations to affect the electron flow to the plate.

Voltage amplification. The increase in signal voltage from the grid to the plate is known as *voltage gain*. If a signal of 0.001 volt is connected to the grid and a 0.1 volt appears at the plate, the *voltage gain* of that amplifier is 100; i.e., signal strength is multiplied 100 times. Even though gains of several hundred may be

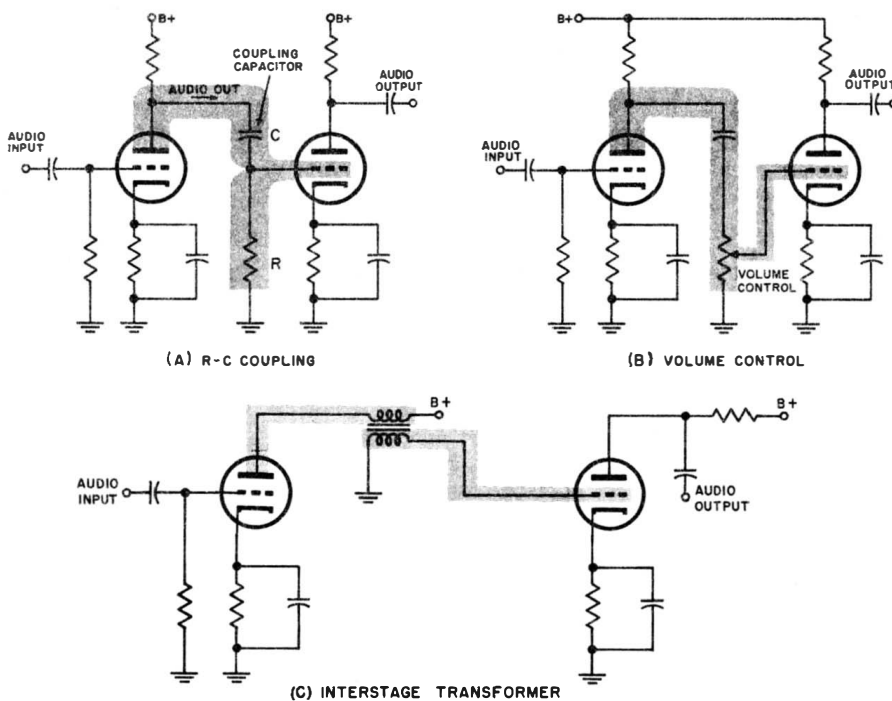


Fig. 5-B. Coupling methods. (A) R-C coupling. (B) R-C coupling with volume control. (C) Interstage transformer.

obtained through the use of pentode tubes, such tubes are generally incapable of handling plate voltage variations of more than a few volts with corresponding variations in plate current below 0.001 ampere. Consequently, the power output of a high-gain *voltage amplifier* tube is generally about 0.001 watt, which is much too small for any purpose except connection to the grid of another tube. When an amplifier must be used to drive a loudspeaker, a radio transmitting antenna, or any device that requires 1, 10, 100, or more watts of power, *power-amplifier* tubes must be used.

Identifying coupling methods. Although voltage gains of several

hundred can be obtained with a single tube, many types of electronic equipment require voltage gains on the order of thousands or hundreds of thousands. Ultimately power amplification is also required.

To accomplish this, several individual vacuum-tube amplifiers must be coupled together. Under such conditions the output signal from the plate of one amplifier is coupled to the grid of the next amplifier. A complete group of amplifiers of this type is known as a *multistage* amplifier with the tubes connected in *cascade*. The individual amplifiers are known as *stages*. The overall voltage gain of a multistage cascade amplifier is found by multiplying the voltage gains of the individual stages. Consequently, if three cascaded amplifier stages have gains of 100, 100, and 20, the total voltage gain is $100 \times 100 \times 20 = 200,000$.

The coupling method most widely used in audio amplifiers is shown in Fig. 5-8A. This method is known as R-C coupling because there are only resistors and capacitors in the connecting network between the two stages. If a variable resistor is connected as a voltage divider in the grid circuit of the following stage, as shown in Fig. 5-8B, R-C coupling still exists, but the variable resistor can be used as a volume control. The closer the slider is moved to ground, the smaller is the signal voltage applied to the grid; and the lower is the signal at the plate of the second stage.

Audio amplifier stages may also be coupled through an interstage transformer, as shown in Fig. 5-8C. Transformers are not often used for this purpose because voltage gains of more than five are difficult to obtain without a loss in the frequencies above 10,000 cycles. Much higher gains are obtainable at lower cost simply by using another vacuum tube.

POWER AMPLIFIER CIRCUITS AND LOUDSPEAKERS

Power amplifier circuits contain vacuum tubes that are capable of handling large currents and large voltage variations; triodes, tetrodes, and pentodes are available for this purpose. One of the most common types of power amplifier found in radio, TV, and record player applications is shown in Fig. 5-9A. Note that a transformer is used to couple the power amplifier tube to the permanent-magnet loudspeaker.

The most common type of loudspeaker in use today consists of a coil of wire (the voice coil) suspended in the magnetic field of a permanent magnet. The cone of the speaker consists of a stiff, specially prepared paper which is attached to the voice coil. When

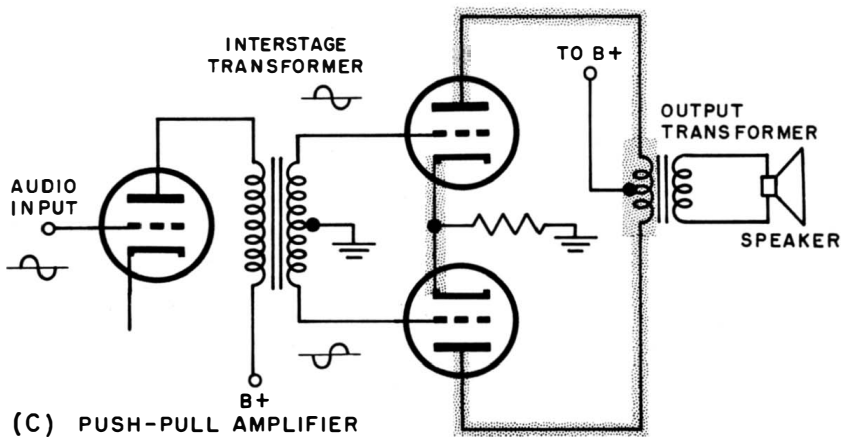
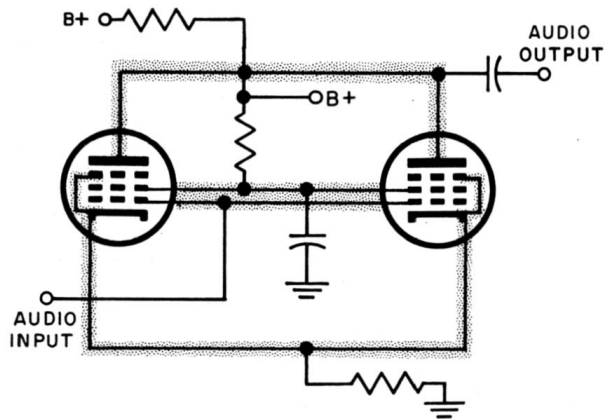
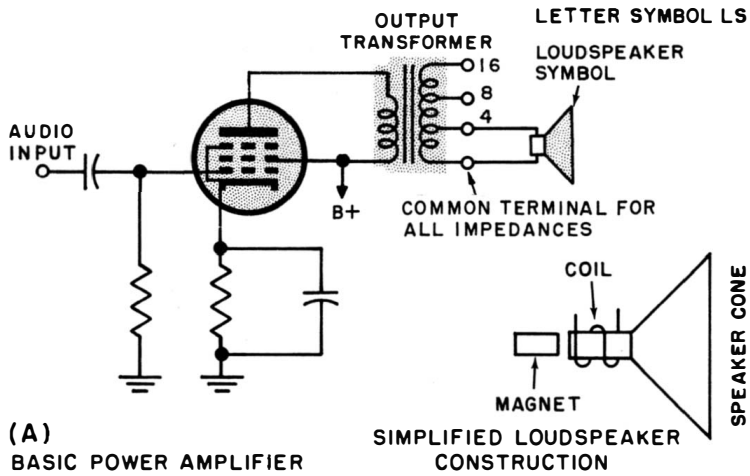


Fig. 5-9a. Power amplifiers. (A) Basic audio power amplifier. (B) Parallel-connected tubes. (C) Push-pull amplifier with interstage transformer input.

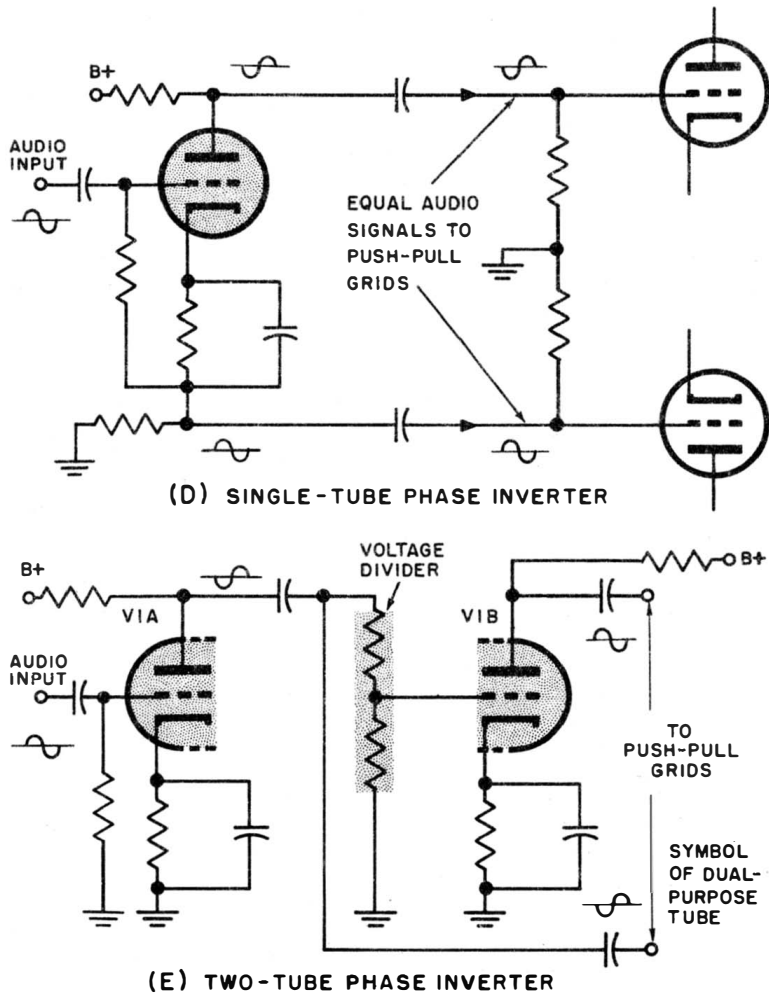


Fig. 5-9b. (D) Single-tube phase inverter. (E) Two-tube phase inverter.

the a-f signal voltages from the power-amplifier output transformer are applied across (i.e., drive) the voice coil, the resulting alternating current causes an alternating magnetic field to be generated. This field reacts with that of the permanent magnet, and the coil, and hence the cone, vibrate at the frequency of the signal producing the sound.

The transformer must be a step-down type for maximum energy transfer from the power amplifier tube to the loudspeaker. Loudspeakers are rated, according to their voice coils, in units of impedance (such as 4 ohms, 8 ohms and 16 ohms). Thus, many output

transformers have taps on their secondaries to match the impedance rating of the voice coil of the speaker used for the maximum energy transfer.

Push-pull power amplifier circuits. When more than several watts of power output are required, the designer may select a power amplifier tube that is capable of delivering larger variations in plate voltage at comparatively large current values. Although such tubes are not noticeably larger in size, they are more expensive and require B+ voltage on the order of 400 or 500 volts or higher. Since this involves the use of more expensive power and output transformers, it is often more economical to use two output tubes which will operate at lower plate voltages. If the two tubes are connected together in parallel, as shown in Fig. 5-9B, twice as much varying plate current will be obtained, and the power will be doubled.

However, if the two tubes are connected together as shown in Fig. 5-9C, the power output may be almost tripled. This circuit is known as a *push-pull* amplifier because when the signal voltage on one grid is increasing, the signal voltage on the other grid is decreasing. Consequently, the plate current in one tube increases while that in the other tube decreases. Higher voltages are applied across the transformer primary, and less d-c plate current therefore flows through this winding than with two tubes connected in parallel. Thus, the output transformer operates at higher efficiency and more useful power output is obtainable. In parts B and C of Fig. 5-9 the paired tubes can be either triodes, tetrodes, pentodes or duo-triode type tubes, depending upon the equipment in which the pair is used.

Push-pull amplifier input circuits. Using an interstage transformer to drive the grids of the power amplifier tubes is expensive, and unless expensive transformers are used, there is a loss in signal strength above 10,000 cycles. The circuits shown in D and E of Fig. 5-9 are more economical. The first circuit employs a single tube to supply one output tube grid from its plate and the other from its unbypassed cathode resistor. The second circuit uses two triodes, the second of which has a signal voltage divider at its grid. Both of these circuits apply equal signal voltages of opposite phase (opposite instantaneous polarity) to the two push-pull grids. These circuits are both known as *phase inverters* because the two output signals are identical in voltage and exactly reversed (inverted) in the shape of the voltage waveform delivered to the push-pull grids.

INVERSE FEEDBACK

The requirements of a good audio amplifier are not only adequate power output, but good *fidelity*. A high-fidelity amplifier must supply an output signal that is larger than the input signal but identical to it in every other way. This means that there must be an absolute minimum of *distortion* or change in signal waveform. It also means that the amplifier must have a good *frequency*

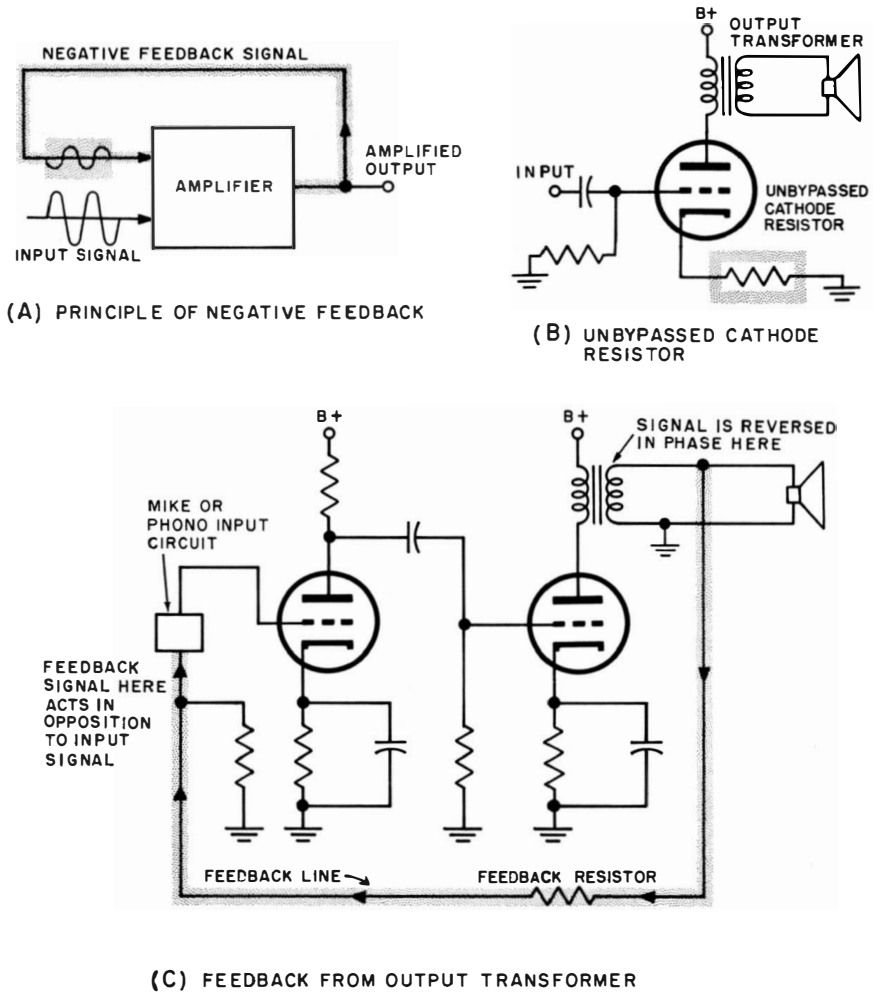


Fig. 5-10. Negative feedback. (A) Principles of negative feedback. (B) Unbypassed cathode resistor. (C) Feedback from output transformer.

response; it must provide the same amount of amplification for all frequencies in the range from 20 to 20,000 cycles.

