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abc's of MODERN RADIO

by WALTER G. SALM

a clear "inside view" of how radio works, step-by-step, from the broadcast station transmitter to the receiver. . .

To many people radio has long been one of the accepted mysteries of modern life. They know how to turn a radio on or off and how to tune it to the desired station, but understanding how a radio works is another matter.

This book is written to help solve the mystery of radio for all laymen. The author takes the uninitiated through the basic concepts and the fundamental circuits in a simple, nonmathematical manner. This book can be easily understood by everyone, and serves as a first step for anyone desiring to learn about electronics.

The text covers everything from the first spark transmitters to present-day FM stereo transmission and reception. Simplified explanations of Ohm's Law and Kirchhoff's Laws are given, along with their applications to resistance and capacitance problems. Hertz's fundamental discoveries in the field of generation and reception of electromagnetic waves are discussed. The theory and the practical applications of antennas, RF amplifiers, mixers, IF stages, detectors, and audio amplifiers are explained in detail. Here is a book that should be required reading for all beginning electronics students and technicians. It also offers a valuable and entertaining volume for laymen, hobbyists, and experimenters.

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ABOUT THE AUTHOR

Walter Salm, for many years an electronics hobbyist, has been active in electronics both as a technician and writer. Prior to entering the publishing field, he worked with electronic instrumentation systems for guided missiles and was a shop repairman in the Signal Corps during the Korean war. He is a frequent contributor of articles on electronics for popular consumer and do-it-yourself magazines.

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TECHNICAL BOOKS

ABC's OF MODERN RADIO

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by

Walter G. Salm

With a specially written chapter for the guidance of the English reader by W. Oliver (G3XT)

FOULSHAM-SAMS
TECHNICAL BOOKS

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Introduction Printed and Made in Great Britain
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It is essential that the English reader should read this chapter.

Radio has become such a commonplace part of everyday life that most people are apt to take its wonders far too much for granted.

They just accept the fact that it works, without ever bothering to consider how or why.

This book explains the "how and why" of radio in a very easily understandable fashion. It will give readers an insight into the working of present-day sets and will also serve to remind them of the amazing progress that has been made in radio, and other branches of electronics, since the days of Marconi's first experiments.

After a survey of the essential basic principles of electricity and magnetism by way of introduction, the author goes on to explain in detail the practical working of each stage of a modern set.

Printed circuits, transistor technique, frequency-modulation, VHF reception and stereophonic reproduction are all dealt with in these pages.

The book originates from the United States, and its American origin gives rise to certain points which may need to be explained or re-orientated to fit the facts of radio, electricity and electronics in Britain.

The purpose of this introductory chapter is to deal with these points and to give any supplementary information that may be helpful or interesting to readers of the English edition. Chapter and page references will be given where appropriate.

Chapter 1, *p.* 9. Batteries. In addition to the familiar accumulator or wet battery (as used in a car) and the ordinary dry cells (as used in electric torches), some other types have been developed in recent years. Ultra-miniature transistor radio sets, for instance, can be fitted with Mallory mercury cells, which are extremely tiny. Their voltage is exactly 1.35 v. per cell.

Battery-operated record-player and tape-recorder motors give up to ten times longer playing-time on leak-proof Mallory Manganese cells (1.5 v. per cell), which incidentally have a shelf life of about two years.

Chapter 1, *p.* 15, *Fig.* 1-12 (and many later references). Mains voltage. In this, as in other American electronic books, references to mains voltage usually quote a figure in the range 110-120 volts AC. American domestic mains are rated at this comparatively low voltage, which is only about half the voltage of 230-240 supplied by British domestic mains. American radio equipment (unless already modified for export) usually has to be suitably adapted—say, by means of an appropriate mains transformer or voltage-dropping resistor—before it can be plugged into our high-voltage mains.

The frequency at which the current alternates is usually 60 cycles per second for American mains and 50 cps for British. The difference is unimportant for radio, but very important for record-player motors, electric clocks, etc., where the rate of revolution is synchronous with mains frequency.

Chapter 1, *p.* 23, *Fig.* 1-20. Colour coding. American and British colour-codes are identical for resistor markings. But variations may occur where other components are concerned. **Caution:** Never place any reliance on the colour-coding of mains leads on any imported electrical equipment being in accordance with the British standard code (which is Green for Earth, Red for Line and Black for Neutral). Always check the actual connections at both ends of each lead or core to make sure that you have identified them correctly before attempting to plug into the mains when using new imported goods for the first time. Any error or misunderstanding over this could be extremely dangerous. If in doubt, seek expert advice locally.

Technical terms. A few of the terms used in American technical writings differ from the British equivalents. But there is a growing tendency to adopt some of the American terms over here.

An aerial is termed an antenna; earth is known as ground; valves are known as tubes or vacuum tubes; LT, HT and GB supplies are called A, B and C supplies, respectively. Thus, in *Chapter* 9, *p.* 97, the reference to B+ is equivalent to HT+ (high-tension positive).

Although not a radio term, the word "faucet" may puzzle some British readers; it means a water-tap and occurs in *Chapter* 1, *p.* 10.

To supplement the detailed account of sound broadcasting given in Chapter 2, the following brief summary may be helpful to the beginner as a preparation for reading that chapter.

The process of broadcasting begins with (original) sound and ends with (reproduced) sound. These sound-waves in air are the first and last links in the chain. All the intermediate links are purely electrical or radio ones.

Variations in the original sound are translated into variations in electrical currents by the microphone. These current-variations are impressed, by a modulator, on radio waves which travel through space from the transmitting aerial to the receiving aerial. On arrival they set up varying electrical currents in the receiving set and these are translated back into varying sound-waves by the loudspeaker. Thus we have sound-waves;

electronic currents; radio waves; electronic currents; and sound-waves—in that order. These are the vehicles, so to speak, which carry the characteristic pattern of each sound from its source to our ears.

How faithfully the reproduced sound—speech, music and so on—will resemble the original sound must depend on the efficiency of every link in the chain. Even one faulty component—a tiny resistor, perhaps—can cause distortion or even total failure.

Chapter 2, *p.* 44. Intermediate frequency. As the author states, 455 kc is the favourite for IF transformers in American sets. In Britain, 465 kc is, perhaps, the present-day favourite for ordinary purposes, but many other IF's are also used.

Among the IF transformers currently available from British manufacturers (such as Denco, Electroniques, Radiospares and Repanco), frequencies favoured range from 455 to 470 kc for ordinary receivers, 10.7 Mc for VHF/FM circuits, 1.6 Mc for some other purposes, and 85 kc for double-superhets.

Chapter 2, *p.* 45; and *Chapter* 4, *p.* 63. Although valve and selenium rectifiers are still in general use, midget silicon rectifiers—which permit a tremendous saving in space—are becoming increasingly popular. Tiny wire-ended types, generally used in conjunction with a fixed "limiting" resistor, are now available which are about the size of a collar-stud!

Even a component as small as this, however, is big in comparison with *some* of the incredibly tiny items found in the miniaturised transistor equipment of the present day.

Chapter 3, *p.* 50. In regard to directional aerials of any kind, a point worth noting is their ability to cut down, or even cut out, interference from unwanted stations in certain cases. This can be a valuable asset in districts where BBC reception is subject to powerful foreign-station interference. The cure only works, however, in locations where the direction of the wanted station lies more or less at right-angles to the direction of the unwanted one. In such a case, orientating the aerial for maximum strength from the wanted station gives minimum interference from the unwanted station.

If both signals are coming from the same direction, or from exactly opposite directions, a directional aerial such as a ferrite rod or frame-loop is no more effective than an ordinary omni-directional type as far as the interference-level is concerned.

Chapter 4, *p.* 61. "Ground in a radio is simply the metal chassis". While a metal chassis forms the common conductor for many of the earth-return connections in a radio circuit, one must not read the quotation above as implying that a metal chassis is necessarily at earth potential. In the case of an AC/

DC receiver with a twin-flex (two-core) mains lead terminating in a reversible two-pin plug, inserting the plug will put the chassis at the same potential as *one* of the mains leads. *Which* one depends on which way round the plug is inserted. One way connects the neutral lead to chassis; the other way connects the line lead (the high-voltage "live" one) to chassis. In the latter case the chassis is at a potential of about 230-240 volts above earth. Touching the live chassis and any earthed or earthy object at the same time (or even standing on a damp floor) could result in a dangerous or lethal shock.

For anyone who is obliged to handle exposed equipment in the course of servicing, etc.—for example, in a radio repair workshop—an isolation transformer is a valuable safeguard to minimise the risk of serious shock. It serves to protect the worker from direct contact with the mains. This type of transformer is mentioned in *Chapter* 1, *pp.* 16-17. Suitable models are manufactured by Radiospares Ltd. This firm supplies direct *only to the trade;* but the general public can obtain Radiospares products through normal retail channels; e.g., a local radio shop or some of the mail order firms, such as Home Radio (Mitcham) Ltd., 187, London Road, Mitcham, Surrey.

Chapter 10, *p.* 108. In Britain, both vertical and horizontal polarization is used by TV transmitters. Some stations use one, some use the other; so the receiving aerials in some areas are all vertical, while those in certain other areas are horizontal (like the American ones). Viewers within the service area of the Tacolneston (Norwich) BBC station, for instance, use horizontal aerials for BBC TV, whereas those within the service area of the London transmitter use vertical aerials.

Chapter 2, *p.* 38; and *Chapter* 10, *p.* 109. The points made in regard to "line-of-sight" limitations are no doubt intended to refer to consistently reliable reception under normal conditions. ("Freak" reception under abnormal atmospheric conditions, however, can be a very different matter.)

Chapter 12. Stereo has reached a more advanced stage in the United States than it has in Britain, where facilities are at present more limited. One should bear this in mind when reading this chapter which is, of course, written from the American angle.

Incidentally, the abbreviation "FCC" on p. 118 refers to the Federal Communications Commission, the authority in the United States which deals with such matters as the issuing of transmitting licences. In relation to radio communication and television, the nearest equivalent authority in Britain is the GPO.

PREFACE

Many people think of radio as something to be enjoyed but too complicated to be understood. Actually, the circuits in a modern radio are no more complicated than many other modern devices that the average person considers to be simple to understand.

ABC's of Modern Radio is exactly what the title implies—a simplified explanation covering all the circuits used in radio. It begins with fundamental electrical theory and progresses through the various circuits that are common to all radios.

Chapters on how radio waves are propagated, antenna systems, transmitters, and receivers explain the radio both inside and out. Tables, diagrams, photographs, and schematics are used throughout the text to simplify the subject.

Whether the reader is a student, home experimenter, or a housewife, this book will serve well as a first introduction to this fascinating subject.

It is not the purpose of this volume to provide a complete detailed study of radio. Instead, it presents a simple and straightforward discussion of the principles of radio that anyone can easily understand.

WALTER G. SALM

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Chapter 1

ELECTRICITY AND MAGNETISM

Radio is closely tied up with its sister sciences, electronics and magnetism. In fact, radio waves are simply special kinds of alternating magnetic fields generated by electronic equipment. Once the basic principles of these two related areas are mastered, then an understanding of radio operation should come easily.