Unfortunately the use of vacuum tubes, coupling circuits, and output transformers introduce some distortion. Furthermore, an amplifier of the type discussed thus far provides less gain for signals below 100 and above 10,000 cycles than it does for signals in the 100 to 10,000 cycle range. These unwanted effects can be corrected to a great extent by the use of larger and more expensive components, but better results can be obtained at extremely low cost through the use of *inverse feedback*.

Inverse feedback (also known as *negative feedback* or *degenerative feedback*), is the use of a small part of the amplified signal in such a manner that it opposes the input signal and causes some cancellation. To accomplish this, that portion of the amplified signal must be exactly opposite (inverse) in phase to the signal at the point where it is fed back. When the input signal voltage becomes positive, the feedback signal must become negative (see Fig. 5-10A). This results in a smaller output signal, but additional gain is easily obtained at extremely low cost because it is now possible to use tubes with higher gain, or to add an extra amplifier stage. Inverse feedback cancels most of the distortion and gives more uniform amplification at all frequencies. It is also a simple circuit to recognize in audio amplifier schematic diagrams.

An audio amplifier with several stages may contain one or more inverse feedback circuits, since it is more effective to correct a particular fault in amplification in the particular stage or stages where it occurs. One common method is to eliminate the cathode bypass capacitor in the power-output tube stage, as shown in Fig. 5-10B. This method is also used in push-pull amplifiers, as shown in Fig. 5-9C. Another method is to take a small amount of signal from the output transformer (Fig. 5-10C) and feed it back to an earlier stage of the amplifier. When an audio amplifier contains a signal connection between a later and an earlier stage, that connection is usually an inverse feedback circuit.

TONE CONTROLS

Purpose. In many sound reproducing systems the loudspeaker sound output drops off at frequencies below 100 and above 5,000 cycles. This can be corrected by supplying extra gain in the amplifier for those frequencies. When such gain is added to frequencies below 500 cycles, it is known as *bass boost*; if the added gain is for frequencies above 2,000 cycles, it is known as *treble boost*.

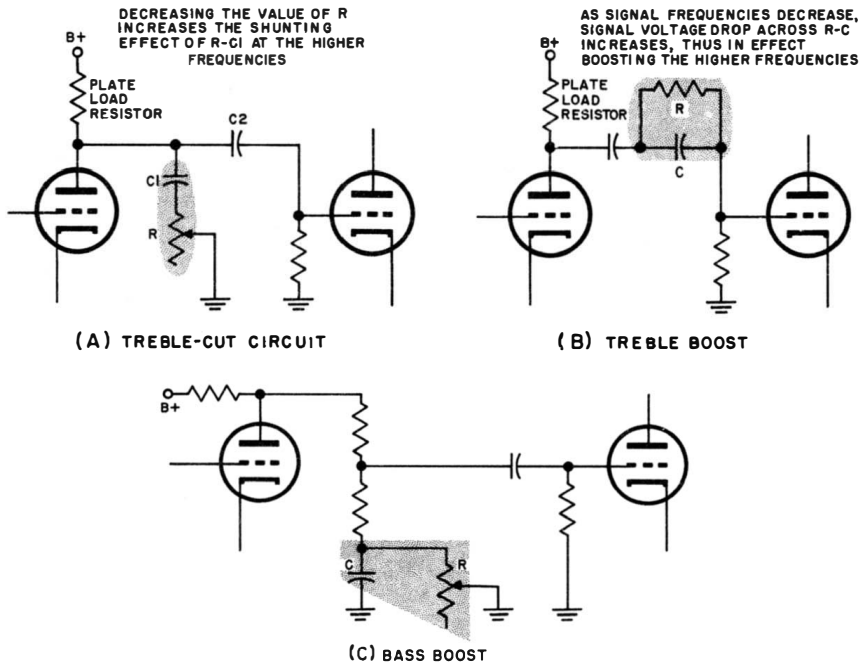


Fig. 5-11. Tone control circuits. (A) Treble cut. (B) Treble boost. (C) Bass boost.

For various reasons there may be distortion or noise in the signals at the lowest or the highest frequencies. In such cases the distortion or noise can be reduced by decreasing (*attenuating*) the amplifier gain in either or both of these ranges. Attenuation of this type is known as *bass* or *treble cut*. In many cases, the personal tastes of the listener require boosting or cutting one or both ends of the frequency range. Many audio amplifiers are equipped with tone controls that permit the listener to make some or all of these adjustments.

Types. Tone controls are a major subject in themselves, and only the simplest types will be considered here. More complex examples will be seen in the analyses of audio amplifier schematic diagrams at the end of this chapter. Most of the simple types are based upon the principles of R-C filters described in Chapter 3. According to these principles, bass or treble attenuation may be obtained by using high- or low-pass filters respectively. If boost is to be obtained, all frequencies can be attenuated by a resistor voltage divider. The boost is then achieved by using a high- or low-pass filter to permit the desired frequencies to bypass the voltage divider.

Simple schematic diagrams. The circuit shown in Fig. 5-11A is a treble-cut circuit. It consists of a capacitor (C1) and variable resistor (R) connected in series from plate to ground in any of the amplifier stages. To permit the low frequencies to pass through unaffected, the capacitor, C1 has less capacitance than the coupling capacitor (C2) to the next stage. The reactance of C1 becomes lower and lower as the frequency increases, and thus effectively reduces the amplitude of the higher frequency signals applied to the grid of the next tube. The variable resistor controls the shunting effect of the capacitor. When the sliding tap is at the top, maximum treble attenuation takes place.

A treble-boost circuit is shown in Fig. 5-11B. Resistor (R) attenuates all frequencies between the two stages, but capacitor C allows the high frequencies to bypass this resistor, allowing a larger proportion of the higher-frequency voltage to reach the grid of the next stage.

Bass attenuation is most simply obtained by using a low-capacitance interstage coupling capacitor, or by an arrangement similar to that of treble boost. A bass-boost circuit is shown in Fig. 5-11C. When resistor R is set at zero ohms (top position), all frequencies pass through with equal attenuation. As the resistance of R is increased, there is less attenuation of frequencies below 500 cycles than above 500 cycles; thus in effect the lower frequencies are boosted relative to the higher audio frequencies.

By making various combinations of these circuits, it is possible to boost or cut either or both the high or low frequencies. In an audio amplifier, any network of resistors, capacitors, or coils is likely to be a tone control circuit.

EXAMPLES OF INTERPRETING AN AUDIO AMPLIFIER SCHEMATIC DIAGRAM

For the first exercise in reading and interpreting a complete schematic diagram, we have chosen a relatively uncomplicated piece of equipment, to make the complete procedures clear in a minimum of time. Once these processes of analysis are clear, the review of the more complex equipments is not difficult.

General procedures. Under ordinary conditions, a schematic diagram is normally accompanied by a brief description of the nature of the equipment it represents. Thus a knowledge of function is an aid to circuit "reading". More can be learned, however, about the interpretation of schematic diagrams if this first example

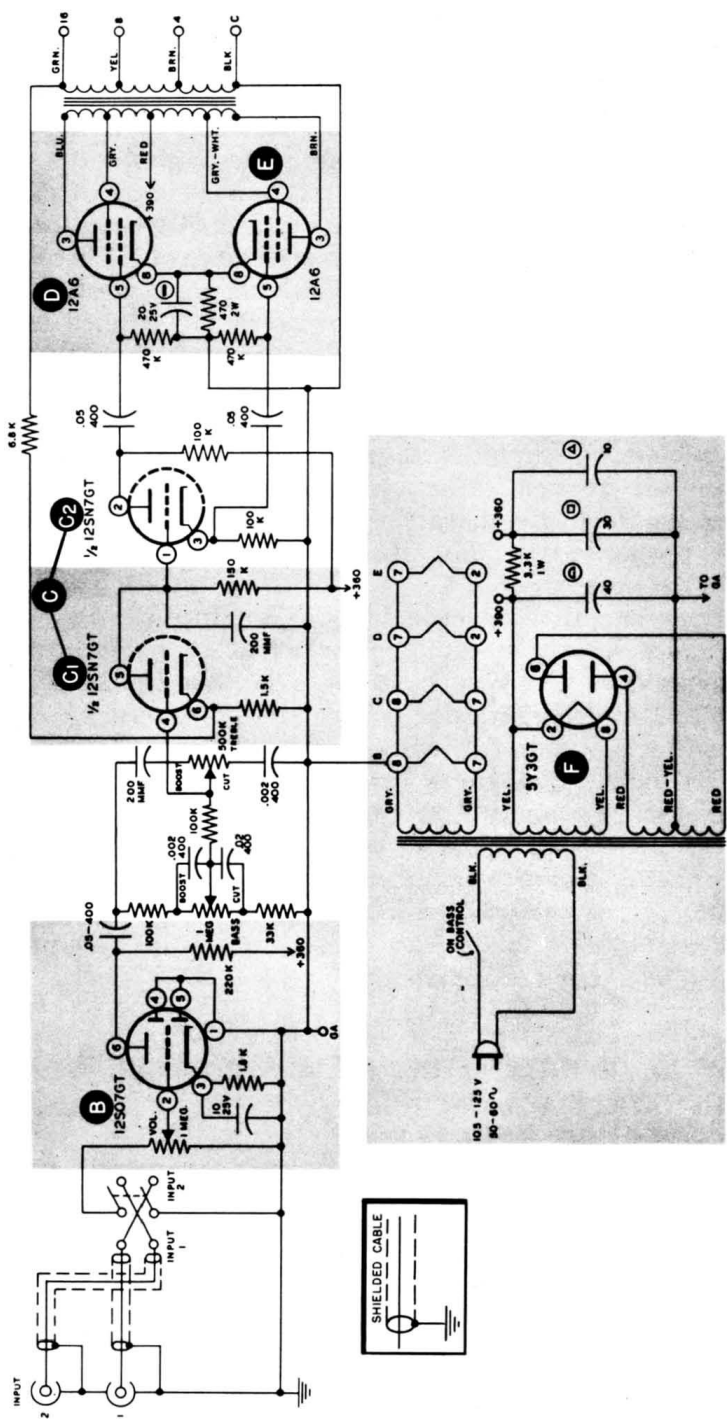


Fig. 5-12. Schematic diagram of complete audio amplifier system. Courtesy Heath Company.

is based upon the assumption that the schematic diagram itself (Fig. 5-12) is the only information available.

General procedure in interpreting a schematic diagram is (1) to take an overall view of the schematic, (2) to determine the nature of each of the stages shown, (3) to identify the nature and purpose of any special circuits, and finally, (4) to comprehend the details of the equipment. Usually, too, it is a good idea to construct a block diagram while interpreting these stages, because the relationships shown in such a diagram make it easier to understand the welding of individual stages and special circuits into the complete equipment. This practice is particularly helpful in complex equipment.

Initial identification. Initial identification of the equipment represented by the schematic diagram in Fig. 5-12 should now present no problem. The individual stages should be easily recognized as the types of audio amplifier stages that have been reviewed in this chapter. The power supply section is also easily identified (from information in Chapter 4). Thus, it should be obvious that the schematic diagram represents an audio amplifier complete with its power supply. Although initial identification is a simple matter in this case, it will be apparent in the next chapter that it becomes more of a problem when the types of stages and sections in the equipment are more numerous and varied.

Initial block diagram analysis. Further information can be obtained by making a stage-by-stage analysis. While doing this, it may be helpful to organize all findings by drawing a block diagram. If the schematic contains fewer than a dozen tubes, it is a practical matter to draw a single block for each stage. In more complex equipments, a series of stages with similar functions would be represented as a single block. The most straightforward way to begin the block diagram is to draw a single rectangle for each stage and to maintain the blocks in the same general arrangement as the tubes on the schematic diagram. If the schematic diagram does not show the signal path in a straightforward manner, the basic block arrangement should be adjusted to show the signal path most clearly.

The easiest way to fill in the details of the block diagram is to identify the functions of all of the tubes, working from the input toward the output, and then to fill in the details of the interconnections and special circuits. Note that the block diagram (Fig. 5-13) being drawn is merely a worksheet, which allows the complex schematic diagram to be condensed into a simplified form that can be more easily interpreted as a whole. Working on this

plan, we see that the sequence of tubes from input to output is B to C1 to C2 to D and E. Tube B can be identified as a conventional triode amplifier with a bypassed cathode resistor. The only unusual thing about this stage is that it contains two extra plates, but examination of these plates show that they are grounded, and therefore not a functional part of the circuit.

Tube C is composed of two triodes (C1 and C2) and two blocks should be used to represent it. The first half of tube C is identified as a triode amplifier (C1) with an unbypassed cathode resistor. Unusual features about this stage are: the connection between the cathode (pin 6) and the transformer secondary winding, and the direct coupling between the plate (pin 5) and the grid of the next stage. The second half of tube C can be identified as a phase inverter, C2. Outstanding features of this type of stage are the equal cathode and plate resistances, and the fact that signal outputs are taken from both the plate (pin 2) and the cathode (pin 3).

Tubes D and E are obviously the two halves of a push-pull amplifier. The 5Y3GT tube at the bottom center of the schematic is easily identified as a full-wave rectifier stage (Chapter 4). At this stage of the analysis the block diagram should be filled in to the extent shown in Fig. 5-13A.

Final block diagram analysis. Now the remaining details of the block diagram can be filled in by going through the schematic diagram once more. At the input of tube B are two input connectors, a switching circuit, and a volume control. Examination of the switching circuit reveals that its purpose is to connect either of the inputs to the top of the volume control while grounding the input not selected.

The complex R-C network between tube B and tube C1 is identifiable as a pair of tone control circuits. The markings on the two potentiometers (bass-boost, cut and treble-boost, cut) indicates that those controls can be used to adjust independently the levels of low and high frequencies reaching the grid of tube C1. The purpose of the 6800-ohm resistor between the cathode (pin 6) of tube C1, and the secondary of the output transformer, is to provide a feedback path. In this case, sufficient signal is fed back in inverse phase to level out the frequency response of the output transformer and to help cancel any distortion taking place in the power amplifiers.

Direct coupling is used between C1 and C2 because it provides an extremely simple method of biasing the grid (pin 1), slightly less positive than the cathode (pin 3), and providing excellent response to low frequencies.

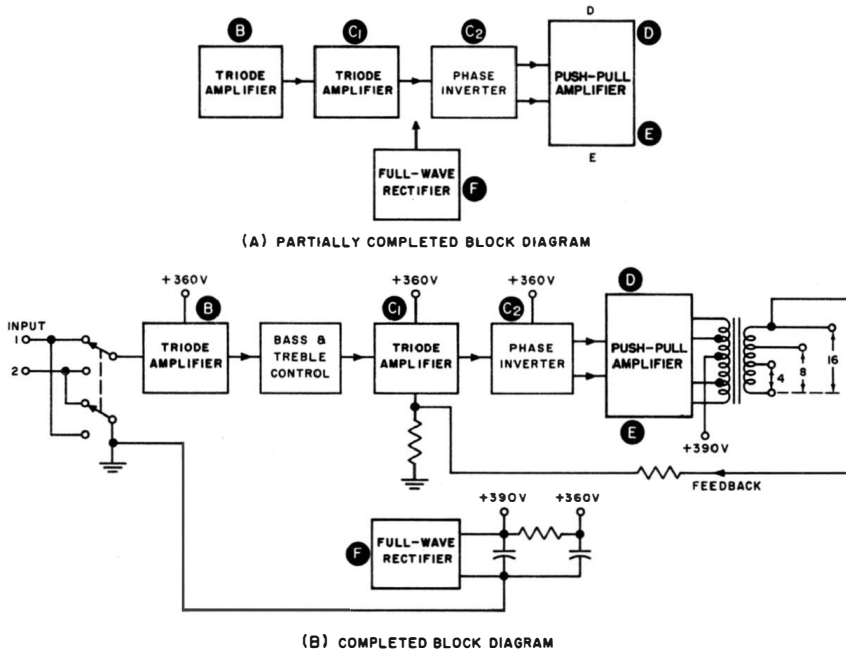
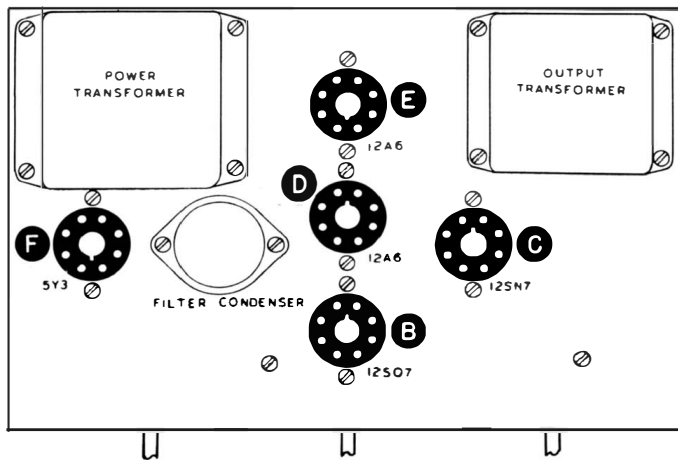


Fig. 5-13. Block diagram for schematic in Fig. 5-12. (A) Partially completed block diagram. (B) Complete block diagram.

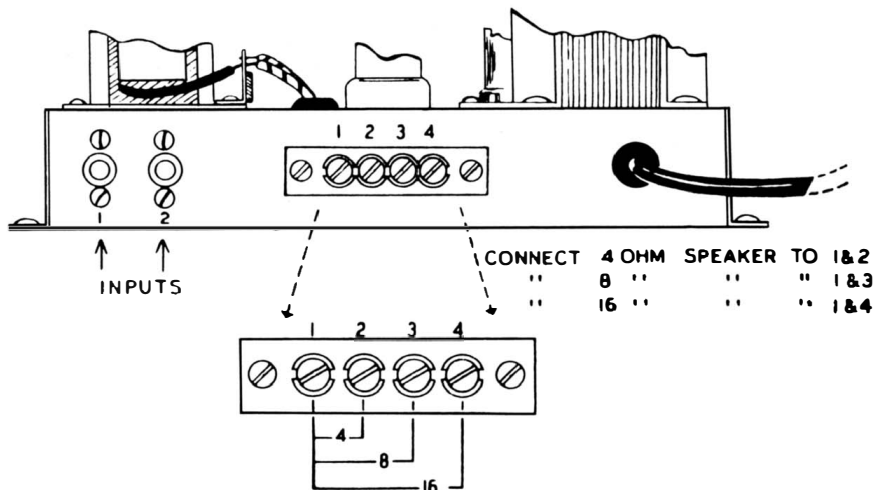
Note that in the push-pull power amplifier stage additional taps have been placed on the output transformer primary winding to supply the screen grids with B+ voltage.

The power supply contains a capacitor input R-C filter, and has output voltages of +390 volts and +360 volts. Since only tubes B and C receive the +360-volt output, there is a very low current drain on the +360-volt supply and a resistor gives very good filtering action. The +390-volt output to tubes D and E is filtered only by the 40- μ f (microfarad) capacitor marked with a half moon, but the hum cancelling effect of the push-pull operation makes this arrangement quite satisfactory. A common ground has been used to reduce hum still further. The completed block diagram now appears as in Fig. 5-13B.

Overall circuit review. The overall nature of the equipment can now be reviewed. The amplifier has a much higher power output than the usual radio or TV set. Special provisions have been made to reduce distortion and obtain good frequency response. Multiple taps on the output transformer secondary permit the use of a wide variety of speakers. Separate bass and treble tone controls have



(A) TOP OF AMPLIFIER CHASSIS



(B) REAR WALL OF CHASSIS

Fig. 5-14. (A) Top of amplifier chassis. (B) Rear wall of chassis. Courtesy Heath Company.

been provided. The input arrangement permits convenient selection of either of two input sources, such as radio (or TV), and phonograph (or tape recorder).

Economies have been effected in the power supply filter, in the

phase inverter, perhaps in the selection of tube B, in the lack of extra input circuits, and in the limited number of special circuits. Most further conclusions require reference to the equipment performance specifications and to the details of physical construction.

PARTS LOCATION FROM SCHEMATIC DIAGRAMS

Whenever there is any testing, servicing, repairing, building, or modifying of electronic equipment to be done, it is very important to be able to locate on the equipment itself any part that is shown on the schematic diagram. It is also important to be able to select any part on the equipment and identify it on the schematic diagram. Several examples of both processes will be considered here, as applied to the amplifier in the schematic diagram, Fig. 5-12.

Chassis top. Figure 5-14A shows the top of the amplifier chassis. Much can be learned about the location of major parts from only a superficial comparison with the schematic diagram. The outstanding parts on the schematic diagram are the five tubes and the power and output transformers.

The power transformer is generally the largest transformer and should be the one at the left rear; the output transformer, therefore, is the one at the right rear. It is also an easy matter to identify the five tubes by comparing the type markings printed on the tube envelopes with the type designations on the schematic diagram. Although this method of locating tubes is perfectly legitimate and highly recommended, it does not always answer all questions, since many of the tubes on the chassis may be of the same type. Other methods of identifying the tubes will be considered shortly.

The bass, volume, and treble controls appear in that order reading from left to right on the front of the chassis (Fig. 5-14A). These parts can be found on the schematic diagram (Fig. 5-12) simply by looking for the familiar variable resistor symbols and reading the markings. Using this method, the volume control is discovered on the schematic diagram immediately to the left of tube B, and the bass and treble controls are located between tubes B and C. Tube C is a twin triode. A more careful reading of the lettering on the front of the chassis would reveal that the bass control also activates the power supply on-off switch, and that the treble control also is used to operate the signal input selector switch.

On the basis of its physical appearance (see Fig. 3-9F), the tubular container located in front of the power transformer is

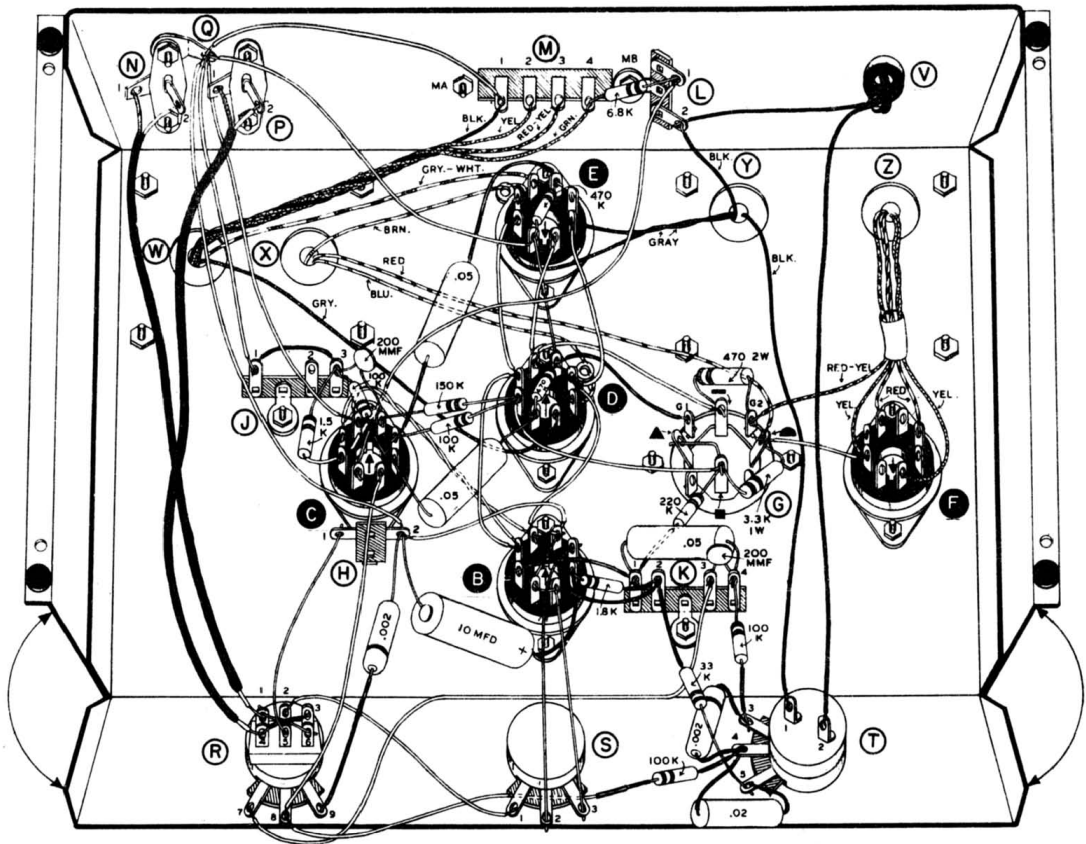


Fig. 5-15. Bottom of audio amplifier chassis. Courtesy Heath Company.

recognizable as an electrolytic capacitor, and since this type of component is generally associated with power supplies, it can be immediately identified on the schematic diagram as the three-section capacitor to the right of the 5Y3GT rectifier tube.

What has been accomplished by a purely superficial examination of the chassis top view and the schematic diagram is the positive location of both transformers, the three controls, the electrolytic capacitor, and most of the tubes. A quick examination of the rear of the chassis (Fig. 5-14B) shows two receptacles to the left, a strip of four screw terminals in the center, and the immediately recognizable power cord to the right.

Chassis underside. When the chassis is turned over and placed in such a position that the three controls remain toward the front, it looks very much like the pictorial drawing in Fig. 5-15.

Before attempting to locate any of the smaller parts on the chassis underside, it is best to identify the major parts. Comparing this bottom view to the top view shown in Fig. 5-14A, it should be recognized that turning over the chassis (keeping the controls toward the front) has caused a left-to-right reversal of all parts.

The transformer leads coming out of holes W and X at the left rear are those of the output transformer, and the leads coming out of holes Y and Z at the right rear are those of the power transformer. According to this same plan, the bottom view shows that controls R, S, and T on the front of the chassis correspond respectively to the treble, volume, and bass controls. The two terminals of the power on-off switch are seen on the back of the bass control and the six terminals of the signal input selector switch are seen on the back of the treble control. The electrolytic capacitor is known to be forward of the power transformer, and its terminals are readily recognizable as those coming out of hole G just to the right of center of the chassis.

On the rear of the chassis the power cord can be recognized coming through hole V. Most of the tubes can be identified in this equipment by their markings. For purpose of illustration they will be identified by the general procedure for locating schematic diagram components on the chassis.

Location procedure. Once the major parts have been identified, there is a general procedure to follow in locating any other schematic diagram component on the chassis. After locating the desired part on the diagram:

1. Locate on the schematic diagram the closest major part (tube, transformer, etc.) to which the desired part is connected directly or through one or more additional parts.
2. Identify on the schematic diagram the terminal number or lead color of this major part to which the desired part is connected.
3. On the chassis, locate the major part in question and find the terminal or lead identified in step 2.
4. From the identified terminal, or lead on the major chassis part, trace each connection through any additional parts found in step 1 until the desired part is found.

The reverse of this procedure is used in locating chassis parts on the schematic diagram.

Locating schematic components on the chassis. The first example will be to locate on the chassis underside (Fig. 5-15) the tube socket of the first amplifier stage. Examination of the schematic diagram shows that the nearest previously identified part is the volume control. The sliding contact of this control is con-

nected directly to pin 2 of the tube. On the chassis front, the volume control previously has been identified as potentiometer S. The center terminal of the potentiometer is the sliding contact terminal. Only one lead runs from this center terminal, and this lead goes directly to pin 2 of tube socket B.

Conclusion: tube socket B is the mounting for the first amplifier stage. On this same basis, tube C can be identified because of its connection to the treble control; tubes D and E are identifiable by their connections to the output transformer. The 5Y3GT rectifier tube is located by its connection to the power transformer.

Using the same methods any of the smaller components on the schematic diagram may be located on the chassis. For example, suppose that it is desired to locate the 6,800-ohm negative feedback resistor. The schematic shows that it is connected between pin 6 of tube C and the green lead of the output transformer. Both the tube and the transformer have already been located. On the chassis underside locate pin 6 of tube C by counting six terminals clockwise from the keyway in the tube socket. A 1,500-ohm resistor is seen connected directly to that terminal, but a check of the schematic diagram shows that this is the cathode resistor of the second amplifier stage.

Following the other wire connected to pin 6 leads to the upper part of terminal strip L near the center of the rear side of the chassis. A 6,800-ohm resistor is seen connected between that terminal and a green wire coming from the output transformer. Since both ends of this resistor go to identified points, and since the resistance value is the one being sought, the resistor is now identified.

Locating chassis components on the schematic. The reverse of this procedure is used in locating chassis parts on the schematic diagram. In the chassis bottom view there is a small disc-shaped object connected between terminals 3 and 4 of terminal strip K. Examination of this part and its color code reveals that it is a ceramic disc capacitor with a value of 200 $\mu\mu\text{f}$. Tracing both leads coming from this capacitor shows that the right-hand lead goes to a 100,000-ohm resistor, which in turn is connected to a terminal of the bass control. A .002- μf capacitor is also connected to the same bass control terminal. The lead of the 200- $\mu\mu\text{f}$ capacitor goes to one of the terminals of the treble control. Another .002- μf capacitor is connected to the other end of this control.

In this case, the major components to be found on the schematic diagram are the bass and treble controls. These are found between tubes B and C. Examination of the treble control symbol

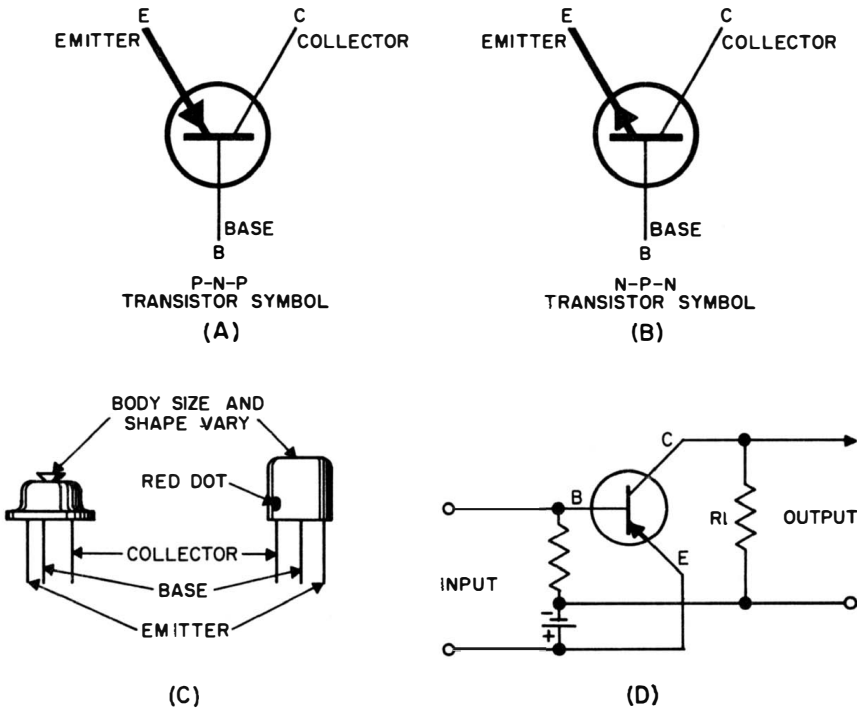


Fig. 5-16. (A) The schematic symbol for the p-n-p transistor. (B) The schematic symbol for the n-p-n transistor. (C) Transistor lead identification, by lead spacing and red dot method. (D) Simplified diagram of a typical transistor amplifier circuit.

shows that it has a .002- μ f capacitor at the lower end and a 200- μ μ f capacitor at the upper end. The other end of this 200- μ μ f capacitor connects to a 100,000-ohm resistor, which in turn connects to the bass control. Since both ends of this 200- μ μ f capacitor connect to the parts identified on the underside of the chassis, this capacitor is the one being sought.

TRANSISTORS

The ability to amplify an electrical signal is not limited to vacuum tubes. In recent years radically different devices, called transistors, have been developed to perform amplification. They can also be used as oscillators, detectors, attenuators, relays, and modulators.

Primarily, transistors are used to replace vacuum tubes as amplifiers in applications where the transistor's smaller size (about one fourth the size of a miniature vacuum tube), lighter weight, longer life, and ruggedness are needed. They are widely used in hearing aids, miniature radios, telephone circuits, computers and in an ever increasing number of industrial, military and commercial applications. As their cost decreases, transistors will begin to appear more and more frequently in electronic equipment and schematic diagrams.

The principles of operation and special applications of transistors are outside the scope of this book; only the major highlights can be mentioned here. Transistors are assemblies of semiconductor crystalline and metallic materials (such as germanium and silicon), enclosed in plastic, glass, or metal housings. They have three, and sometimes more, electrodes attached for making electrical connections.

Transistors amplify because of the unusual property semiconductors have of permitting two kinds of simultaneous conduction—of excess electrons, or the usual negative electrical charge, and of *holes*, which are considered to be the absence of electrons and to have an equal positive charge. The electrons flow more rapidly than the holes.

Manufacturers make two kinds of transistors—the *point-contact*, which are usually available as triodes or tetrodes, and the *junction*.

Although the mode of manufacture determines some electrical properties, both forms come in two types, depending on the type of germanium and impurities used. These two types are the *n-p-n* and the *p-n-p*. They have different schematic symbols, as shown in Fig. 5-16 (A) and (B). The schematic letter symbol for any transistor is *Q*, followed by the manufacturer's type number.

In general, the operation of a transistor amplifier may be considered to resemble that of a triode vacuum tube. The transistor base element, see Fig. 5-16 (A) and (B), has a function similar to that of the vacuum tube's triode grid; the emitter can be compared to the cathode of the tube; and the collector's functions resemble those of the plate. The *n-p-n* type transistor corresponds to an electron tube with ordinary electron flow. (Note that the emitter arrow on the *n-p-n* schematic symbol points *out*.) The *p-n-p* type transistor corresponds to a theoretical tube emitting positive electrons. (The emitter arrow on the *p-n-p* schematic symbol points *in*.)