ELECTRONS IN MOTION

All materials are made up of atoms. Of the basic parts of the atom, the electron is the most easily dislodged. It is easier to knock an electron loose from some materials than others. These substances are said to have *free electrons* and are usually called *conductors*. Such materials include water, silver, and copper, but for reasons of economy and workability, copper is the most commonly used conductor.

Electrons revolve around the nucleus of an atom in much the same way as the earth and other planets revolve about the sun (Fig. 1-1). The particles in the outer shell, or ring, are the free electrons; it is these that are easily knocked loose and made to do work for us.

When an outer-shell electron is displaced it usually jumps to the outer shell of an adjacent atom. This jump knocks one of the outer-shell electrons of the adjacent atom loose. This electron jumps to the outer shell of the next atom, and so on. Thus a kind of chain reaction is created and is called an electric current.

Quite a few of these electrons must be in motion before a current can actually be measured. Since each electron is surrounded by a magnetic field, when many electrons are in motion, the copper wire is surrounded by a magnetic field. The strength of this field is proportional to the current flowing in the conductor. The direction of the lines of force for this magnetic field is perpendicular to the direction of current flow. To determine the

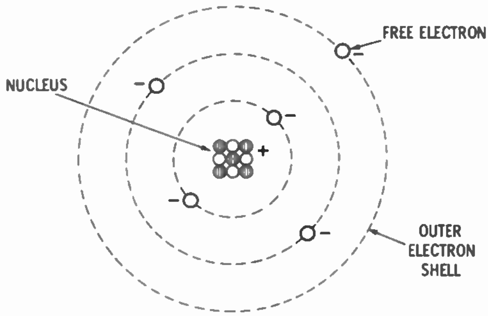


Fig. 1-1. Structure of the atom.

direction of the lines of force, grasp the wire with the right hand with the thumb pointing in the direction of current flow (toward the positive terminal); the finger will then point in the direction of the magnetic lines of force as shown in Fig. 1-2.

The flow of an electric current can be detected with a device called a galvanometer (Fig. 1-3). The instrument shown can be made with some magnet wire and an ordinary compass. A single coil of the wire can be wound around almost any nonmagnetic material, and the compass can then be laid on top of the coil. After the needle settles down and points to the magnetic north pole, connect a flashlight battery to the two wires leading to the coil. The magnetic field generated by the electric current will make the compass needle gyrate until it is lined up along the magnetic lines of force of the coil, as shown in Fig. 1-3.

For any kind of measurement, you must be able to know the amount of current flowing through the conductor. Current flow is measured in *amperes*, and one ampere is 6.28×10^{18} (628 followed by 16 zeros) electrons flowing past a given point in 1

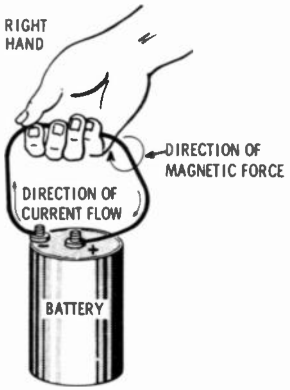


Fig. 1-2. Right-hand rule.

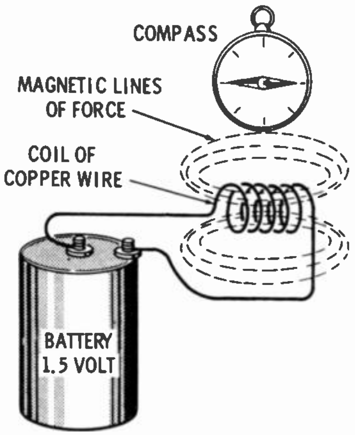


Fig. 1-3. Principle of a galvanometer.

second. Spelled out, that is six-quintillion, two-hundred and eighty quadrillion electrons. If you have trouble visualizing this number, you'll understand why it is usually written as 6.28×10^{18} (Table 1-1). This technique is called *scientific notation*, and it is used whenever a number is so large or small that it involves too many zeros to be practical.

SOURCES OF ELECTRICITY

The simplest and best-known source of electrical energy is the battery. In any wet or dry cell there are two electrodes made of different materials immersed in a solution called an *electrolyte*. A chemical reaction between the electrolyte and one of the two metals produces many free electrons on the electrode constructed of this metal. This becomes the negative electrode (since electrons are negatively charged). In wet (automobile-type) storage batteries and flashlight cells it is made of zinc. The electrons flow from the negative electrode through the circuit—also called the *load*—and finally back to the positive electrode (copper in wet cells, carbon in dry cells), completing the circuit.

The amount of "push" behind these electrons is called *voltage*. Also called *electromotive force* (emf), the voltage is very much like the pressure or head developed by a water tower when it is filled. If a tank contains 1,000 pounds of water and is 50 feet high, it is said to have a head of 50,000 foot-pounds. This represents the *potential*, an ability to do work, and voltage means exactly the same thing (Fig. 1-4).

When water is released, the pressure forces it to release its energy, either in the form of heat, a high-flowing jet of water

Table 1-1. Common Prefixes and Multipliers Used in Electronics

Prefix	Abbrev.	Multiplier	Add No. of Zeros
Kilo	k	10^3	3
mega	M	10^6	6
giga	G	10^9	9
			Move decimal to left
milli	m	10^{-3}	3 places
micro	μ	10^{-6}	6 places
nano	n	10^{-9}	9 places
pico	p	10^{-12}	12 places

These prefixes are all multiplication factors. If you have 10 kilowatts and want to know how many watts this is, then add three zeros and the answer is 10,000 watts. If you have a current of 30 ma (milliamperes) and want to convert this to amperes, move the decimal 3 places to the left, and the result is .03 ampere.

The column labeled "Multipliers" is the form usually used to express very large or small numbers. This system of using "powers of ten" is called "scientific notation." 10^6 means 10 multiplied by itself 6 times, or more conveniently, it is 1 followed by 6 zeros. 10^{-6} is the same as $1/10^6$, and written out in decimal form this would be .000001.

from a fountain, or the high pressure of water rushing out of a faucet. The total work of electricity, or *power*, is measured in *watts*, the product of amperes × volts. For example, if there is a circuit that is drawing 2 amperes from a 6-volt vattery, the power consumption is 12 watts.

Another source of electrical energy is the generator. It is usually a rotating magnetic device in which a copper conductor is forced to move through the magnetic lines of force of a magnet.

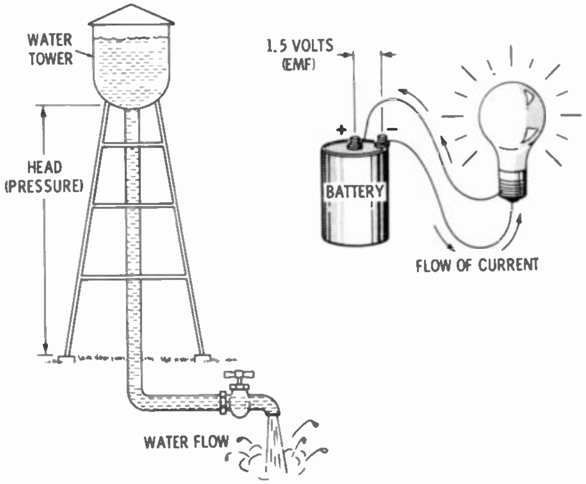


Fig. 1-4. Analogy of water pressure to voltage.

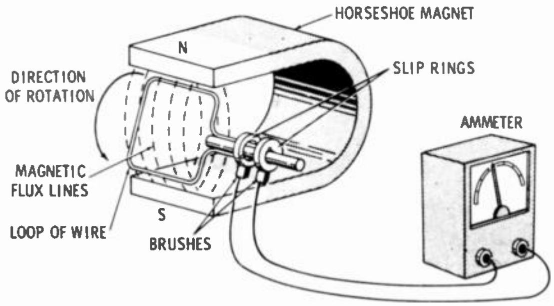


Fig. 1-5. Elementary generator.

Whenever a conductor moves through a magnetic field, electrons are forced to flow in the wire. An elementary generator is shown in Fig. 1-5. As the loop of wire starts from its resting position parallel to the lines of force, it begins to cut through these lines and electrons start to move through the conductor. When it reaches its peak, exactly perpendicular to the lines of force and

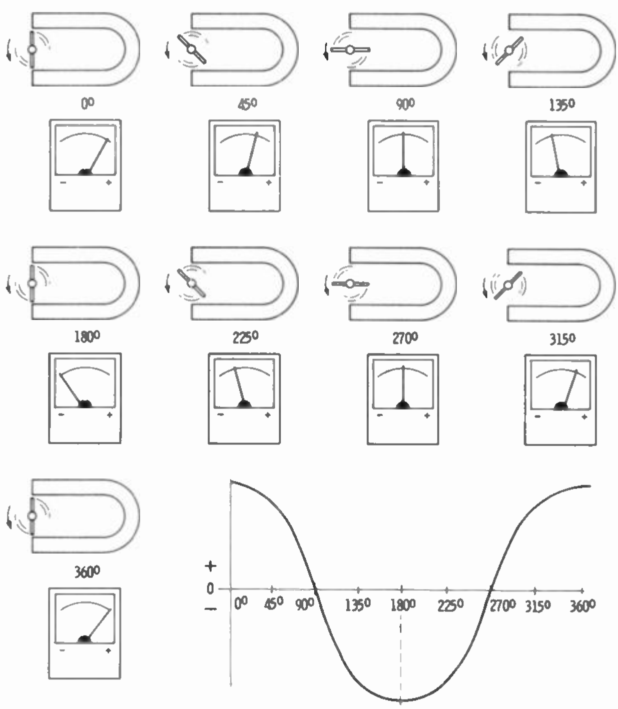
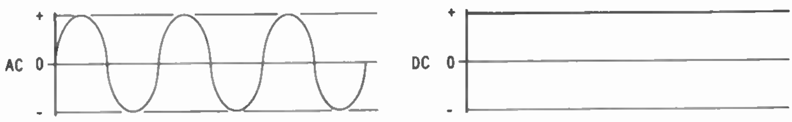


Fig. 1-6. Operation of an elementary single-loop generator.



(A) AC waveform. (B) DC waveform.

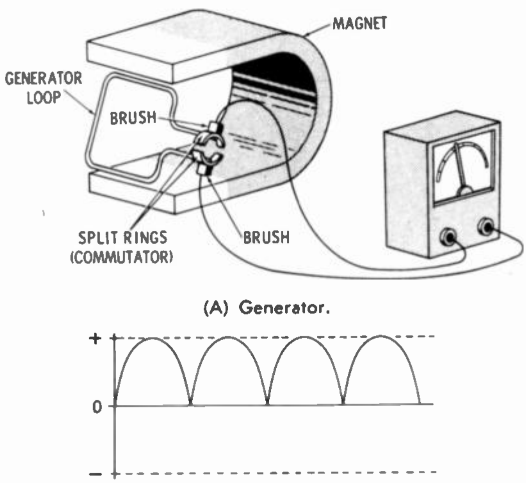
Fig. 1-7. Graphical representations of AC and DC.

cutting through the maximum number of lines possible, the greatest amount of current is flowing (Fig. 1-6).