*For a complete treatment of transistor formation, circuitry, and applications, see *Fundamentals of Transistors*, by Leonard Krugman, published by John F. Rider Publisher, Inc.

In both cases, the emitter arrow shows the direction of electron current flow.

The three leads are readily recognizable on the transistor. The base is always in the center and the emitter is the lead closest to it.

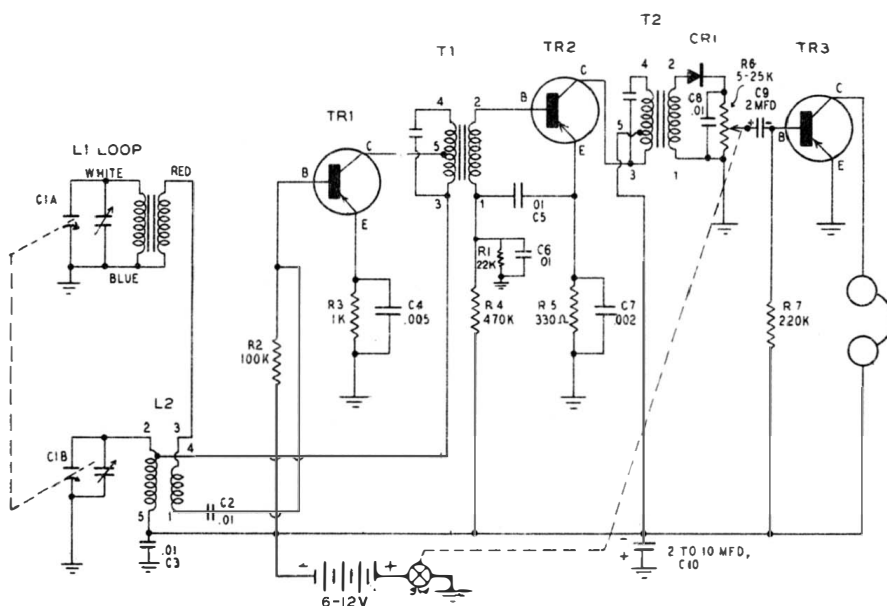


Fig. 5-17. A three-stage transistorized superheterodyne broadcast receiver.
 Courtesy Lafayette Radio, Inc.

If the leads are equally spaced, the manufacturer identifies the collector by a red dot, see Fig. 5-16 (C). Transmitter lead (or pin) size and spacing permits their insertion into either standard transistor sockets or 5- and 7- pin subminiature tube sockets.

Transistor circuits resemble those used with vacuum tubes. When proper voltages are applied to the transistor electrodes, see Fig. 5-16 (D), current flows between emitter and collector. Applying an electrical signal across the base and emitter causes large current variations in the emitter-collector current through the load resistance R1, producing effective amplification of the input signal.

TRANSISTORIZED RECEIVER

A transistorized broadcast receiver is very similar to a vacuum

tube broadcast receiver. A three-stage transistorized superheterodyne broadcast receiver is shown in Fig. 5-17. Transistors TR1, TR2, and TR3 are *p-n-p* type transistors. TR1 acts as an oscillator-mixer, TR2 as an i-f amplifier, and after detection with CR1, TR3 performs as an audio-amplifier. The output of the audio-amplifier TR3 is applied to the headphones which supply the load resistor for this stage. In operation, signals are selected by the loop antenna coil L1 which has a low-impedance winding secondary. Loop coil L1 is tuned with capacitor C1A. The primary of oscillator coil L2 is tuned with capacitor C1B. The design of the oscillator and antenna tuned circuits L1, C1A, C1B, and L2, is such that the difference frequency is 455kc which serves as the i-f value for the receiver. Power is supplied by a 6- to 12-volt battery; a switch to turn the receiver on and off is also provided. Note that the circuitry associated with each transistor is very similar to the one used in a vacuum tube receiver.

Chapter 6

INTERPRETING SCHEMATICS: RADIO AND TELEVISION CIRCUITS

This chapter shows the reader how to read and interpret complex and complete schematic diagrams, using radio and television circuits as examples.

RADIO-FREQUENCY AMPLIFIERS

For purposes of schematic reading, radio-frequency amplifiers differ slightly from the audio amplifiers considered previously. The most outstanding characteristics of r-f amplifiers are that they function at higher frequencies and usually employ tuned interstage transformer coupling. These tuned (resonant) circuits may be either fixed or variable as determined by the frequency requirements. Radios and television sets contain both fixed and variable tuned circuits in their r-f amplifiers. Although the signal acceptance capabilities of these amplifiers span a very wide band, only a narrow region of the band is processed when the system is tuned to a single station.

Radio station WRCA in New York for instance, operates at a frequency of 660 kc, but to receive the signals of this station the r-f amplifier need only amplify signals between 655 and 665 kc. Television stations send out signals at frequencies in the region of a hundred million cycles per second, but the r-f amplifier tuned to channel 5 need only amplify signals from between 76 and 82 mc. The purpose of this comparatively narrow band of frequencies is not to simplify the design of r-f amplifiers (although it does this) but to prevent the amplification of signals from unwanted sta-

tions. If the frequency range of the amplifier is maintained at the limits mentioned, all the intelligence being transmitted by the desired station will be received, and normally no signals from the undesired stations will be picked up.

Recognizing tunable amplifier circuits. Tunable r-f amplifier stages are used to provide a radio or TV receiver with a means of

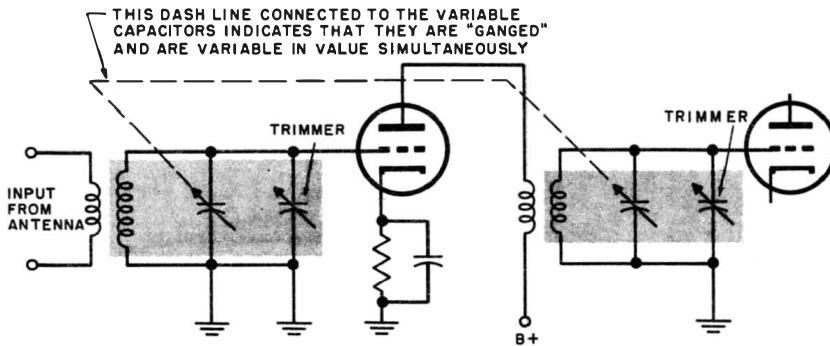


Fig. 6-1. Tunable r-f amplifier.

selecting the band of frequencies to be amplified. In radio receivers these amplifiers are rather simple in form; a common type used in the more expensive receivers is shown in Fig. 6-1.

The only outstanding feature of this amplifier is that it has two tuned circuits. Each of these consists of a parallel tuned transformer that presents a very high impedance to the band of signals to be amplified (thus building up a high signal voltage across the circuit), and a very low impedance to all other frequencies. Consequently, all unwanted signal frequencies picked up by the antenna develop very little if any, voltage across the parallel tuned circuit. In effect these signals are shorted to the ground, and only an extremely small portion of them reach the grid of the first tube. The second parallel tuned transformer circuit (substantially the same as the first) effectively cuts the unwanted signals down to zero and feeds the desired signal to the next tube.

Note that each tuned circuit contains an identical variable capacitor, and that these capacitors are mechanically coupled (ganged) together so that both can be tuned simultaneously with a single control knob. Also note that each tuned circuit contains a small parallel connected *trimmer* capacitor. The purpose of the trimmers is to provide a means for equalizing any small capacitance

differences between the ganged units so that both transformer systems are tuned to the same frequencies.

Antennas and antenna coupling circuits. The antenna is that portion of a radio or TV receiver which picks up the signal from

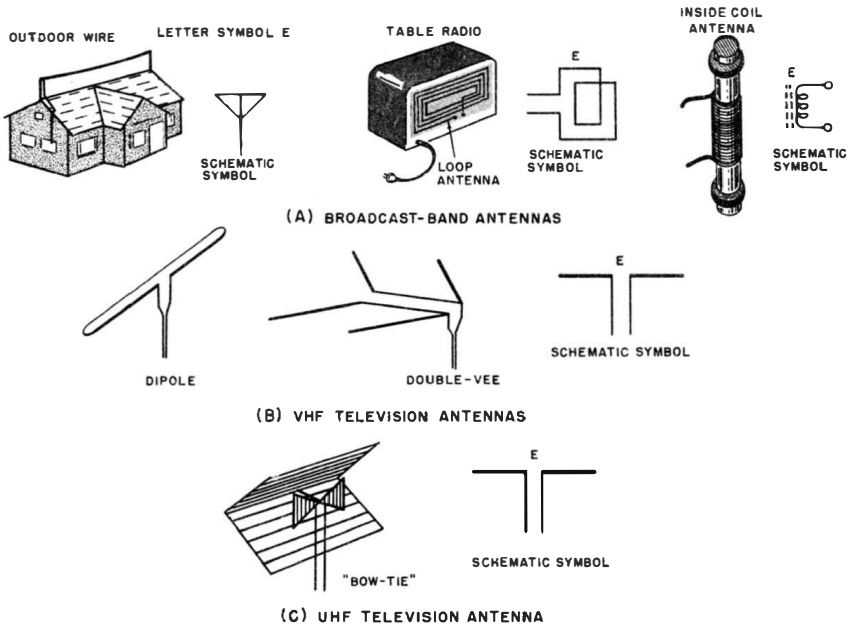


Fig. 6-2. Antennas. (A) Radio broadcast band antennas. (B) V-H-F television antennas. (C) U-H-F television antenna.

the transmitting station. The general size and shape of the antenna are determined by (among other considerations) the frequency of the signal to be received.

Radio broadcast-band antennas are often long outdoor wires, but more often they consist of 10 or 12 turns about 8 to 10 inches in diameter, mounted on a fiber board that is used as the back of the cabinet, or a small coil or ferrite loop antenna mounted inside the cabinet. Figure 6-2A shows these types and their schematic symbols. Figure 6-2B shows two types of antennas used for the vhf (very-high-frequency) band occupied by television channels 2 to 13. The uhf (ultra-high-frequency) band, which is not in widespread use at present, often employs an antenna such as that shown in Fig. 6-2C.

There are many methods by means of which the antenna signal

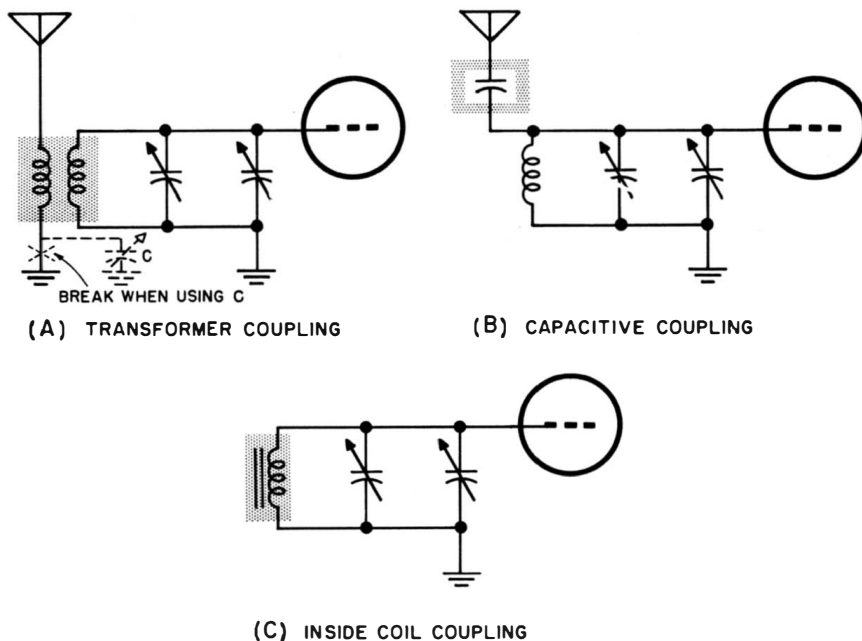


Fig. 6-3. Antenna coupling methods. (A) Transformer coupling. (B) Capacitive coupling. (C) Inside coil (loop antenna) coupling.

may be fed to the input of an r-f amplifier. The most common of these is connecting the antenna to the primary of an r-f transformer that has a tuned secondary, as shown in Fig. 6-3A. Occasionally the primary of the transformer is tuned as shown by the dashed-lined capacitor, but this is seldom done in low-priced home receivers.

It is also possible to couple without a transformer. This may be done by using a capacitor (or a capacitor and a resistor) to couple the antenna to a tuned grid circuit, as shown in Fig. 6-3B. An inside coil antenna is connected as shown in Fig. 6-3C.

Interstage coupling. The most common way of coupling an r-f amplifier to the next stage is by a transformer with an untuned primary and a tuned secondary, as shown in Fig. 6-4A. The primary winding also may be tuned, as shown in Fig. 6-4B, but the addition of a variable capacitor usually does not result in sufficient improvement to warrant the extra cost, bulk, and complexity. Other methods of coupling do away with inductive coupling of a transformer and employ capacitive coupling with either a tuned grid or a tuned plate circuit. Those methods are shown in C and D of Fig. 6-4.

Bandswitching circuits. When a tuned circuit contains only

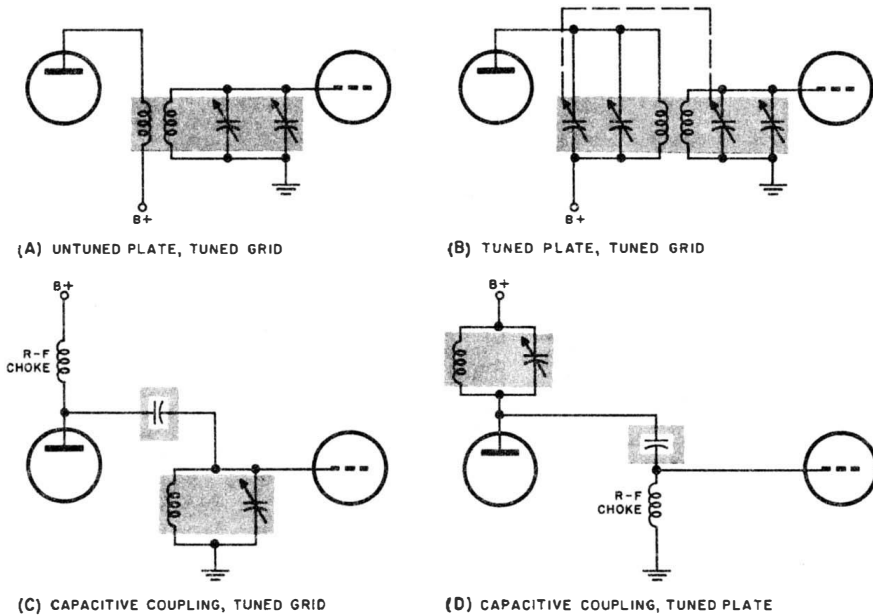


Fig. 6-4. R-F amplifier interstage coupling.

a single coil and a variable capacitor, there is a limit to the range of frequencies that can be tuned. Since the standard radio broadcast band covers the frequency range of 535 to 1605 kc, this entire range can be tuned with only a single coil and a variable capacitor in each variable tuned circuit. However, when the same receiver is required to tune in stations over a frequency range of 535 kc to 100 mc, a number of alternative tuned circuits, each covering a separate frequency band, are required in place of the tuned circuit employed previously. In the case of a vhf TV receiver, 12 separate tuned circuits are required in place of each r-f tuned circuit used in a radio broadcast-band receiver.

The simplest method of changing from one range of frequencies to another is to make use of plug-in tuned circuits that can be changed by hand. Although this method is used in amateur radio receivers and transmitters, it is too inconvenient for most applications. The most common method is to mount all of the required tuned circuits in the set with provision for switching from one to another.