As the loop descends, cutting fewer lines, the amount of current flow decreases until the loop is parallel to the lines of force (Fig. 1-6). Current flow at this point is zero. The loop continues to rotate, and current begins to flow again. This time, however, flow is in the opposite direction, since opposite halves of the loop are now cutting the lines of force. Again, the current flow reaches a peak (a negative peak on the graph) and decreases toward zero once more as the loop returns to its starting position.

One complete rotation of this loop is called a *cycle*, and the graph that shows the current flow (and voltage developed) in Fig. 1-6 is called a *sine wave*. The type of current generated by a single-loop generators is an *alternating current* (Fig. 1-7A), while a battery delivers *direct current*, which is represented by a straight line (Fig. 1-7B).

All generators are of the alternating-current (AC) type. If direct current (DC) is desirable, then a split-ring commutator is added to the generator (Fig. 1-8A). Each time the loop rotates,



(A) Generator.

(B) Output voltages.

Fig. 1-8. DC generator and voltage output graph.

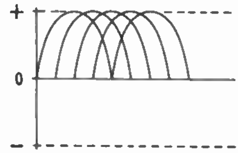


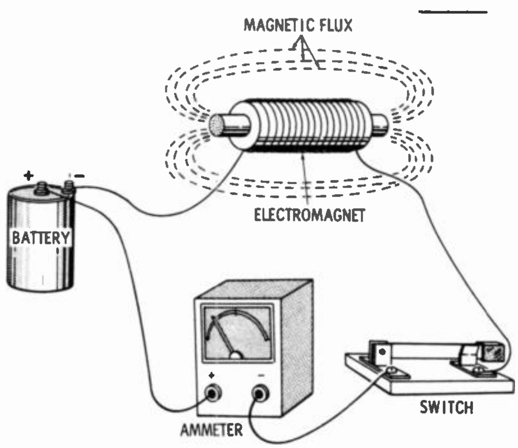
Fig. 1-9. Pulsating DC waveform from a practical DC generator.

the polarity of the brushes reverses (plus becomes minus and minus becomes plus) so that the current is always flowing in the same direction. The output is known as *pulsating DC*. It is DC since it always flows in the same direction. It pulsates because of the rotation of the loop through the magnetic field.

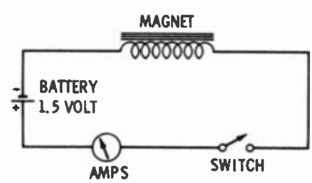
If many more loops are added, each with their own set of commutators, then the pulsating DC will be smoother, as shown in Fig. 1-9.

COILS AND MAGNETISM

One method of putting an electric current to work is with an electromagnet. This is simply a coil of wire wound around a rod of soft iron. The magnetic field normally generated by the flow



(A) Pictorial presentation.



(B) Schematic presentation.

Fig. 1-10. The simple electromagnet.

of electric current through the coil is concentrated by the iron core. Fig. 1-10A is a pictorial presentation of such a circuit; Fig. 1-10B shows the *schematic* equivalent. A pictorial drawing shows the physical appearance and locations of electronic components. A schematic is a kind of electronic road map that presents the circuit in a clearly understandable form. The symbols used in a schematic are always the same for individual components, no matter what their physical size or electrical characteristics or how complex the circuit may be. The most commonly used electronic symbols appear in Chart 1-1 at the end of this chapter.

When the switch is closed completing the circuit in Fig. 1-10, current begins to flow, but because of the power needed to build up the magnetic field, the maximum amount of current possible does not flow immediately. It takes a certain length of time for the magnet to build up its field, and because of this, a graph of the current flow would look something like Fig. 1-11. Once the current flow reaches its peak, the magnetic field is up to full strength, and current continues to flow through the circuit undiminished. If the switch is opened, the magnetic field will collapse, and the collapsing lines of magnetic force will cut through the wires of the coil, generating more electrical current. Gradually it will diminish until the field has entirely collapsed. The decay of the current flow is also shown in Fig. 1-11.

Because of its ability to concentrate the magnetic field, the iron core actually causes more power to be consumed in an AC circuit than the coil would by itself. If the iron core is removed from the coil in an AC circuit, the reading on the ammeter will increase, indicating increased current flow. This is a useful characteristic, and how it is used in radio will be shown later.

When an alternating current is used as the power source for this electromagnet, the magnetic field around the magnet builds up and collapses continuously. The actual rate at which the field changes depends on the type of iron core used, the number of wire turns, and the diameter of the wire and the core. If these values

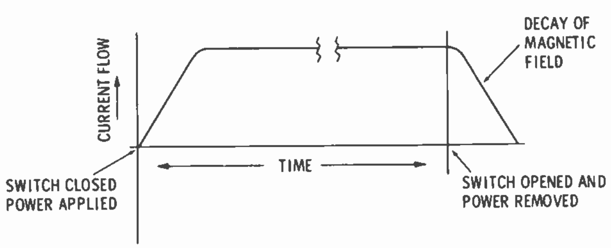
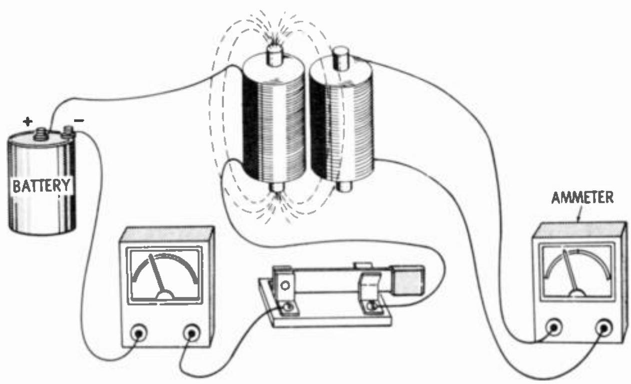


Fig. 1-11. Graph of current flow in an electromagnet when power is applied.

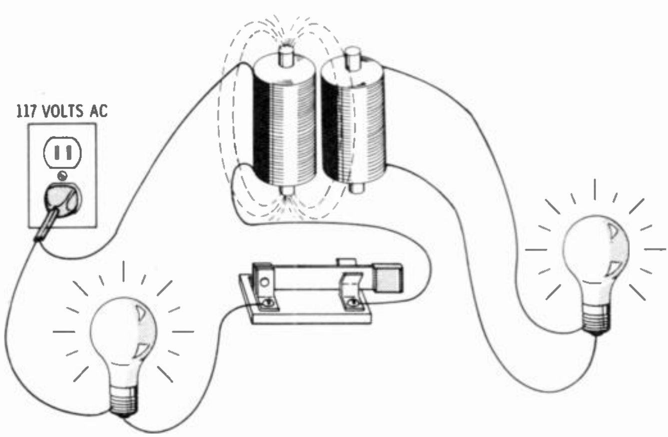
are properly selected, the build-up and decay of the magnetic field will not lag behind the applied voltage by an appreciable amount, and the coil can be made to do useful work.

TRANSFORMER ACTION

If a second electromagnet is brought near the first (Fig. 1-12A) and a direct current is applied to the left magnet, the lines of the magnetic field, as it builds up, will cut the conductors in the right coil, thus generating an electric current in the coil as long as the magnetic field is in motion. When the field reaches its maximum



(A) With DC applied to primary coil.



(B) With AC applied to primary coil.

Fig. 1-12. Principle of the transformer.

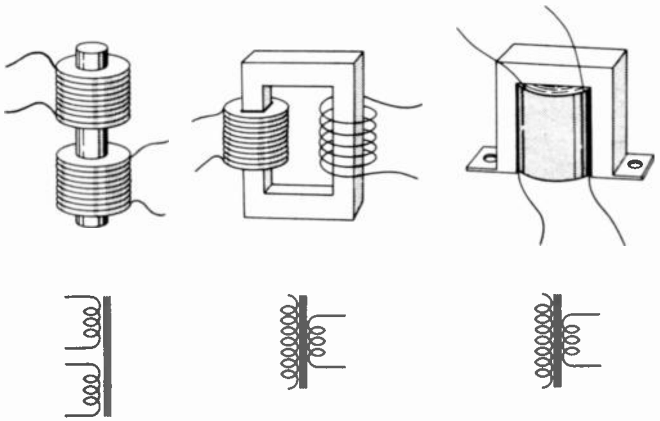


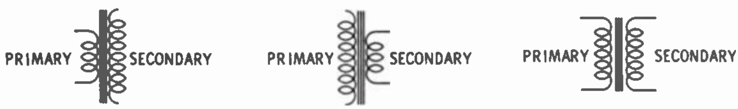
Fig. 1-13. Pictorial and schematic presentations of different types of transformers.

equilibrium point, it is no longer in motion and the current flow in the second coil drops to zero. When power in the left coil is interrupted by opening the switch, the field collapses, lines of force cut the conductor of the second coil, and a current is once again induced to flow in the second coil until the field has completely collapsed.

If AC instead of DC is applied to the first coil, the magnetic field will continually build up and collapse, and a continuous alternating current will be *induced* in the second coil. These two coils then form a basic *transformer*. The first coil, which is driven by input power, is called the *primary*; the second coil, which has power induced in it, is called the *secondary*. Several types of transformers are shown in Fig. 1-13.

Transformers can serve many functions. The first application is as a step-up device where higher voltages are required. It can actually change the voltage from one level to another. This change depends on the ratio of the number of turns on the primary to the number of turns on the secondary (Fig. 1-14).

In a typical application, there may be 100 volts available and 300 volts are required. The primary to secondary ratio must be



(A) Step-up. (B) Step-down. (C) Isolation or 1:1.

Fig. 1-14. Schematic presentation of turns ratios on step-up, step-down, and isolation transformers.

1:3, such as 100 turns of wire on the primary and 300 turns on the secondary. This will provide 300 volts on the secondary when 100 volts are applied to the primary. But you can not get something for nothing so there will be a corresponding drop (3 to 1) in current. If the current at the primary is 3 amperes, the current at the secondary will be 1 ampere. The total power at the primary and secondary will be the same—300 watts.

This should make the transformer a perfect machine, doing work without the loss of energy that is normally expected in a mechanical device because of friction. To tell the truth, there are losses in the transformer due to *hysteresis* (resistance of the soft iron to changes in its magnetic state) and the electrical resistance of the wire in the coils. But the transformer is still a highly efficient machine, and efficiencies of 95% or more are commonplace. Many of the better-quality transformers have efficiencies of 98 and 99%, a figure that is so high that in most calculations, 100% efficiency is assumed for the device.

Transformers are also used for step-down applications where a lower voltage is required. The action is exactly the same as for the step-up transformers—the change in voltage corresponds to the ratio of the turns of wire on the primary and secondary. This time the voltage is stepped down and the current capability is increased by a corresponding ratio.

A third type of transformer has equal turns on both the primary and secondary. This type of device is frequently called an *isolation transformer*, since its function is to electrically isolate one portion of a circuit from another, even though a transfer of energy is required. This type of transformer is frequently used for coupling the power lines to a power supply.

RESISTANCE

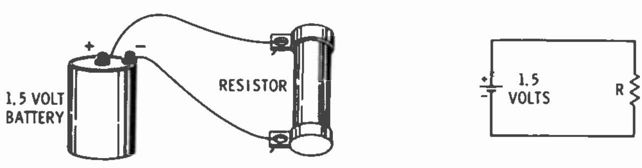
Every conductor, no matter how freely electrons may move through it, has a certain amount of *resistance*. This is the electrical equivalent of friction, and just as the name implies, it is resistance to the flow of electric current. It depends on four factors:

1. Temperature
2. Coefficient of resistance
3. Length
4. Cross-section area

The coefficient of resistance is a constant for any material. For example, the coefficient of copper is smaller than bakelite, which has few free electrons. In most materials, the resistance increases as the temperature increases; an increase in the length also increases the resistance. The cross-section area of the material has the opposite effect. As the area increases, the resistance decreases.

Since resistance is the electrical equivalent of friction, it naturally dissipates some of the electrical energy flowing through it, and this energy is transformed into heat. An example of such a resistance is the tungsten filament in an electric bulb. The filament has a very high resistance and the passage of current causes it to become extremely hot. In this case, some of the heat takes the form of visible light. The heating elements in an electric toaster or an electric iron are other typical applications of useful resistance-caused heat.

In electronics specific amounts of resistance are often required at various points in a circuit; the fact that a resistance uses up some energy can be a useful factor. To see how this works, look at Fig. 1-15. Here, a single resistance is connected across the terminals of a 1.5-volt battery. The change in voltage across the resistor, called the *voltage drop*, is 1.5 volts, since it is connected



(A) Pictorial presentation. (B) Schematic presentation.

Fig. 1-15. Example of voltage drop across a resistor.

directly to the battery terminals. If the resistor draws 1.5 amperes of current, then the resistance is 1 ohm. This follows *Ohm's law,* which states that the current (in amperes) is equal to the electromotive force (in volts) divided by the resistance (in ohms).

The common form is:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

or

$$I = \frac{E}{R}$$

At first glance, two of the letters in the formula seem to have little relationship to their meaning. The I which designates current is a purely arbitrary symbol, chosen because it would cause no conflict with other letters, such as A for area and C for capacitance. In electronics, I always means current, and it is always measured in amperes.

The letter E is not quite so arbitrary. It stands for *electromotive force,* frequently called *emf.* By definition this means voltage. The third letter, R, is easy enough to remember, since it stands for resistance.

Series Circuits and Kirchhoff's Laws

With Ohm's law it is possible to determine any one of the three elements in a DC circuit, as long as the other two are known or can be found. The ohm, which is a measure of resistance, is usually indicated by the Greek letter omega (Ω), and this symbol will be used throughout the book.

When two resistors are connected in series (Fig. 1-16), the total resistances add. In this circuit, R1 is 10Ω and R2 is 30Ω.

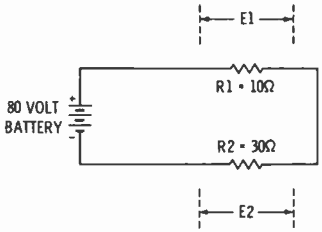


Fig. 1-16. Voltage drop across series resistors.

Since series resistances add, the total resistance of the circuit is 40Ω. The battery supplies 80 volts, so the current in the circuit will be:

$$I = \frac{E}{R} = \frac{80}{40} = 2 \text{ amperes}$$

This 2-ampere current is flowing equally throughout the circuit. The current in a series DC circuit is always the same throughout the circuit. This is one of Kirchhoff's laws and will be very useful in many radio calculations.

Resistors have a different effect on voltage. If a voltmeter is connected across R1 in Fig. 1-16, it will read 20 volts. Connected across R2, it will read 60 volts. The total of the two (20 plus 60) equals 80 volts, or the total applied voltage. This is Kirchhoff's other law for DC circuits; that is, the total voltages across all branches of a DC circuit will exactly equal the applied voltage at all times.

The amount of voltage drop across a resistor in a DC circuit is exactly proportional to the resistance. In this case, the ratio of R1 to the total resistance is 1:4; thus, it will drop one quarter of the total voltage. The ratio of R2 to the total resistance is 3:4, so it will drop three quarters of the total voltage.

By solving Ohm's law for the other two factors (E and R) you have these relationships:

$$E = IR \text{ and } R = \frac{E}{I}$$

Since the voltage (E) equals I times R, the voltage drop across a resistor or other component is frequently called the *IR drop*. These relationships will be useful for calculations in all phases of radio work.

Parallel Circuits

When two resistors are connected in parallel (Fig. 1-17), the voltage measured across the resistors is the same as the voltage measured across the battery—the points are electrically the same. The current, however, depends on the resistance of each element.

If, in Fig. 1-17, R1 is 10Ω and R2 is 20Ω, more current will flow through R1 than through R2, since electricity will always follow the path of least resistance. Applying Ohm's law:

$$I_1 = \frac{30}{10} = 3 \text{ amperes}$$

This is I_1, the current flowing through R1. The numbers after the symbols are used to tell one component from another when there is more than one such part in a circuit. Thus, R1 and R2 designate two different resistors in the same circuit. I_1 is the current through R1, and I_2 is the current flowing through R2. E_1 would be the voltage drop across R1, which is the same as across R2 in parallel resistances.

In Fig. 1-17 the current through R2 is:

$$I_2 = \frac{30}{20} = 1.5 \text{ amperes}$$

To determine the resistance of such a circuit, there is a simple rule when only two resistors are involved. Remember that resistors in series *add*; in parallel, the situation is quite different. The smallest resistor (R1) is 10Ω, and most of the current (3 amperes) flows through this resistor. However, not all of the

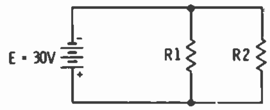


Fig. 1-17. Voltage drop across two parallel resistors.

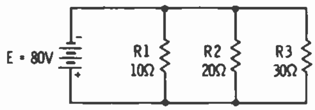


Fig. 1-18. Voltage drop across three or more parallel resistors.

current will flow through R1, since there is an alternative path through R2. The addition of R2, even though it is larger than R1, will have the effect of lowering the resistance of the circuit. To find the total effective resistance of a two-resistor parallel circuit, first multiply the two resistances together, then divide by their sum. The operation looks like this:

$$R_T = \frac{R1 \times R2}{R1 + R2} = \frac{10 \times 20}{10 + 20} = \frac{200}{30} = 6.67\Omega$$

R_T, the total resistance of the circuit, is 6.67Ω, quite a bit less than the 10Ω of R1. This method of dividing the product by the sum is really just a simplification of the standard formula for resistances in parallel.

If three or more resistors are wired in parallel (Fig. 1-18), then the method is a little more complicated. The general formula for this is:

$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \text{ (etc.)}$$

R_T is the total circuit resistance, R1 (Fig. 1-18) is 10Ω, R2 is 20Ω, and R3 is 30Ω. Substituting resistance values in the formula, you have:

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30}$$

$$= \frac{6 + 3 + 2}{60} = \frac{11}{60}$$

$$\frac{1}{R_T} = \frac{11}{60}$$

$$R_T = \frac{60}{11} = 5.45\Omega$$

Again, this total circuit value is smaller than the smallest resistor, and this will always be the case in parallel resistance circuits. There is a shorthand method of handling the three parallel resistors. It is a variation of the product-divided-by-the-sum method. Take any two resistors from the circuit, such as R1 and R2. Disregard R3 for the moment. The circuit resistance for R1 and R2 will be:

$$R = \frac{10 \times 20}{10 + 20} = \frac{200}{30}$$

$$= 6.67\Omega$$

Now, combine this value of R with the third resistor (R3) in the same way:

$$R_T = \frac{6.67 \times 30}{6.67 + 30}$$

$$= \frac{200.1}{36.67} = 5.46\Omega$$

This is the total circuit resistance. Since the methods used were somewhat different, there is a small difference in the answers, but if the results are rounded off to one decimal place, they will be the same for both methods: 5: 5Ω. Generally speaking, an accuracy greater than two significant figures is not required for resistors in radio work.

Power Ratings

Commercially manufactured resistors come in a variety of packages, depending on the type and purpose. The two most common types are *wirewound* and *deposited carbon*. Examples of these two types are shown in Fig. 1-19.

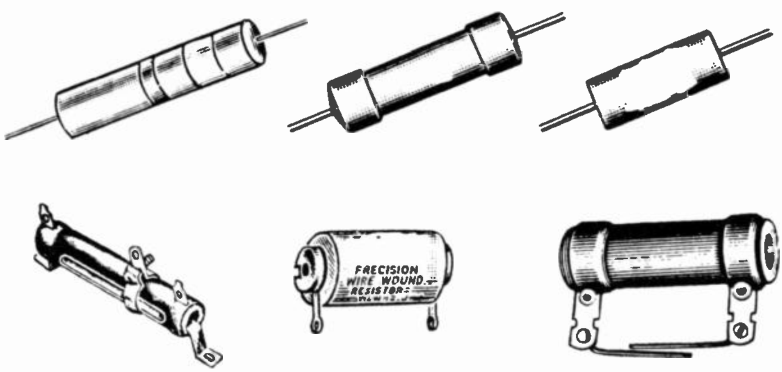


Fig. 1-19. Examples of typical resistors.

Wirewound resistors are usually used for one of two reasons: they can be made with extremely high accuracy and can be sealed in insulating materials with high heat-dissipating ability. This second reason is very important in high-powered circuits where the resistor gets very warm in operation. To prevent the heat from damaging the resistor or changing its value, the package is designed to radiate a great deal of heat. The ability of a resistor to handle power is called its *power rating* and is measured in *watts*. A typical power resistor is made to handle 50 watts, and in operation it may be so warm that touching it can cause a burn.

When selecting a resistor, the power rating is a very important consideration. A safety factor must be taken into account for all resistors. If it is going to dissipate 10 watts of power and it will be in a well ventilated location, then the recommended safety factor is 2. This means that a 20-watt resistor should be used. If it is going to be in a poorly ventilated location, such as the underside of a radio chassis, then the safety factor is 4, and in this case a 40-watt resistor should be used. This is a good reason for mounting power resistors above the chassis whenever possible. It is more economical (higher power resistors cost more) and there is less chance of heat damaging other components.

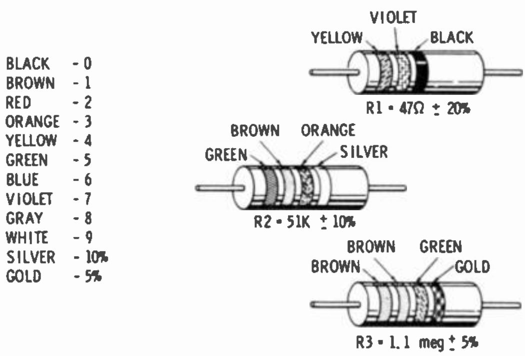


Fig. 1-20. EIA system for color coding resistors.