Interpreting the schematic. This method is called *bandswitching* and is illustrated in Fig. 6-5. In the two stages of amplification

shown there are two tuned circuits at the grid of each stage. In the case of a TV receiver there would be a dozen such tuned circuits at each grid. It can be seen that each tuned circuit consists of a coil and a variable capacitor, which is set by the manufacturer. Note that the two switches are ganged together so that they can be set with a single control knob. Note also that there is a single

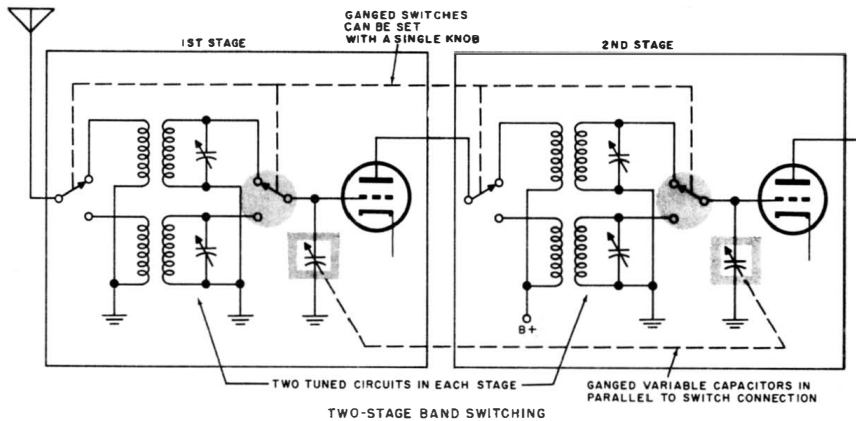


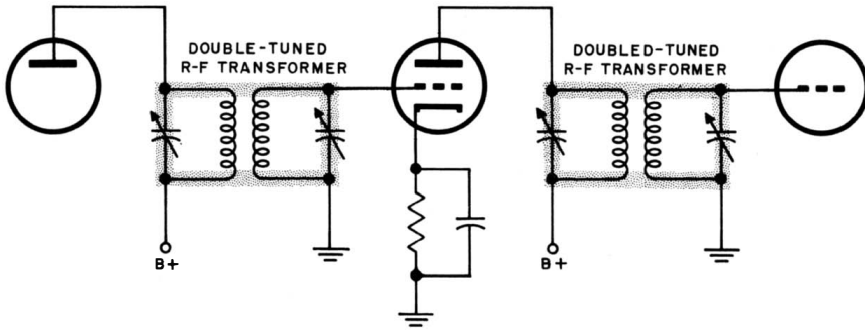
Fig. 6-5. Bandswitching in two stages of r-f amplification.

variable capacitor at the grid of each stage, and that these two capacitors are always connected to the grid regardless of the setting of the switch. These two variable capacitors are also ganged together, and are in parallel with any tuned circuit to which the switch is connected.

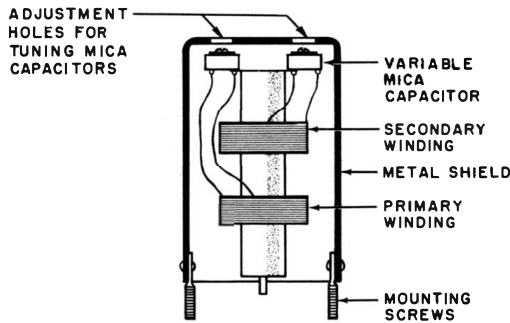
When the receiver is in use, the switch is set to the general band or channel desired. This connects the proper tuned circuit to the two stages. The two unswitched capacitors are ganged together, and are used as a fine adjustment to tune in the desired station.

Fixed-frequency amplifier circuits. Another type of r-f amplifier (much more common in modern radio and TV receivers) is the *fixed-frequency amplifier*. This is almost identical to amplifiers with variable tuning, except that the variable capacitor is adjusted by the manufacturer, and there are no provisions for tuning it from the *outside* of the set. Such amplifiers are usually designed to operate at an "intermediate" signal frequency, much lower than those of radio or TV transmitters. They are capable of supplying much higher gain than is possible with variable tuning.

Any of the coupling methods previously shown for r-f amplifiers with variable tuning is satisfactory for use in fixed frequency ampli-



(A) FIXED-FREQUENCY R-F AMPLIFIER



(B) SECTIONAL DIAGRAM OF FIXED-FREQUENCY R-F TRANSFORMER

Fig. 6-6. (A) Fixed-frequency r-f amplifier. (B) Sectional diagram of fixed-frequency r-f transformer.

fiers. However, the most common method of coupling involves the use of transformers with tuned primaries and tuned secondaries, as shown in Fig. 6-6A. The coupling transformers are generally mounted in containers such as the one shown in Fig. 6-6B.

Cost of the unit is about the same as for a variable tuned circuit, but there are smaller space requirements plus mechanical simplicity. In this case the cost of the extra capacitor tuning (discussed in connection with Fig. 6-4B) is balanced out by the extra gain and selectivity that it makes possible.

Detector circuits. Figure 6-7A is a simplified block diagram illustrating the basic function of modulation and detection in a simple transmitting and receiving system. The microphone at the transmitting studio translates sound into an electrical audio signal. To obtain long distance wireless transmission, a process called *modulation* is used to superimpose the audio signal upon an r-f signal,

which travels through space to the receiver. After passing through a series of r-f amplifiers in the receiver, the signal enters the *detector* circuit. The purpose of the detector is to remove the r-f portion of the signal and to send the remaining audio signal (intelligence) to the audio amplifier and the speaker.

Demodulation (or *detection*) is the name given to the process performed by the detector. A similar process is used in the video section of television receivers. In TV receivers the circuit is often referred to as a *video detector*.

Detector circuits rectify the input signal and then filter the r-f component out of the rectified signal. Although the r-f signal can be detected with a diode, multi-element tubes are sometimes employed to obtain amplification during the process of demodulation. The easiest method of recognizing a detector is by the fact that it always contains an r-f tuned circuit at its input, while its output is fed to an audio amplifier (or headphones), or a video amplifier (or picture tube). Sometimes R-C filters can also be recognized in the output circuit of a detector (Fig. 6-7B).

Figure 6-7 B, C, and D shows schematic diagrams of several

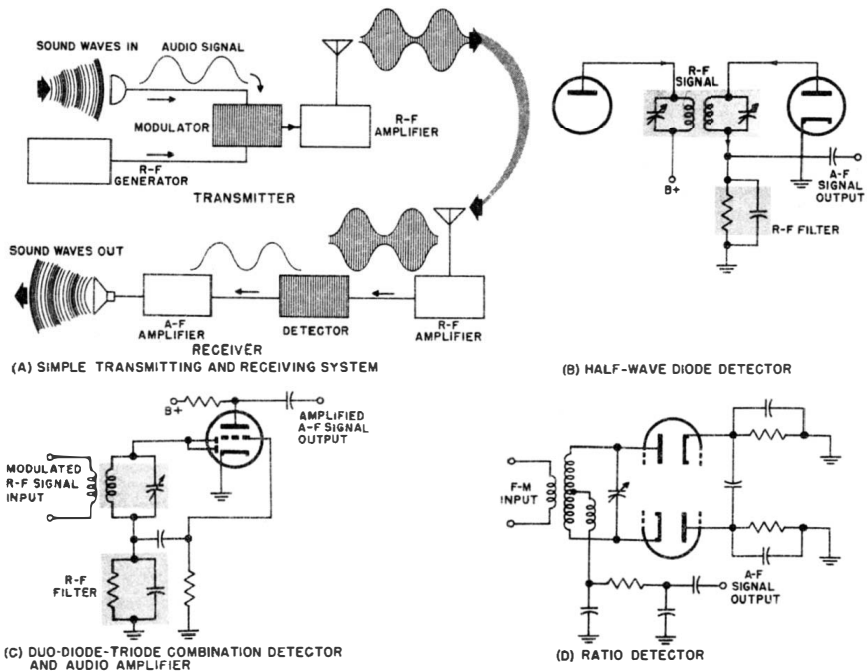


Fig. 6-7. Detectors. (A) Simple broadcasting and receiving system. (B) Half-wave detector. (C) Duo-diode-triode combination detector and audio amplifier. (D) Ratio detector.

widely used types of detectors. The basic half-wave diode detector circuit is shown in B, and C is a dual-diode-triode tube where the diode section is used as the detector, and the triode section as the first stage of audio amplification. This circuit is very widely used in small radio receivers.

A somewhat different type of detector is used in F-M radio receivers and the sound section of TV receivers. One of two types are employed: the *ratio detector* or the *discriminator*. These two types are somewhat similar in circuit appearance. Both employ two diodes with an input-tuned transformer circuit, and both are referred to as *F-M detectors*. Their purpose is the same as the A-M detector, i.e., to receive the rf from the output signal, and obtain the audio intelligence in the output. A ratio detector circuit appears in Fig. 6-7D.

Oscillator Circuits. Sine wave signals at various fixed or controllable frequencies are required in nearly every modern radio or TV receiver (and transmitter), and such signals are also required in many types of specialized equipment. A sine wave can be generated by a circuit known as a *sine-wave oscillator* (simply referred to as an *oscillator*, without an input signal being required). Such an oscillator always consists of an amplifier circuit in which part of the plate output signal is fed back to the grid circuit. The feedback signal does not oppose the amplification taking place in the tube, but aids it, and consequently is known as a *positive feedback* signal. The specific applications of oscillators will be described in conjunction with the review of mixer circuits.

Some schematics contain waveforms. Simple sine waves are usually omitted, as it is assumed that the reader knows of their presence. Other waveforms may be included to show the waveshapes of inputs and outputs or to show the serviceman what waveforms should be obtained at test points, along with their voltage measurements.

Recognizing oscillator types. Any amplifier will oscillate if proper *in-phase* feedback is used between the output and input. A sine-wave oscillator is an amplifier that is specially connected so that the feedback will produce a sine-wave output. In most equipment applications it is required that this sine-wave signal be stable in frequency and amplitude. Resonant L-C circuits with fixed or variable tuning are used to produce r-f oscillations at the resonant frequency, and R-C filters are used to produce a-f oscillations at the resonant frequency passed by the filter. These characteristics are usually sufficient to identify oscillators in schematic diagrams.

Figure 6-8 includes schematic diagrams of three widely used

oscillators. The *Hartley* (A) and *Colpitts* (B) are two very popular r-f oscillators. Most of the oscillators used in radio and TV receivers are variations of these. The circuit of Fig. 6-8C can be recognized as an audio oscillator because of the feedback through an R-C filter network.

Mixers. It is difficult to amplify the radio and TV signals taken from the antenna because their frequency is high, and because the amplifier tubes must operate over a wide range of frequencies. However, years ago that is exactly what was done in radio receivers. The radio antenna was connected to a series of tunable r-f amplifiers, which were connected in turn to a detector and an audio amplifier. A block diagram of this *tuned radio-frequency* (trf) receiver is shown in Fig. 6-9A.

Superheterodyne diagrams. Most present day radio receivers use the *superheterodyne* arrangement, shown in block diagram form in Fig. 6-9B. A tunable r-f amplifier and oscillator are mechanically coupled together and their individual outputs go to a *mixer* stage. The output of the mixer is at a frequency equal to the frequency difference between the r-f signal and the oscillator signal.

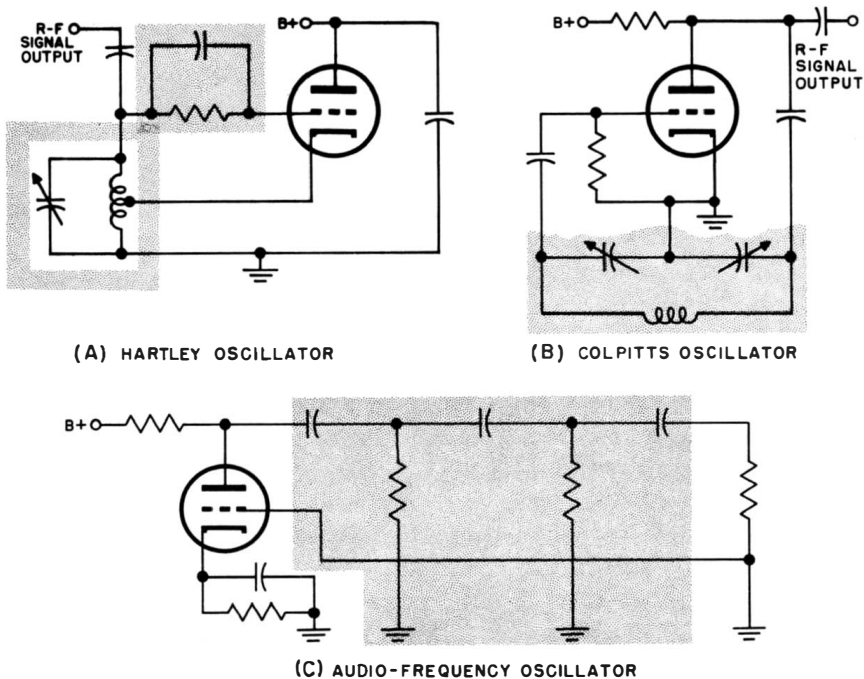


Fig. 6-8. Common oscillator circuits. (A) Hartley. (B) Colpitts. (C) Audio-frequency.

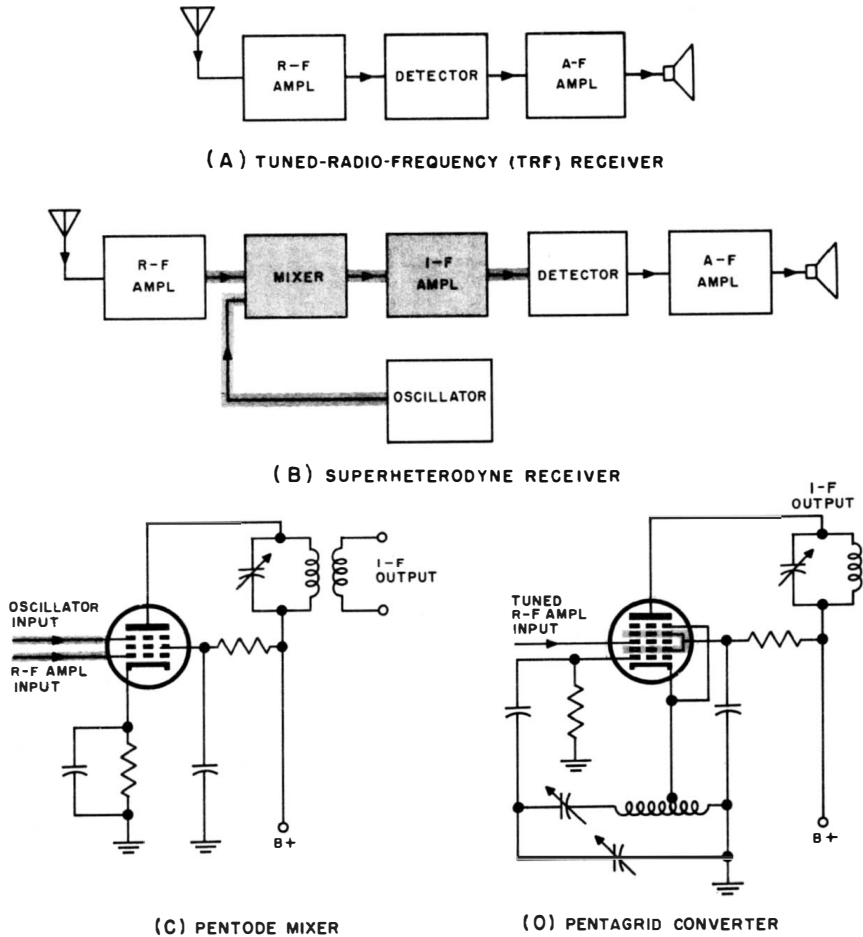


Fig. 6-9. (A) Tuned r-f (TRF) receiver to which a mixer is added to make a (B) superheterodyne receiver. (C) Pentode mixer. (D) Pentagrid converter.

Because the oscillator frequency is shifted whenever the r-f amplifier is retuned, the mixer output is always at the same frequency. Since this frequency is much lower than the transmitted signal, amplification can be accomplished by several stages of fixed-frequency amplifiers operating at a relatively low frequency. Because the frequency of this second amplifier is between that of the transmitted r-f signal and the final audio signal, it is known as the *intermediate-frequency* (i-f) amplifier. A similar arrangement is used in TV receivers.

Other widely used names for the mixer tube are the *first de-*

tector and the *converter*. Mixing can be done with a pentode circuit in which the r-f signal input is connected to the control grid and the oscillator tube is connected to either the cathode or the suppressor grid. This arrangement is shown in Fig. 6-9C.

In one very widely used arrangement the mixer tube contains an extra pair of grids which are tied together. This is shown in Fig.

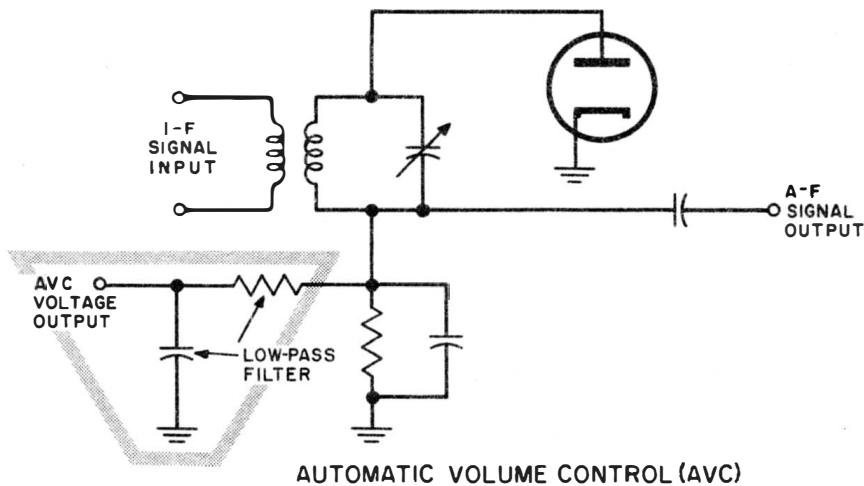


Fig. 6-10. Automatic volume control (AVC) circuit.