Carbon resistors are generally rated from .25 watt to about 5 watts. Occasionally you may come across some other ratings, but these are usually made to order for a specific purpose. Carbon resistors generally have no printed value markings of any kind. The power rating is determined by the physical size of the component. The resistance value and *tolerance* (amount of variation possible above and below the indicated resistance) are indicated by bands of color printed on the resistor body. These stripes correspond to the EIA (Electronics Industries Association) *color code* and are in common use in the United States.

The color code is shown in Fig. 1-20. Starting from the end, the first band is the first number, the second band is the second number, and the third band is the multiplier (number of zeros). The fourth band is the tolerance. In Fig. 1-20, R1 has three bands. The first is yellow (4), the second is violet (7), and the third is black (0). This means that the resistor is 47Ω, and since there is no tolerance band, the tolerance is ±20%.

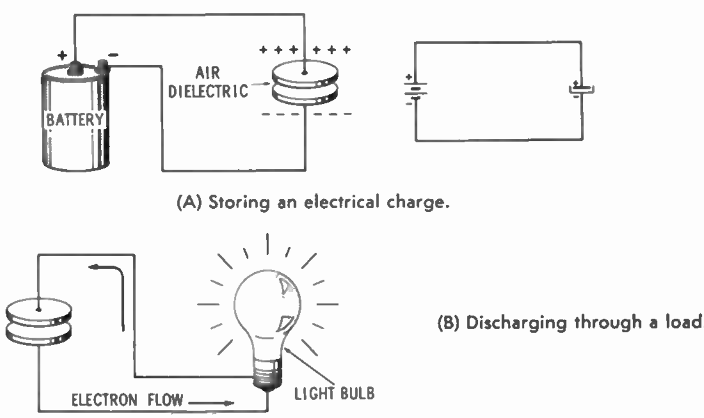
In the same figure, the color bands of R2 are green (5), brown (1), orange (3) and silver (10%). Thus the resistor is 51,000Ω with a tolerance of ±10%. The value 51,000Ω is frequently written in electronic shorthand as 51kΩ, (k = kilo, and kilo = one thousand), or simply as 51K.

The third resistor (R3) has the color bands brown, brown, green and gold. This gives it a value of 1,100,000Ω with a tolerance of ±5%. Here again, there is a shorthand way of writing the number. A million ohms is called a *megohm*, abbreviated as *meg*. In radio terminology, R3 would be called a 1.1 meg resistor. The prefix *mega* means a million times and will be used quite frequently in later chapters.

CAPACITANCE

An important component in electronics is the *capacitor*. This is also frequently called a *condenser*, but it really does not condense anything. A capacitor is essentially made of two flat plates of a metal separated by an insulator. This insulator is called the *dielectric* and can be made of such materials as air, glass, mica, and certain plastics.

The capacitor shown in Fig. 1-21 will store an electrical charge when it is connected to a battery. When the connection is made, electrons from the negative side of the battery start to flow to the lower plate of the capacitor. Electrons on the opposite plate are repelled by these electrons (remember that like charges repel) and move across the conductor to the positive side of the battery. If the capacitor is then removed from the circuit, it is charged—one plate is positive and one plate is negative—and this charge can be released through a load such as a light bulb (Fig. 1-21B). The bulb will glow only for an instant, just long enough



(A) Storing an electrical charge.

(B) Discharging through a load.

Fig. 1-21. Principle of a capacitor.

for the excess electrons to rush through the filament to the positive plate of the capacitor. As soon as the number of electrons on each plate is the same, the capacitor is said to be *discharged*, and it will remain this way until another charge is put on the plates.

Some capacitors, such as the very large filters used in TV sets, can maintain a high charge for a long period of time. Their charge is sufficient to cause severe shocks and can possibly kill a person who is unlucky enough to touch them, even though the power is disconnected.

The capacitance, the ability of a capacitor to store an electric charge, is measured in *farads*. The farad is an extremely large unit, so for convenience, capacitance is usually spoken of in *microfarads*. A microfarad is one millionth of a farad, and the symbol for this unit is μf.

The μ is the Greek letter "mu" and in this case means *micro*. Because many typewriters and printers do not have the μ, it is common practice to print microfarads as uf, mf, or mfd. But the only really correct way of writing it is μf.

An even smaller unit is the micromicrofarad. This is one farad $\times 10^{-12}$ and is a convenient size for high-frequency applications. A common abbreviation for this is mmf or uuf, but the correct symbol is $\mu\mu$f. Because micromicrofarad is an awkward term to handle, a new prefix, *pico* has come into use and is now fairly common. Thus, a 20 micromicrofarad capacitor is 20 picofarads, abbreviated 20 pf. Both methods are equally correct, but the $\mu\mu$f is obsolescent and is rapidly giving way to the easier-to-handle term pf.

Capacitance is determined by three factors: the area of the plates facing each other, the dielectric constant of the insulating material, and the distance between the plates. The larger the area of the plates, the greater is the capacitance. The dielectric constant refers to the amount of insulation a material provides between the two plates. The greater the distance between the plates, the smaller is the capacitance, since a greater distance will be between the charged fields of negative (electrons) and positive charges (protons).

The dielectric constant of air is 1. The constant for other dielectric materials is much greater. If two plates when separated by air have a capacitance of 10 μf and a sheet of glass is sandwiched between the plates the capacitance may increase to as much as 90μf.

Breakdown in an air-dielectric capacitor simply means that the electric charge will *arc* (form a spark) across the plates, short-circuiting them. The capacitor will still be the same after the arcing has taken place, but breakdown in other types of capacitors is catastrophic, since the carbon deposit produced by the arc will form a conducting path through the dielectric and make the capacitor useless.

Capacitors are manufactured commercially with aluminum foil as the plates and very thin wafers of glass, mica, plastic or layers of waxed paper sandwiched between the foil as the dielectrics. A common type of capacitor is the *paper tubular*, which is made by rolling up the foil and waxed paper into a tube.

The name given to a type of capacitor is taken from the dielectric material used. Thus there are mica capacitors, glass capacitors, bakelite, ceramic, etc.

Usually a safe voltage for a capacitor is selected. This voltage, called the *working voltage*, is far enough below the breakdown voltage that no damage will result when it is placed across the plates. It must be specified along with capacitance.

A variation on the two-plate capacitor is the *electrolytic* capacitor. In this type of component there is a single sheet of aluminum foil in a liquid such as an aluminum compound. This compound acts as the other plate of the capacitor and the dielectric is formed by passing an electric current (DC) through the capacitor. This causes some of the aluminum to oxidize on the foil, forming aluminum oxide which is the dielectric. Since the dielectric made this way is extremely thin, the effective distance between the "plates" of the capacitor is very small and the capacitance is quite large for a small-size unit. Electrolytics are very temperamental and frequently go bad, thus requiring replacement. The liquid is usually semisolidified by other additives, and such a capacitor is called a *dry electrolytic.*

CAPACITORS IN CIRCUITS

If two capacitors are connected in parallel (Fig. 1-22), the effect is the same as adding the plate areas. Thus, capacitors in parallel *add* their capacitance. If C1 in Fig. 1-22 is 10 μf and C2 is 30 μf, then the total capacitance of the parallel circuit is 40 μf.

If the two capacitors are placed in series (Fig. 1-23), the smallest capacitance in the circuit will be the limiting factor. If C1 is 10 μf and C2 is 30 μf, obviously C1 cannot hold the same charge

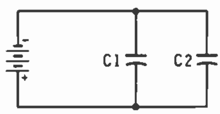


Fig. 1-22. Capacitors in parallel.

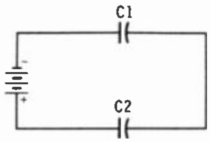


Fig. 1-23. Capacitors in series.

Fig. 1-24. Typical variable tuning capacitor.

as C2. The effect is to decrease the total capacitance of the circuit and the total capacitance can be found with the formula:

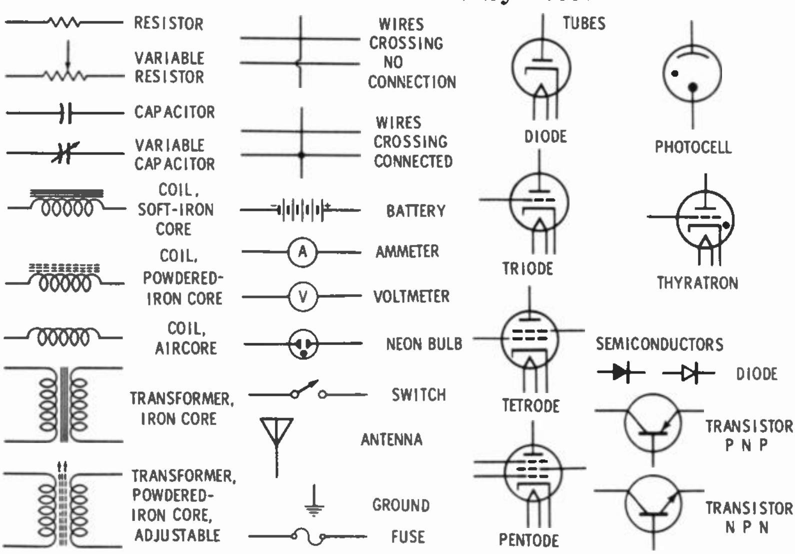
$$\frac{1}{C_T} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} \text{(etc.)}$$

Look familiar? The relationship is exactly the same as resistances in parallel, and the same mathematical tricks can be used to find total capacitance. The C_T of the circuit in Fig. 1-23 is:

$$C_T = \frac{10 \times 30}{10 + 30} = \frac{300}{40} = 7.5\ \mu f$$

One valuable aspect of capacitors is the ease with which the total capacitance can be varied. This characteristic is useful in adjusting tuned circuits. A typical variable air-dielectric capacitor of the type used in radio sets is shown in Fig. 1-24. This type of capacitor varies the area of the plates that are opposite each other. Other types may vary the distance between the plates. The use of capacitors in tuned circuits is explained in the next chapter.

Chart 1-1. Schematic Symbols



Chapter 2

RADIO WAVES, TRANSMITTERS, AND RECEIVERS

Heinrich Hertz, called by many the father of radio, experimented with a device called a spark coil. This was basically the same type of coil used in today's automobiles to change the low-voltage direct current provided by the battery into high-voltage alternating current.