6-9D; the tube is known as a *pentagrid converter*. The advantage of this circuit is that the tied-together grids act as the plate of the oscillator, and the same tube can combine the functions of both oscillator and mixer. Other combination oscillator-mixer circuits are also used to enable a single vacuum tube to serve both purposes.

Regardless of the type of circuit used, it is easy to recognize a mixer because it has both an oscillator and a variable tuned circuit at its input and a fixed-frequency amplifier at its output. In low-cost radio receivers there may be no tuned r-f amplifier, but there is always a tunable resonant circuit to select the r-f signal to be fed from the antenna to the mixer.

Automatic volume control circuit. Automatic volume control, or *avc*, is a feature incorporated into almost all radio receivers. Its effect is to maintain a reasonably constant volume of sound out of the loudspeaker when the antenna signal fades due to atmospheric conditions, or when the receiver is retuned to a station with a weaker or stronger signal. This is accomplished by taking advantage of the fact that a d-c voltage is developed by the rectifying

action of the (second) detector tube. The voltage output of the detector increases and decreases with changes in signal strength. By feeding part of this voltage back to one or more grids in the preceding amplifier stages, the gain of those stages can be raised when the detector output tends to fall, or lowered if the detector output tends to rise. Figure 6-10 is a schematic diagram of a typical avc circuit.

Television receivers also contain avc circuits for maintaining a stable sound output from the speaker. A very similar circuit, called automatic gain control (agc), is used to maintain an image of uniform quality on the picture tube. Provisions for automatic volume control are easily recognizable due to the fact that they form a link between a detector stage and one or more previous amplifier stages.

We shall now interpret some typical schematic diagrams.

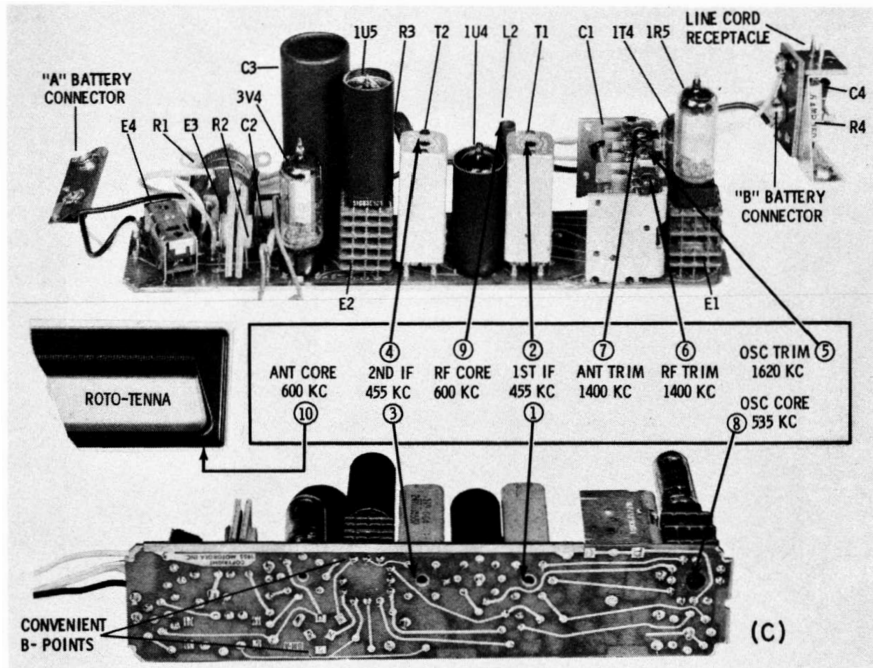
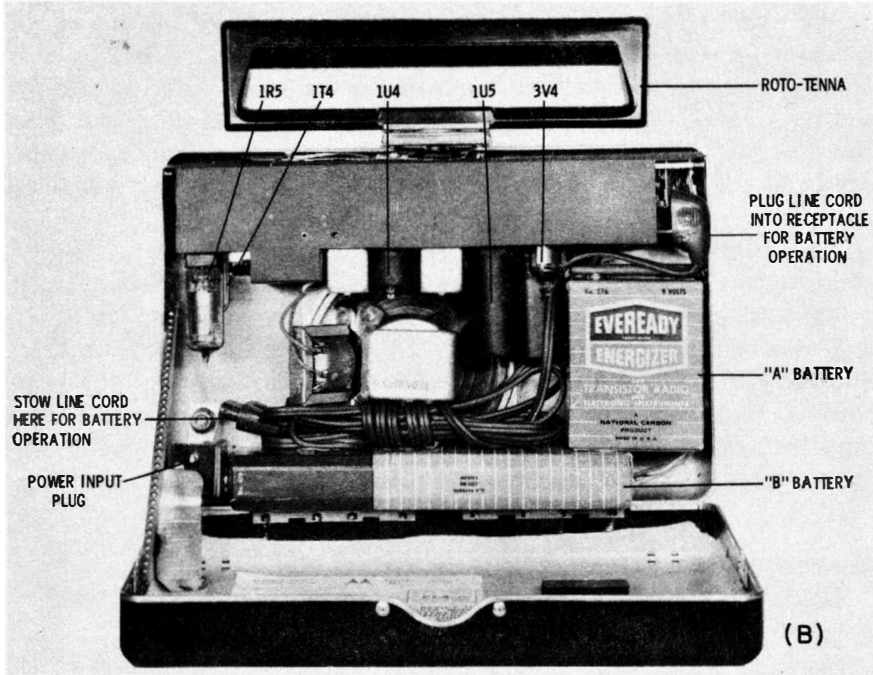
READING AND INTERPRETING A RADIO RECEIVER SCHEMATIC DIAGRAM

Physical examination. Figure 6-11A shows a photograph of the front of a portable radio. The large dial at the right is a tuning control, the knob at the left is a combination volume control and



Fig. 6-11A.
Portable radio receiver. Courtesy
Motorola, Inc.

(A)



on-off switch. The antenna is in the carrying handle. Little more can be determined from the outside.

Opening the back of the case reveals the inside view shown in Fig. 6-11B. From this it is seen that the case contains two large batteries, marked *9 volts* and *90 volts*. The power-cord plug is inserted into a receptacle in the upper right-hand corner of the case, and the other end of the cord is free, but can be connected to a plug in the lower left-hand corner. The back of the speaker can be seen in the center, and a small transformer is mounted on the speaker frame.

Running across the top of the cabinet is the chassis, which is mounted so that the tubes hang downward. If the chassis were removed it would be seen to consist of a printed circuit board upon which the tubes and other major components are mounted (see Fig. 6-11C). Another outstanding thing about this chassis is that the shielded tube near the center and the unshielded tube at the extreme right are mounted upon multilayered bases which are recognized as modular units. Careful examination of the major parts would reveal further information, but much more can be learned by reading and inspecting the schematic diagram.

Schematic diagram interpretation. Figure 6-12 is a schematic diagram of the portable radio. The methods of interpreting this schematic are the same as those employed in the previous examples considered.

On the schematic, all the tubes are labeled with their functions. The sequence, from left to right, is: r-f amplifier, converter, i-f amplifier, detector-avc-audio amplifier, and power amplifier. The symbol on the extreme right is easily recognized as the loud-speaker. Knowledge of the nature of r-f amplifier and radio receiver circuits (previously discussed) leads to the deduction that the circuit on the extreme left is a tuned, built-in antenna. Thus, the arrangement is that of a straightforward superheterodyne receiver. Note the non-standard use in the diagram of the letter E for switches.

A search for tuned circuits reveals that in the first two stages there are two tunable r-f amplifier circuits and a tunable local-oscillator circuit. All three of these tunable circuits are mechanically coupled together, as indicated by the heavy dashed line. Examination of the i-f amplifier reveals that it has tuned transformers at its input and output.

Figs. 6-11B and C. (Opposite) Portable radio receiver. (B) Top: rear view; (C) bottom: printed circuit chassis layout. Courtesy Motorola, Inc.

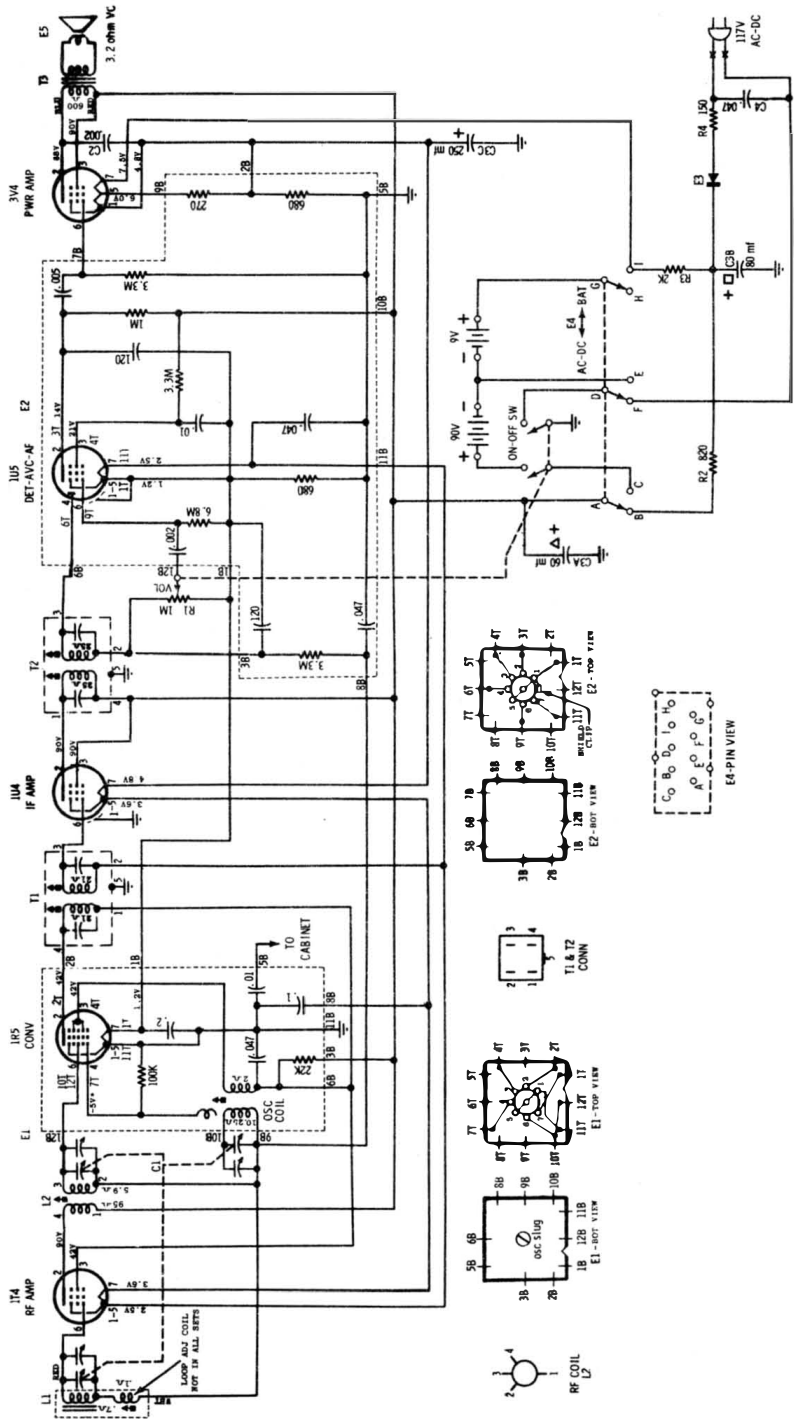


Fig. 6-12. Portable radio receiver schematic diagram. Courtesy Motorola, Inc.

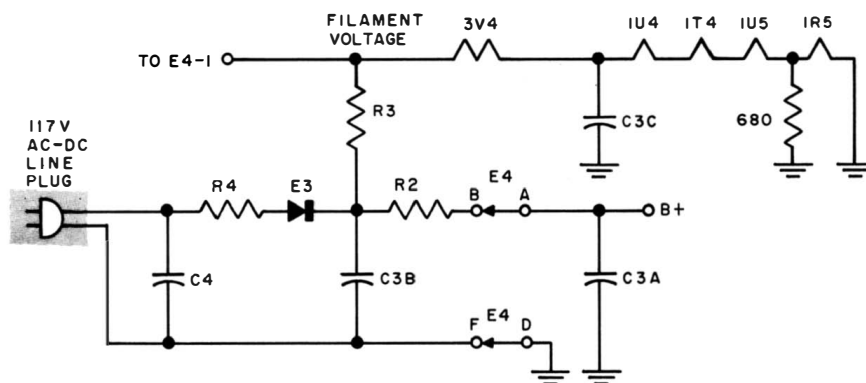
The arrangement of the schematic diagram is so straightforward and so adequately labeled that a block diagram is unnecessary. However, if such a block diagram were drawn it would look exactly like B of Fig. 6-9. Further investigation is required only to reveal the nature of the symbols in the lower part of the diagram and the nature of the power supply in the lower right portion of the diagram.

Examination of these symbols reveals that each symbol is marked with code numbers, which correspond to identical code numbers on the schematic diagram below. Further investigation reveals that symbols E1 and E2 are marked *bot.view* and *top view*. This should make it clear that the purpose of these code numbers is to identify the physical location of terminals on various chassis units. On that basis, the first symbol identifies the terminal numbers on r-f coil L2, and the fourth symbol identifies the terminals on tuned i-f transformers T1 and T2. Note that the schematic diagram contains a dotted line marked E1 around the area of the converter tube, and a dotted line marked E2 around the area of the detector tube.

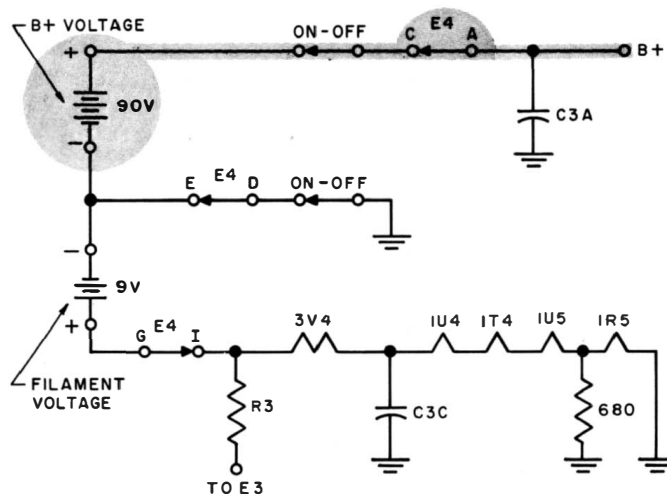
Since there are a number of resistors and capacitors within each of these regions, and since there are a large number of terminal code numbers in these regions, it can be deduced that E1 and E2 are the modular units seen in Fig. 6-11C. The top views of symbols E1 and E2 are seen to contain the representation of the tube sockets in the tops of the modular units, and these and their accompanying *bot.view* symbols, therefore, physically identify the terminals on the modular units.

Analysis of the power supply section may be difficult, owing to the presence of switches and crossed lines. Difficulty is also caused by the fact that the tubes of this set have no separate cathodes; hot filaments serve the function of cathodes. This causes cathode resistors and bypass capacitors to be connected to the filament, somewhat confusing the picture of the actual filament heating circuit. In a case such as this, it may be more helpful to draw a simplified schematic of the filament section of the power supply on a separate sheet of paper rather than attempt to memorize the power-supply connections to the filaments.

A simplified schematic of the power supply is shown in Fig. 6-13. From this it can be seen that the receiver will operate either from a power-line (ac or dc) or from its own batteries. When operated from the batteries, the line-cord plug is placed in the receptacle shown in Fig. 6-11B; the pressure of the plug terminals throws switch E4 to the battery ("bat") position. This connects



(A) AC - DC SYSTEM



(B) BATTERY SYSTEM

Fig. 6-13. Simplified schematic diagrams of portable radio power supply. (A) A-C/d-c system. (B) Battery system.

the positive terminal of the 90-volt battery directly to the B+ line, and the filaments in series with the 9-volt battery.

When the line plug is removed from the receptacle, switch E4 automatically switches to the ac-dc position. Note that the power supply operates as a half-wave power supply with R-C filtering. This is an a-c/d-c set, and a dry-metal rectifier is used instead of a vacuum-tube rectifier. The B+ output of the filter is now connected directly to the B+ line. An interesting feature, is that part

of the d-c current output of the rectifier is connected through a voltage dropping resistor (R3) and used to heat the filaments.