The spark coil was little more than a curiosity in Hertz's day; it could perform interesting scientific parlor tricks like making an electric spark jump across the gap between two balls that formed a break in the circuit. But Hertz went one step further; he formed the wires leading to the metal balls into a square loop (Fig. 2-1). He then placed another square loop the same size with its own spark gap near the first one. There was no electrical connection between the two loops, yet when a spark jumped across the gap in the first, another spark formed across the gap

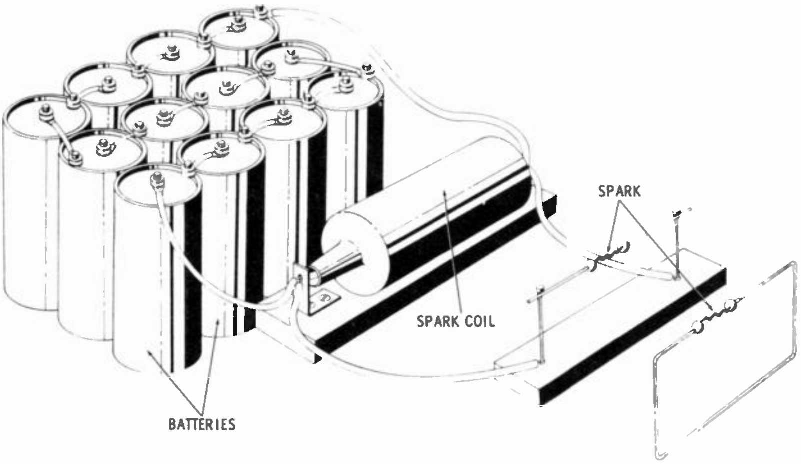


Fig. 2-1. Hertz demonstration showing principle of radio-wave transmission and reception.

in the second, as shown in Fig. 2-1. This was the first known case of radio transmission.

ALTERNATING CURRENT

Ordinary house current is commonly known as *alternating current* (abbreviated AC). It is called *alternating* because the current keeps reversing itself. First it flows in one direction and then the other. One complete *cycle* of an alternating current is the time it takes for the current to start flowing, build up to a maximum, drop back to zero, and then repeat the process in the other direction. The graph of this current flow (Fig. 2-2) is called a *sine wave* and is typical of all alternating currents and radio waves.

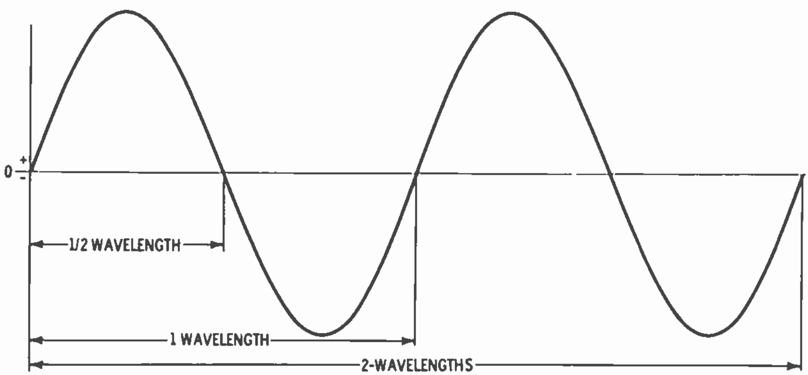


Fig. 2-2. Graph of alternating current.

The AC available in the United States alternates at the rate of 60 cycles every second. This rate of alternation is called the *frequency,* and the frequency here is 60 cycles per second (abbreviated 60 cps).

If an electromagnet is connected to a 60-cycle AC source, its magnetic field will build up and collapse 120 times each second. Another, similar electromagnet placed in the field of the first magnet (Fig. 2-3) will be affected by the changes in the field.

As the field of the first magnet builds up and collapses, an alternating current is *induced* in the second electromagnet. This is true even though there is no electrical or physical connection between the two. This electromagnetic transfer of energy is the same as the transfer of energy that caused the spark to jump the gap in Hertz's second loop. Radio transmissions use vastly refined versions of this electromagnetic induction principle, but, basically, they are the same.

When a high-voltage spark jumps across a spark gap (Fig. 2-1), a strong electromagnetic field builds up. Part of the wire loop can be run outside and strung between two poles or other high structures. This wire, which is part of the spark system circuit, will radiate the alternating magnetic field, and this field can be detected many miles away. This length of wire is known as the transmitting *antenna*.

The antenna radiates most strongly in the direction that it is facing (Fig. 2-4) and the length of the antenna is very important.

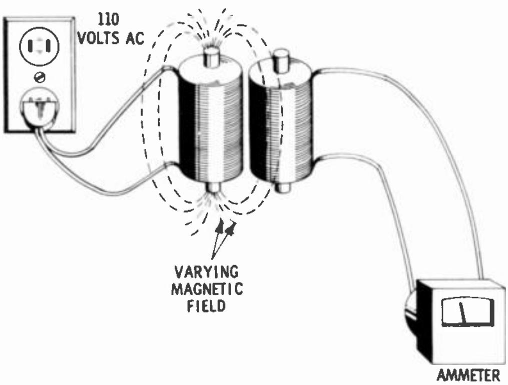


Fig. 2-3. Example of induced current.

Ideally, it should be equivalent to one *wavelength* at the frequency being transmitted.

The wavelength depends on the frequency—as the frequency increases the wavelength decreases. One simple formula governs this relationship:

$$c = f\lambda \text{ or } \lambda = \frac{c}{f}$$

where,

c = the velocity of light in meters per second (300,000,000),
f = the frequency in cycles,
λ = the wavelength in meters.

If the frequency (f) of a transmitter is 100,000 cycles (100 *kilocycles*), the wavelength (λ) is:

$$\lambda = \frac{300{,}000{,}000}{100{,}000} = 3{,}000 \text{ meters}$$

The wavelength for a 100,000-cycle frequency is 3,000 meters (about 3,280 yards). An antenna this long would be very cumbersome and expensive to build. A method that is frequently used is to cut the antenna to one-half the wavelength (1,500 meters) or even one-quarter wavelength (750 meters). Such antennas are called half-wave or quarter-wave antennas.

As the frequencies get higher, the wavelength decreases and so does the necessary length of the antenna. The same holds true for receiving antennas. By way of comparison, VHF television signals, which go from 54 megacycles to 216 megacycles are received by a quarter-wave antenna—the rooftop type that is in common

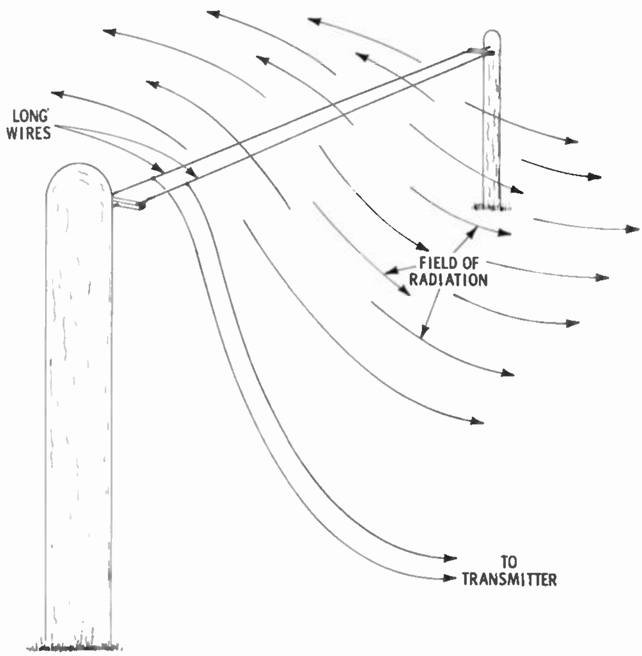


Fig. 2-4. Example of antenna showing field of radiation.

usage. Actually, this antenna is a compromise, since there is a wide range of frequencies involved. Its length is approximately midway in the range of wavelengths being received. For really good TV reception on the higher frequencies (Channels 7 through 13), a very small antenna should be used; in TV "fringe" areas, this upper-channel antenna is frequently mounted on top of the low-channel antenna.

In spark transmitters the frequency of the transmitted signal depended on the number of turns of wire in the spark coil and on the associated components. A typical frequency for a spark-type transmitter is about 100,000 cycles per second (100 *kilocycles*).

In Marconi's early experiments the spark discharge was set off by a telegraph key, and it was this system that was first used for wireless telegraphy. The discharge could not be maintained for very long, since it depended on the rate that a high-voltage capacitor (a device for storing electricity) could be charged up and discharged.

For this reason Marconi started using rotating alternators. With these units, (they were something similar to an electric generator) he was able to get somewhat higher frequencies, and most important, he had a constant source of power for the spark discharge. He was actually able to communicate across the Atlantic Ocean with this crude transmitter.

VACUUM TUBES

The development of the vacuum tube revolutionized radio design and operation. The vacuum tube circuit can be made to *oscillate*, that is to make an electrical signal alternate at very high frequencies—much higher than could ever be obtained with mechanical alternators.

If the microphone in a public-address system accidentally gets in front of a speaker, as shown in Fig. 2-5, some of the sound from the speaker is picked up by the microphone. This signal is boosted by the amplifier, comes out the speaker, back through the microphone again, and so on until the result is a loud squeal, which is really an oscillation taking place at an audio frequency. The sound from the speaker that is picked up by the microphone is called *feedback*.

Something of this sort happens in a vacuum-tube oscillator, but here the signal is electronic instead of acoustic, and the frequencies involved are much higher.

In an oscillator tube, some of the signal is picked up from the tube output circuit (the plate circuit) and is fed back to the tube input (the grid circuit). When certain circuit conditions are met, this action causes an oscillation to occur.

The tube circuit oscillates by taking some of the voltage from the output (plate) and feeding it back to the input (grid). This *feedback* causes oscillation. The frequency at which the oscillations occur depends on the *tuned circuit* at the input. A tuned circuit consists of a coil and a capacitor either in parallel (Fig. 2-6A), or in series (Fig. 2-6B). The parallel-tuned circuit (Fig. 2-6A) is also sometimes called a *tank circuit;* it is the type that is normally used in oscillator inputs.

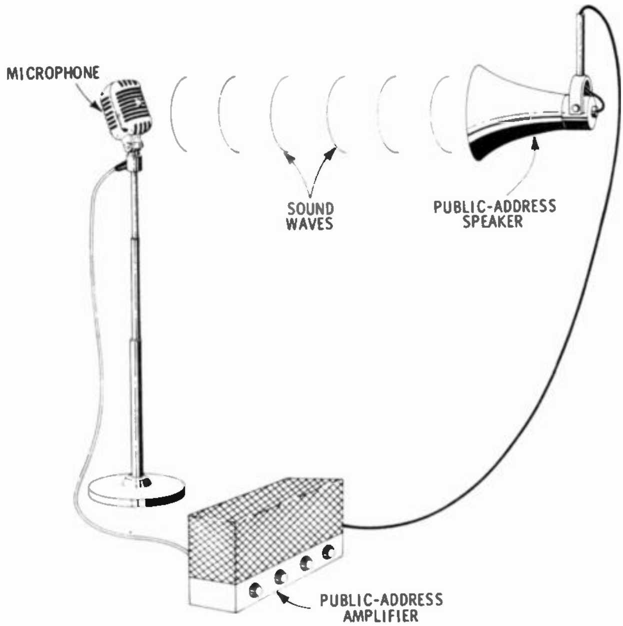
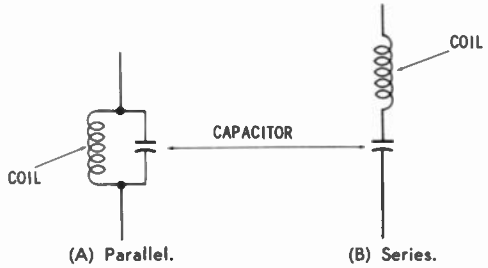


Fig. 2-5. Example of feedback in a public address system.

The tuned circuit has a natural resonant frequency, and it is at this frequency that the circuit oscillates. The output voltage is usually too weak for radio transmission, so it goes through several *stages* (sections) of amplification.

A vacuum tube is a versatile device. As an amplifier it can take a very weak signal voltage and boost it many times. In a transmitter the oscillator signal is boosted through several vacuum-tube amplifiers until it is at a level high enough to broadcast. The output of the last tube (called the power amplifier) then



(A) Parallel. (B) Series.

Fig. 2-6. Example of tuned circuits.

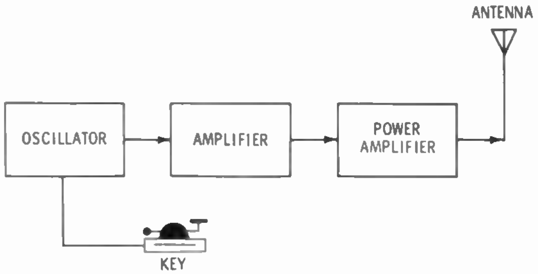


Fig. 2-7. Block diagram of a simple transmitter.

goes to the transmitting antenna (Fig. 2-7). The field radiated here is very much like the magnetic field that surrounded Hertz's spark-gap device, but with several differences. In the first place, because a vacuum-tube oscillator is used, the frequency of the transmitter can be much higher than for a spark-type unit. The added stages of amplification make it possible to build a transmitter of very high power—sufficient to reach all the way around the globe if necessary. The tubes can be controlled much more easily than a spark, so high-speed telegraph keying, or teletype transmission is possible. And the frequency can be controlled so it will not vary the way a spark transmitter frequency does. This feature is called *frequency stability.*

TRANSMITTING VOICE

Another advantage of the vacuum tube is the fact that it can be controlled in a very special fashion. If a voice signal from a microphone (Fig. 2-8) is fed into one of the transmitter amplifier tubes, it can control the strength of the output voltage from that tube. This process is called *modulation,* and since it controls the signal level or *amplitude,* it is called *amplitude modulation* (AM).

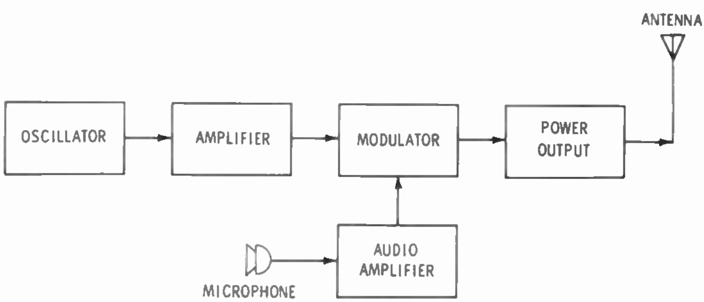
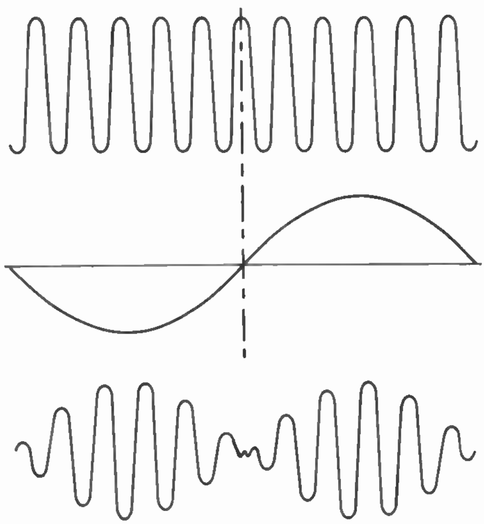


Fig. 2-8. Block diagram of a simplified audio-modulated transmitter.

The amplified oscillator signal from a radio transmitter is called the *carrier*. The signal from the microphone is called the *audio* signal, and this audio signal modulates (changes) the carrier as shown in Fig. 2-9. The amplifier stage where this takes place is called the *modulator* (Fig. 2-8).

SOUND WAVES

The audio (sound) signal that modulates a transmitter originates at the microphone. The microphone is simply a device that



(A) RF carrier waves.

(B) Audio signal.

(C) RF modulated by audio signal.

Fig. 2-9. Diagram showing audio modulation of an RF carrier.

converts sound waves, which travel in the air, into an electrical signal voltage. A vibrating violin string or a vibrating vocal cord cause compressions of the air which, in turn, make the diaphragm of the microphone vibrate (Fig. 2-10).

The diaphragm in a dynamic microphone moves a coil of fine wire through the field of a permanent magnet, generating an audio signal voltage in the coil as shown in Fig. 2-10. The audio signal is usually too weak to use directly to modulate the transmitter, and therefore, it is fed to an audio amplifier. This is something like the amplifier used in high-fidelity systems, and it does the same thing as a hi-fi amplifier—it boosts up the weak audio voltage to a usable level.

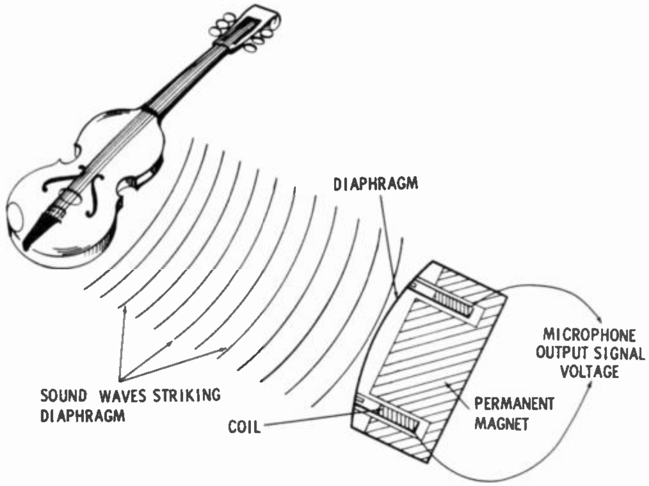


Fig. 2-10. Operating principle of a microphone.

The audio-amplifier output is applied to the grid of the modulator tube as shown in Fig. 2-11.

Another feature of the transmitter shown in Fig. 2-11 is the *frequency multiplier,* in this case a *frequency doubler.* This is used to increase the frequency above the oscillator frequency. In many cases an oscillator cannot operate at a high enough frequency for broadcast operation. Every oscillator, in addition to putting out a *fundamental* frequency, also generates *harmonics* (Fig. 2-12). These harmonics are multiples of the fundamental

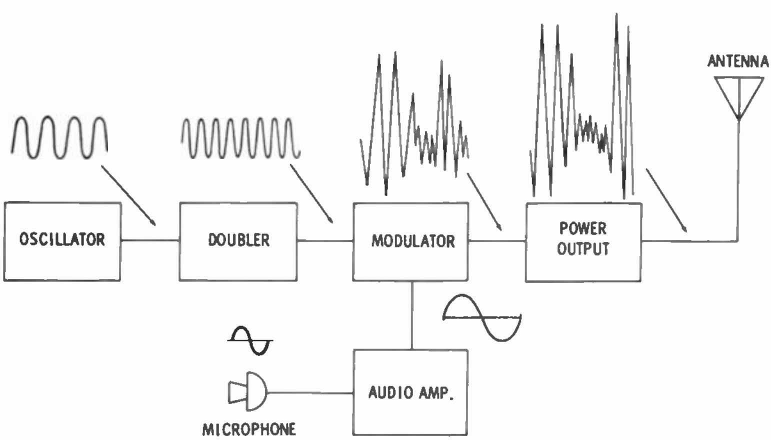


Fig. 2-11. Block diagram of an audio-modulated transmitter.

frequency and can be used or rejected by proper design of the later stages in the transmitter.

If the fundamental is 1 megacycle (this is one million cycles per second and is abbreviated mc) and a frequency of 2 mc is required, then a frequency doubler is used. This picks off the *second harmonic* of the fundamental frequency by using selective tuned circuits. All of the other frequencies are trapped or shunted out of the circuit.

In the same transmitter, if a 3-mc frequency is required, the multiplier tank circuit is tuned to 3 mc, and it is called a *tripler*.

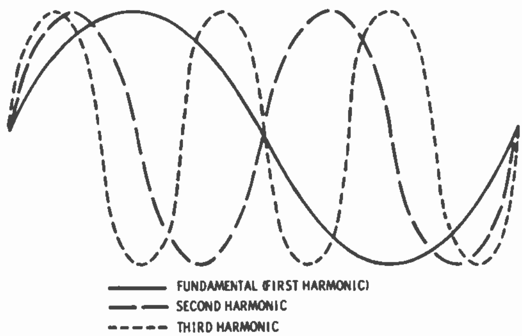


Fig. 2-12. Diagram showing harmonics of a fundamental frequency.

Sometimes, if there is not enough signal gain (amplification) and a harmonic such as 4 mc is needed, the transmitter will use two doublers. The first doubler takes the 1-mc oscillator frequency and produces 2 mc. The second doubler, in turn, selects the second harmonic of 2 mc which is 4 mc. The frequency output of two doublers is at a much higher voltage level than the output of a single *quadrupler*.

SIGNAL PATHS

The most common type of transmission is known as the *ground wave*. This is simply the radiated signal leaving the transmitter antenna, traveling a certain distance along the ground and being picked up by the receiving antenna (Fig. 2-13). This ground wave gives the clearest and strongest radio signal and is the type of transmission that is picked up when a radio is tuned to a local broadcast station.

The transmitting antenna really radiates in many directions, including up through the atmosphere. Most of the signal that is radiated upward is lost. It is either absorbed by the atmosphere, or it just keeps going into outer space. Part of the signal is reflected by the upper layers of the atmosphere. This layer, called the *ionosphere* or *Heaviside layer,* is made up of electrically charged particles which reflect radio waves that strike it at an angle back to earth. These waves are reflected back to the ground again at an angle, and a radio receiver located in the area where these signals strike the ground can receive the radio station, even though the receiver cannot receive the ground wave from the station (Fig. 2-13).