SCHEMATIC DIAGRAMS FOR OTHER RADIO RECEIVERS

Other standard broadcast band radio receivers may differ from the two considered here, but these differences are basically minor ones involving the physical construction, the nature of the power supply, and the intended conditions of use. For example, in the radio schematic diagram shown in Fig. 1-2, the major differences are those of physical layout, and in the circuitry of the power supply.

In a broadcast-band receiver intended for use in a large living room, there would be other differences. An expensive set might employ a power supply with a transformer and L-C filtering. Also, it might have a more elaborate audio-power amplifier with several loudspeakers, and perhaps special circuits for automatically keeping the r-f circuits tuned to the desired station. A communications receiver intended for airport, marine, amateur radio, or professional studio use would have elaborate bandswitching arrangements, and special circuits for the reduction of noise and assistance in receiving code signals.

Regardless of these special features, almost every standard broadcast or shortwave receiver has more or less similar methods of changing the r-f signal picked up by the antenna, to an audio signal with sufficient power to drive a loudspeaker. The superheterodyne principle is almost universally employed.

TELEVISION RECEIVER VIDEO AMPLIFIERS

Video amplifiers are used in TV, radar, and all other equipment in which a picture tube is employed. In these applications the video amplifier handles signals of unusual waveshapes which vary at frequencies from 30 cycles to 4 mc, or higher. With such wide-band requirements, video amplifiers must have very low distortion with excellent frequency response, although output power requirements are quite small. Since there is some difficulty in obtaining good frequency response in audio amplifiers (which have much narrower bandwidth requirements), it can be seen that this is a major problem in video amplifiers. These problems are solved by the use of compensating circuits in the interstage coupling, by inverse feedback, by special wiring techniques, and by low-capacitance tubes. Most video amplifiers employ several of the methods to be considered here.

Compensating circuits. There are separate compensating networks for correcting losses in gain at high and low frequencies. The drop in gain at low frequencies may be corrected by the use of a voltage-divider capacitor in the plate circuit of the amplifier tube, as shown in Fig. 6-14A.

A simple way of explaining this arrangement is to regard it as a low-pass filter. Since the compensating capacitor has a low impedance for high-frequency signals, it bypasses part of these signal voltages to ground; and only a part of them reach the grid of the next stage. On the other hand, the compensating capacitor has a high impedance for low frequencies, and nearly all of the low-frequency signal voltages reach the grid of the next stage. The total effect of this circuit is to emphasize the low-frequency voltage gain.

Frequency response may be improved at the upper end of the band by use of a *peaking coil*, as shown in Fig. 6-14B. This coil is actually a choke that presents a high impedance to the higher frequencies, while presenting less impedance to the lower frequencies. The circuit may be regarded as a high-pass filter that favors the amplification of high-frequency signals.

PICTURE TUBES

A brief review of some features of television picture tubes and their images will reveal much concerning the nature of the special

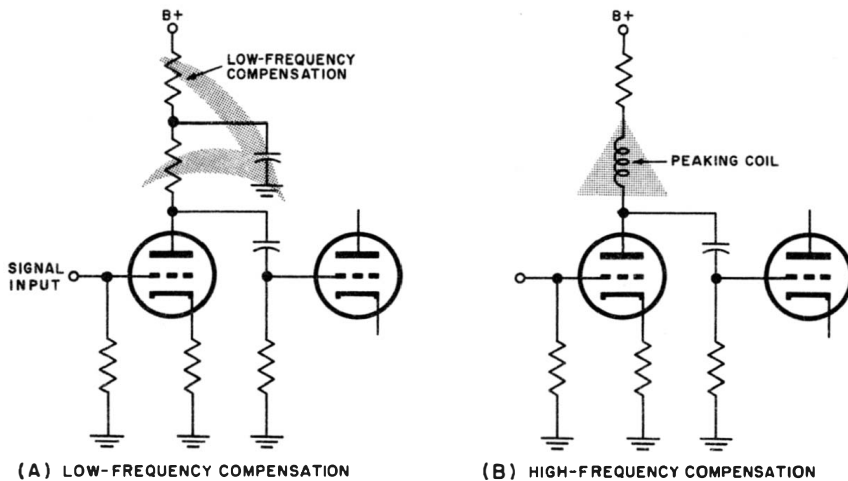


Fig. 6-14. Video amplifier compensating circuits.

circuits that must be included in a television set. Although details of these circuits will not be considered here, the reader will have the opportunity of using the techniques of reading and interpreting schematic diagrams to identify them for himself.

Many things can be learned from a review of what is seen and heard during the reception of a television program. First, the

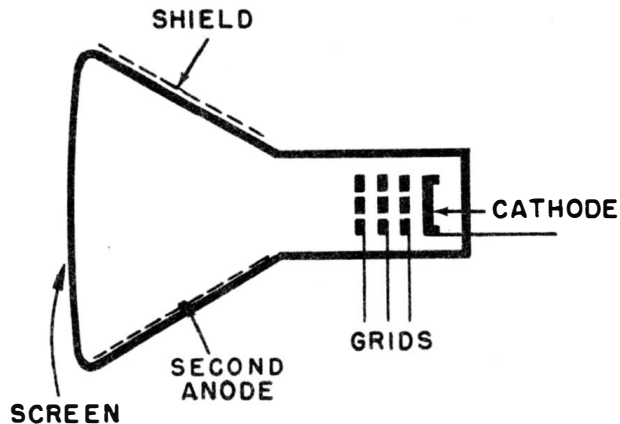
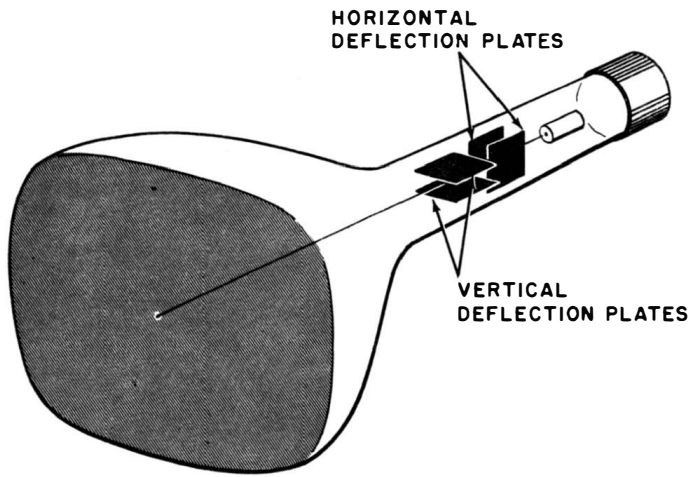


Fig. 6-15. TV picture tube.

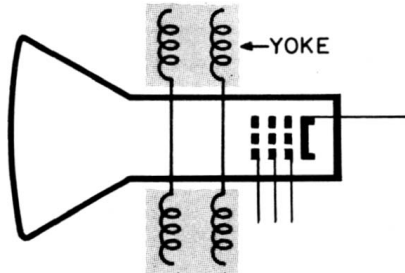
sound of the program can be heard from a loudspeaker. From this it is safe to assume that the set contains provisions for duplicating the processes that take place in a broadcast receiver. This implies the presence of one or more r-f amplifiers, oscillators, i-f amplifiers, detectors, and audio amplifiers.

An examination of the face of the picture tube indicates that the image on the screen is composed of a number of horizontal lines. Further examination of a reproduced picture shows that each line varies in brightness as it extends across the screen. When the many horizontal lines are seen closely spaced together, a complete image is built up by a merging of the light and dark portions of the individual lines.

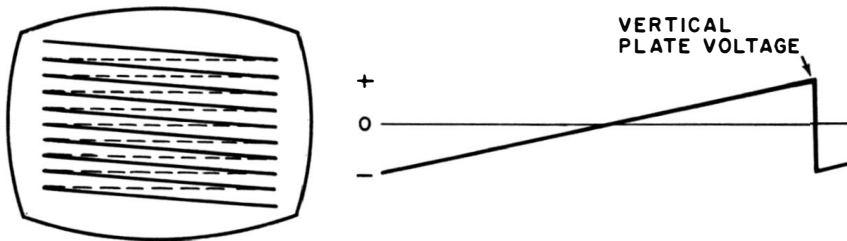
Construction and schematic symbol. Figure 6-15 shows the schematic symbol of a television picture tube and indicates the contents of such a tube. In the narrow portion (neck) of the tube is a heater, cathode, and grids. Around the inside of the wide section (bulb) of the tube there is a conductive coating (the *second anode*) that acts as a plate. There is also, usually, an outside conductive coating that acts as a shield.



(A) POSITION OF DEFLECTION PLATES



(B) HORIZONTAL AND VERTICAL DEFLECTION COILS



(C) COMBINED EFFECT OF HORIZONTAL AND VERTICAL SAWTOOTH VOLTAGES

Fig. 6-16. Picture tube electron beam deflection.

On the inside of the broad face of the tube is a screen of special material. When proper operating voltages are applied to the various tube elements, electrons flow in a stream, commonly known as a beam, from the cathode to the second anode (plate). Since the plate voltage is usually above 10,000 volts, the speed of the electrons is so great that they fly right past the plate and strike the center of the screen. When the high-speed electrons strike the special screen material, a luminous spot is formed. Varying the cathode-to-grid voltage has no effect other than to cause the spot to become bright or dim.

Operation in circuit. An image can be formed by deflecting the bright spot across the face of the tube to form the horizontal lines mentioned previously. The electron beam can be *deflected*, thus moving the bright spot, either by inserting additional plates in the path of the beam, as shown in Fig. 6-16A, or by placing a special coil assembly, called a *deflection yoke*, around the neck of the tube, as shown in Fig. 6-16B. The beam is deflected by applying either sawtooth-shaped voltages to the plates, or sawtooth-shaped currents to the yoke, to attract and repel the electron beam from side to side and up and down. The latter deflection system (yoke) is magnetic in action and is the one used in today's TV sets. The application of the properly shaped currents to the yoke will produce a pattern of horizontal lines, called a raster, on the screen (see Fig. 6-16C). In TV sets these deflection voltages produce a raster containing a 525-line image 30 times a second.

The individual horizontal lines must be brightened and darkened to produce a complete image upon that raster. Varying degrees of bright and dark spots can be produced by applying video signals to the cathode (or grid) of the picture tube. These signals change the cathode-to-grid voltage, changing the number of electrons in the beam, and thus altering the brightness of the various portions of the horizontal lines. This video signal is transmitted by the television station along with the audio signal, and is a varying voltage that corresponds to the light and dark areas in the studio image being transmitted. Its typical waveform is shown in Fig. 6-17.

It may be seen from this illustration that these voltage variations cover a wide range of frequencies (from 0 to 4 million cycles) and are received in sequences $1/30$ of a second in duration. Thus, each horizontal line has a video signal superimposed upon it, and the sequence of 525 horizontal lines forms a complete image.

From this brief description it will be seen that a television receiver must be expected to contain the basic elements shown in the simplified block diagram in Fig. 6-18. A superheterodyne type

of input receives the r-f signals from the TV transmitter. These r-f signals are modulated by both audio and video intelligence.

An audio (ratio) detector and amplifier system detect and apply the sound signals to the speaker. A video detector and video amplifier detect and apply the video signals to the cathode of the picture tube. Sawtooth sweep-current generators supply sawtooth current

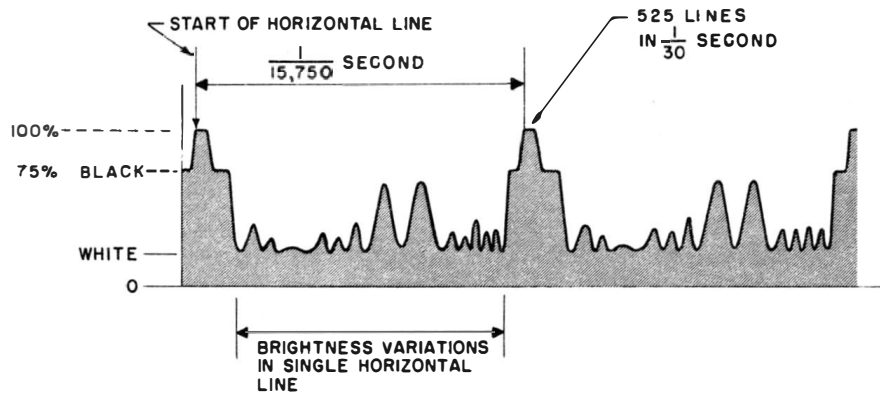


Fig. 6-17. Video signal showing details of two horizontal lines.

waves to the deflection coils. A synchronizing (sync) system is used to keep the picture from shifting on the screen. Special sync signals, which are part of the input video modulated signals, are applied to the sync system which in turn are applied to the sweep systems. A high-voltage power supply activates the anode of the picture tube. A low-voltage power supply is required for the amplifiers and sweep circuits. When all of these units operate together, the image in the television studio is reproduced on the picture tube.

READING AND INTERPRETING TELEVISION RECEIVER DIAGRAMS

Television receivers are one of the most complex units of commercially available electronic equipment. The reason for this is that synchronization, sweep and video circuits are complex; in addition, both the sound and picture portions of the program are transmitted as separate signals, relatively close in frequency. Synchronizing impulses are transmitted as part of the picture signals to prevent the picture from shifting on the screen.

To fulfill its requirements in a straightforward manner a typical TV set would require over 25 separate tubes to receive programs

transmitted in black-and-white. The use of dual-purpose circuits has reduced the number of tubes required, so that only about 15 to 17 tubes (including crystal diodes) are contained in the average set.

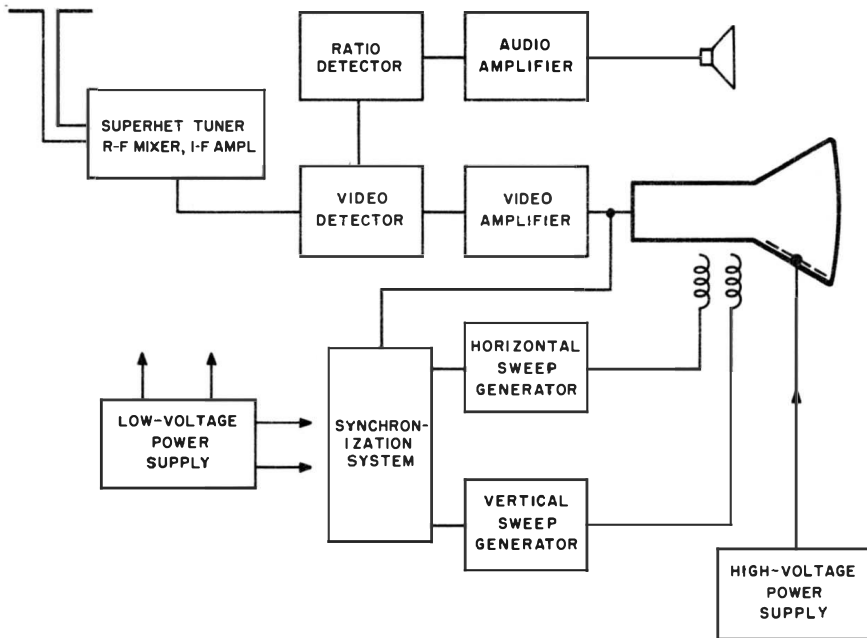
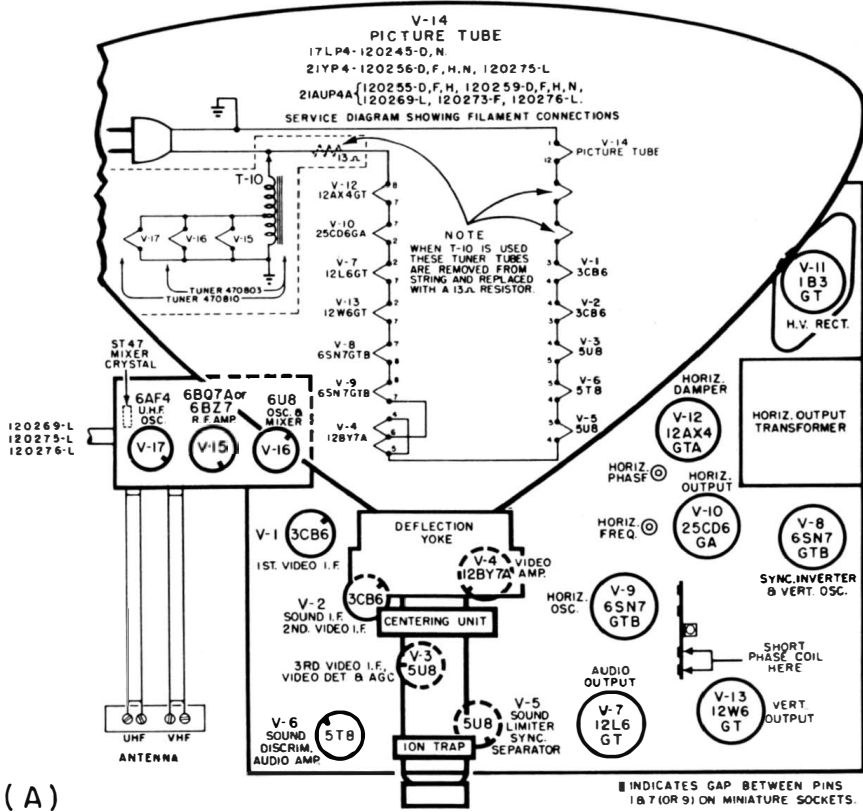


Fig. 6-18. Basic components of a television system.

These improvements are obtained through the use of circuits that do several jobs at the same time.

The following is not an attempt to explain the operation of a TV receiver. Instead, the approach will be to see just how much can be learned about TV by using some of the methods described thus far in this book. The receiver to be examined here is representative of modern set design, and all that is learned may be applied to other sets as well.

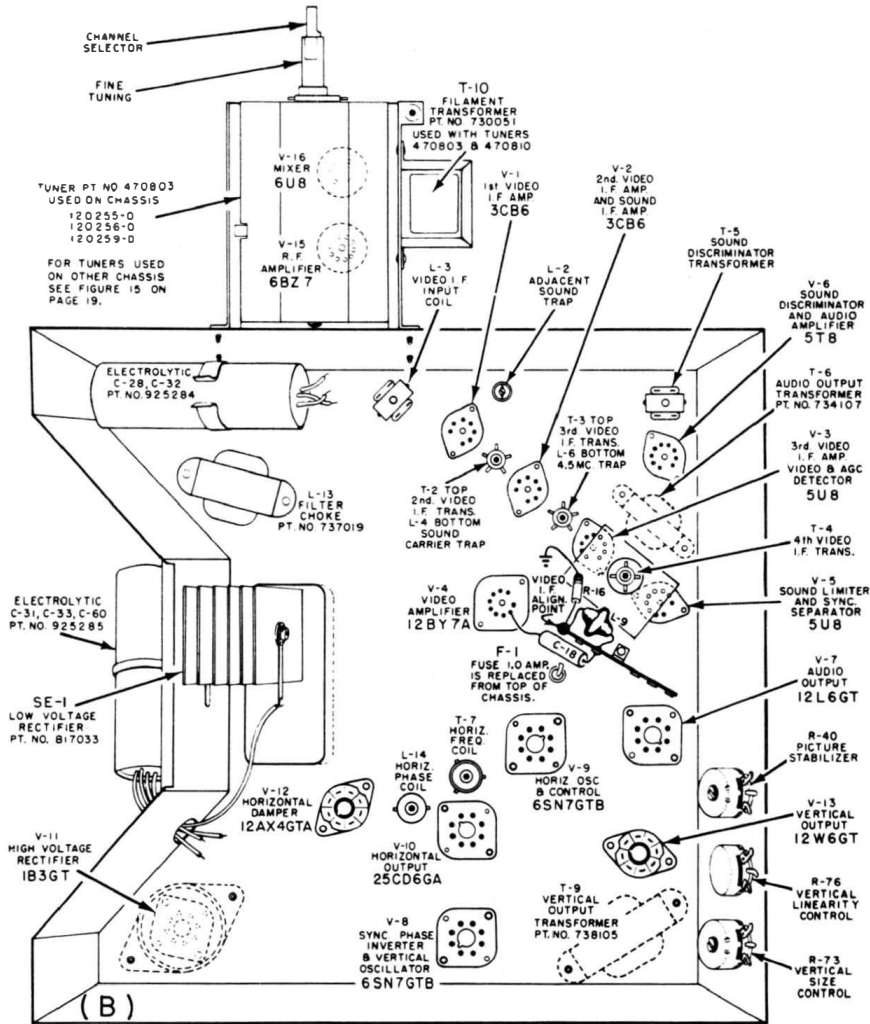
Chassis views. Figure 6-19 shows the servicing diagrams of the top (A), and bottom (B), of a typical TV chassis. The TV set consists of a main chassis containing 14 tubes (including the picture tube) and a tuner chassis containing 3 tubes. Actually, the manufacturer has several kinds of chassis and tuners, and they may be used in various combinations to form the many different models he has for sale. (Any particular model contains only one tuner and one main chassis.)



(A)

Fig. 6-19. TV receiver chassis. (A) Top view. (B) (Opposite) Bottom view. Courtesy Emerson Radio & Phonograph Corp.

A search for power and output transformers on the top of the chassis, Fig. 6-19A, reveals only a unit called the *horiz. output transformer* on the right-hand side. Continuing this search on the underside of the chassis (Fig. 6-19B), a *filament transformer* (T10) is found on the right of the tuner unit, at the top of the diagram. The note near the filament transformer indicates that this transformer is used only with certain tuners and supplies separate filament voltage to the tubes of these tuners. Also on the underside of the chassis is found a *sound discriminator transformer* (T5), in the upper right-hand corner of the diagram; the *audio output transformer* (T6) is seen just below it. In the lower right-hand corner of the bottom view diagram, Fig. 6-19B, is a *vertical output trans-*



former (T9). No familiar high-voltage power transformer has been found.

The diagram of the underside view of the chassis also contains other useful information. Examination reveals that the *channel selector* and *fine tuning* controls are located on the tuner unit, at the top of the diagram. At the lower right-hand corner three controls, R40, R76 and R73, are seen mounted on the rear wall of the chassis. A *high-voltage rectifier tube* (V11) is at the lower left, and a *dry-metal low-voltage rectifier* (SE1) and *electrolytic capacitor* (C31, C33, C61) are visible just above. Another *electrolytic ca-*

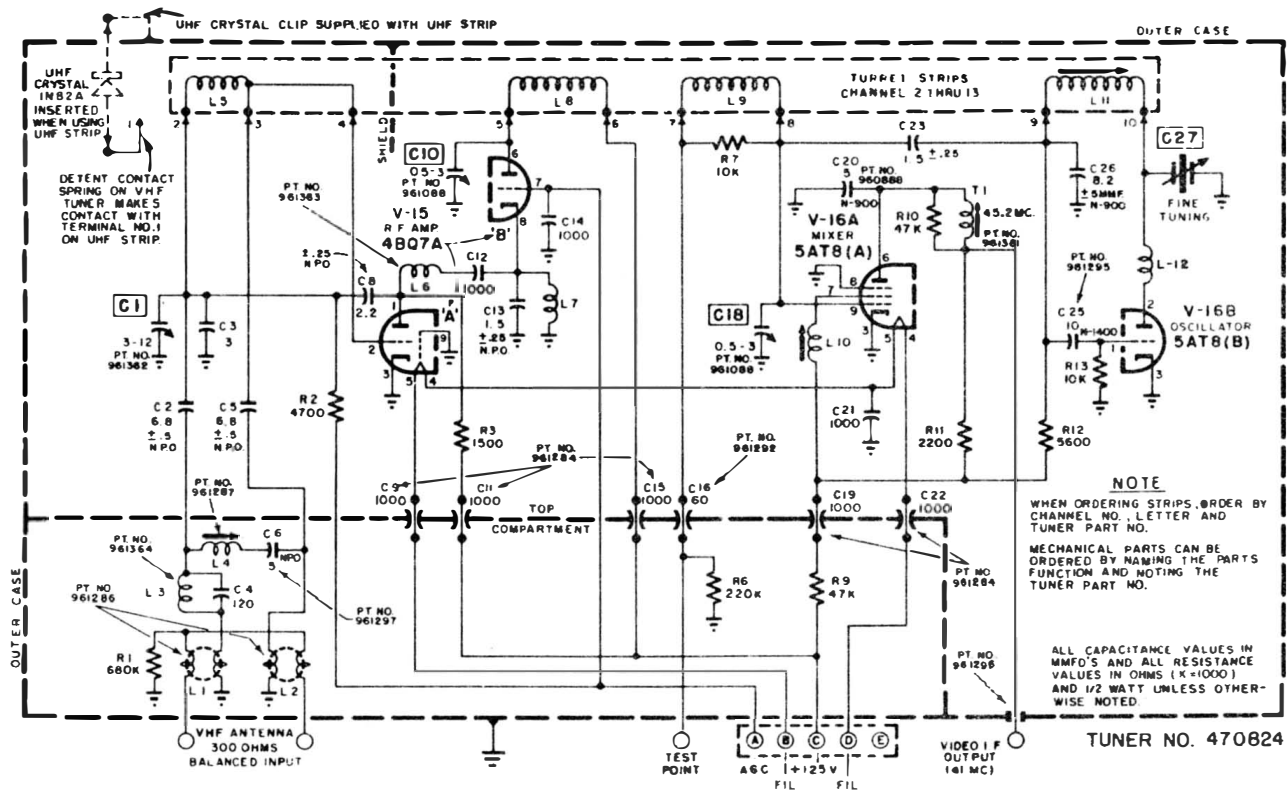


Fig. 6-20. Tuner schematic. Courtesy Emerson Radio & Phonograph Corp.

pacitor (C28, C32) is seen in the upper left-hand corner; just below it is a *filter choke* (L13).

Further investigation reveals many familiar terms referring to audio, video, and i-f amplifiers. On the tuner there is a reference to a *mixer* (V16) and an *r-f amplifier* (V15). The part numbers (PT NO.) referred to on these drawings indicate the manufacturer's code number when these parts have to be ordered and replaced.

It may be concluded from this preliminary investigation that a TV receiver has many familiar as well as unfamiliar circuits. References to r-f amplifiers, mixers, and i-f amplifiers, plus audio and video amplifiers, seems to infer that the superheterodyne arrangement is used. The lack of a power transformer and the presence of a dry-metal rectifier seem to imply that there is a selenium rectifier power supply for B+ voltage. Presence of a high-voltage rectifier tube (V11) implies that there is also a high-voltage power supply, which is probably for the picture tube.

Tuner schematic diagram. Examination of the tuner schematic diagram (Fig. 6-20) reveals that it contains an r-f amplifier, a mixer, and an oscillator. The presence of the terminal strip on the lower-right edge of the diagram indicates that the tuner gets filament voltage and +125 volts from a power supply that is not on the tuner chassis. The signal input to the tuner seems to be from a vhf antenna and the output terminal is marked *video i-f output*.

Detailed block diagram. To discuss a complete schematic diagram of the TV receiver is outside the scope of this book. However, a detailed block diagram will prove very useful in clarification of signal paths and the function of each stage, and is given in Fig. 6-21. In this diagram correlation is made to the functionary parts in Figs. 6-19A and B, and Fig. 6-20. The V numbers on the block diagram refer to the same V numbers on Fig. 6-19. The letters A and B next to the same V numbers in some of the blocks indicates that a dual purpose tube is employed and is serving two functions.

According to the tentative block diagram and the tuner schematic, a superheterodyne arrangement is used to mix (in V16A) the amplified antenna signal (from V15) with the output of the oscillator (V16B). The result of this mixing is called the *video i-f signal*. All of these preceding operations are accomplished in the tuner.

Remaining signal processing takes place on the main chassis. The video i-f signal output from V16A is amplified by V1, V2, and V3A, respectively. It is then detected by V3B; an agc voltage (corresponding to avc in a radio receiver) is also developed. The de-

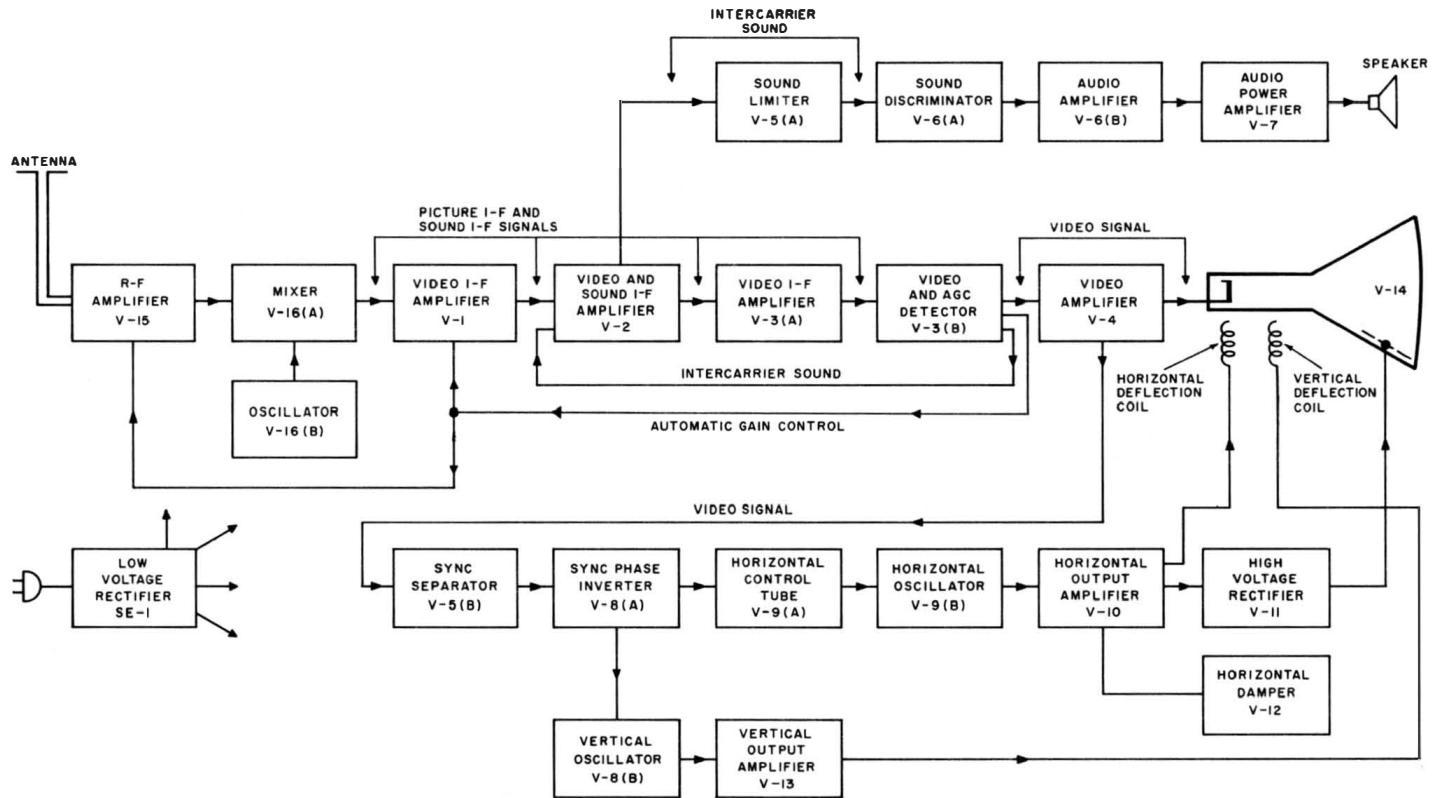


Fig. 6-21. Block diagram of a typical TV receiver.

tected video signal is then amplified by V4 and applied to the cathode of the picture tube, where it controls the intensity of the cathode-ray beam (electron beam), causing the picture to be developed on the raster on the screen.

The sound system of this TV receiver is referred to as a *reflex intercarrier type*. To determine the path of the sound signal first start at the output of V16A. Note that the block diagram indicates the simultaneous presence of picture i-f and sound i-f signals at the outputs of V16A, and also at V1, V2, and V3A. These two i-f signals are amplified together in the tubes mentioned. The video detector (V3B) processes these two signals and produces two outputs, one a video signal (which goes to V4) and the other a 4.5-mc *intercarrier sound* signal (which results from the beat difference between the two input i-f signals). This intercarrier sound signal from V3B is fed back to V2. Consequently, tube V2 amplifies the video i-f, the sound i-f, and also the intercarrier sound signals. The sound i-f signal and the intercarrier sound signal contain the exact same sound intelligence transmitted at the studio.

Since the sound signal is amplified twice by the same tube (V2), the effect produced by V2 is known as reflex amplification. The reflex intercarrier sound signal of 4.5 mc is tuned-circuit coupled from V2 to V5A where it is amplified. It then goes to V6A where it is detected and its resultant audio output is amplified by V6B and V7, and is finally fed to the speaker.

Part of the video signal coming out of video amplifier V4 is coupled to the sync separator V5B. This tube extracts the horizontal and vertical sync pulses which are a part of the video signal, and applies it to V8. In turn, V8 applies the horizontal and vertical sync pulses to their respective systems for control of the frequency of their oscillator circuits, to ensure picture lock-in. Blocks V9A, V9B, and V10 are the horizontal stages that produce the voltage that passes through and produces a sawtooth current in the horizontal deflection coil. Part of the output of V10 (via the horizontal output transformer) applies a high pulse voltage to the rectifier V11, which applies a very high d-c voltage to the picture tube, as described previously. The result is the formation of the picture tube electron beam and its deflection to form the basis of the horizontal scanning lines on the screen.

Blocks V8A and V13 are the vertical stages that help produce the sawtooth current through the vertical deflection coil. The result causes the *succession* of horizontal lines (the raster) on the face of the picture tube.

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