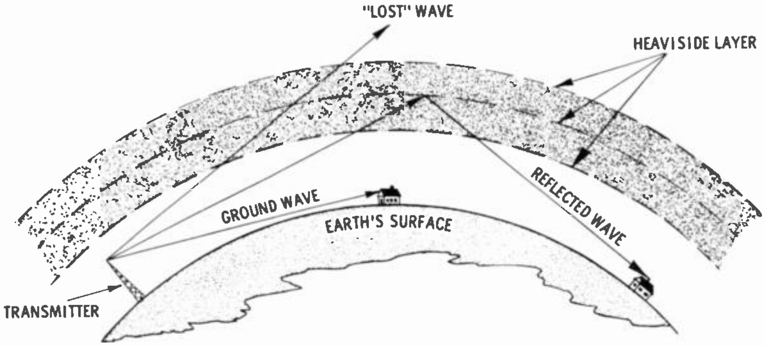


Fig. 2-13. Characteristics of radio waves.

Part of this reflected signal strikes the ground and is reflected back to the Heaviside layer again. If the transmitter output power is strong enough, the signal will continue to "bounce" around the earth in this fashion and can be received by sensitive receiving equipment many thousands of miles away.

At night, because of changes in atmospheric temperature at different altitudes, the Heaviside layer moves farther away from the earth, sometimes as much as several hundred miles. As a result of this shift, the first "hop" carries the reflected radio wave much farther away from the transmitter than it does during the day. For this reason it is possible to pick up commercial broadcast stations hundreds of miles away at night when it is impossible to receive them during the day.

At higher frequencies, such as those used for television and FM radio, the radio signals will not be reflected by the Heaviside layer at all. Instead, they will continue right through the outer atmosphere and into outer space or will be absorbed in the atmosphere. For this reason TV and FM broadcasts must have the receivers within what is called "line of sight" (Fig. 2-14). This means that the transmitter and receiver cannot be separated by the curvature of the earth. Such a type of transmission is the reason for television fringe areas—areas where the signal is just barely strong enough to be received by receivers connected to high antennas.

Sometimes, too, a mountain or other topographical obstacle will be between the transmitter and the receiver, and again, the broadcast cannot be received.

This line-of-sight transmission (Fig. 2-14) can be an advantage where security of transmission is involved. A system of very-high-frequency radiocommunications called *microwave* operates on

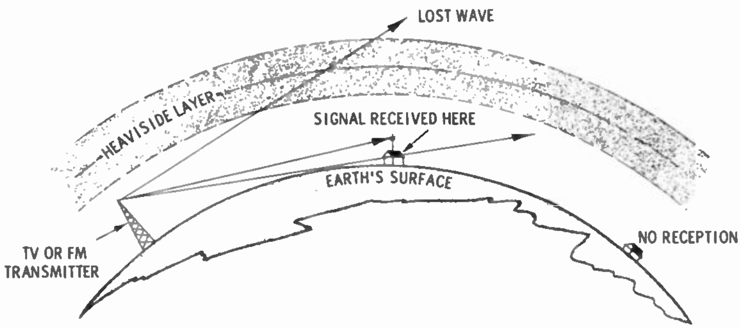


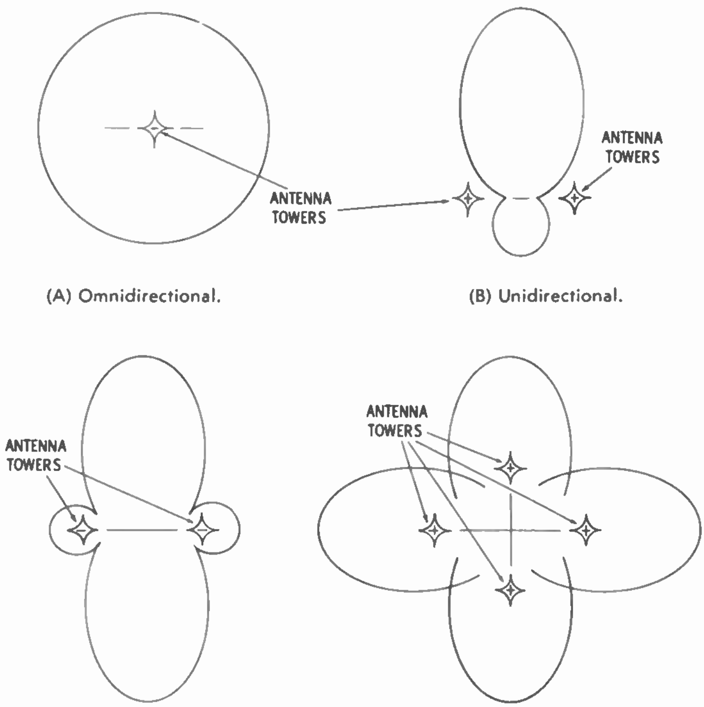
Fig. 2-14. Line-of-sight reception of higher frequencies.

this principle. Microwave radio signals are focused into a very narrow beam and pointed at another similarly focused receiving antenna 20 or 30 miles away. The microwave beam is very much like a searchlight beam in this respect. The transmission generally cannot be received by any other radio equipment unless it accidentally happens to be in the path of the microwave beam. Such high-security transmissions are used for relaying telephone calls and television channels cross-country instead of using the more common telephone and coaxial lines which are frequently difficult to set up and maintain.

ANTENNA RADIATION PATTERNS

The output of a transmitting antenna can be adjusted to have maximum output in any one direction, or it can have uniform field strength in all directions of the compass. An antenna that radiates equally in all directions, such as is normally used for standard AM broadcast, is called an *omnidirectional* antenna (Fig. 2-15A). If, for example, a transmitter is located near the seacoast, any power radiated out to sea from such an antenna (from a standard broadcast station) would be so much wasted energy. In this case it would be desirable to adjust the transmission pattern or transmission *lobes* of the antenna.

If a prime audience exists in only one direction from the antenna, all the power may be channeled in that direction, as shown in Fig. 2-15B. Such an arrangement is called a *unidirectional* antenna, but this type of pattern is very difficult to obtain for standard AM broadcasting. There are other patterns, such as the



(A) Omnidirectional.

(B) Unidirectional.

(C) Bidirectional.

(D) Omnidirectional using two bidirectional arrays.

Fig. 2-15. Antenna radiation patterns.

bidirectional where the two major lobes are directed outward from opposite sides of the antenna. The secondary lobes on the sides of a bidirectional antenna (Fig. 2-15C) are usually very low powered and only nearby receivers can receive any useful ground wave. Because of the efficiency of the bidirectional arrangement, broadcast stations frequently use two such patterns with the lobes positioned at right angles to each other, to obtain maximum coverage of their audience area (Fig. 2-15D).

THE RADIO RECEIVER

Radio waves are invisible. They fill the air, but without a receiver, it is impossible to tell they are there. A radio is a special kind of "trap" to catch some of these elusive radio waves and convert them into sound. Several common types of radio receivers are shown in Fig. 2-16.

The first element in a receiver is the *antenna*. Remember that the antenna was the last element in the transmitter. It was carefully cut to the length of the radio wave (or a half or a quarter of the wavelength), and it radiated the radio waves.

The antenna on the receiving end usually cannot be cut to a quarter wavelength—it is just too inconvenient, especially since you will be receiving many different frequencies (or wavelengths) and you cannot run outdoors and cut off a piece of the long-wire antenna (or add a piece) each time you want to change stations. Besides, a long-wire antenna is a nuisance most of the time, unless you are trying to get Paris, Peking, or Melbourne.

So the antenna on your set is a compromise—in most cases, just a special type coil of wire. It contains enough turns of wire to trap the radio signal and feed it to the first stage of your radio.

Crystal Radios

The earliest type of radio receiver for home use was the well known "crystal set." The crystal radio became so popular for

Fig. 2-16. Typical modern radio receivers.

the simple reason that no good and reasonably priced vacuum-tube receivers were available at the time.

The crystal radio had three parts: the antenna, tuned circuit, and crystal detector (Fig. 2-17). Since the set provided virtually no amplification, a pair of earphones had to be used.

While rather elaborate tuning arrangements were employed in a few sets, the tuned circuit in most of the sets in the 1920's was very crude. Generally, you "tuned" to a station by moving a clip or other metal fastener along the open loops of the coil and clipping it on when a station was heard. Then, if you wanted more volume, you would have to jiggle the "cat whisker" around on the galena crystal until you hit a sensitive spot.

The crystal was the detector. It separated the audio signal from the carrier, performing virtually the same function a vacuum-

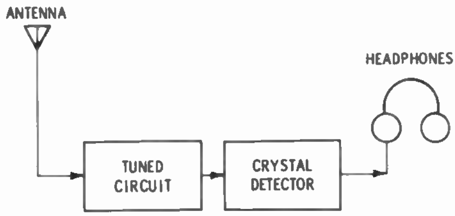


Fig. 2-17. Crystal set is simplest of radios.

tube diode does. Because of the crudeness of many of the crystal arrangements, and the amplification provided, the first vacuum-tube radios were very popular, even though they were more difficult to operate.

TRF Receivers

The first vacuum-tube radios were the TRF (tuned radio frequency) receivers (Fig. 2-18). The basis of the whole radio was

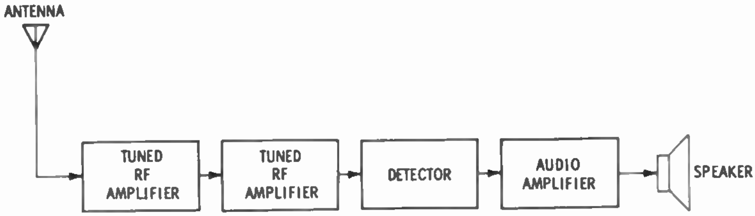


Fig. 2-18. Tuned-radio-frequency receiver uses several TRF stages.

the tuned circuit. Each stage (section) of the radio was a tuned circuit that had to be tuned separately to the frequency of the radio station. Usually it was possible to "gang" two tuned circuits together on the same control shaft, and with a four-stage TRF radio, this meant that there were only two tuning knobs to contend with. If you wanted more amplification, it was necessary to buy a set with more stages and more tuning controls, making it even more difficult to tune in a station.

The disadvantages of the TRF radio led to a frantic search for better receiver circuits. The result was a circuit called the superheterodyne, and it was so good that it is still in use today.

Superheterodyne Radio

The first stage of the superheterodyne radio receiver in Fig. 2-19 is the radio-frequency (RF) amplifier. Some of the better AM radios contain this stage; however, the common AC/DC table model radios with which we are so familiar usually do not. In this case, the antenna is connected directly to the mixer. An amplifier in a radio does the same thing that it does in the transmitter—it takes a very weak signal and boosts it up to a much greater strength. The signal on the antenna, even when very close to the radio station, is too weak to be used by itself, except in one of the toy crystal radios requiring earphones and a long-wire antenna.

The antenna is coupled to a *tuned circuit* (not shown). This is a special kind of circuit that is especially sensitive to one particular frequency. This particular tuned circuit is adjustable by turning the tuning knob on the front of the radio; this changes the *resonant* frequency of the tuned circuit.

The tuning knob also adjusts another tuned circuit—the grid circuit of the local oscillator. Remember that in transmitters, the oscillator generates a sine-wave, radio-frequency signal. It does the same thing here, but for a different reason. The incoming

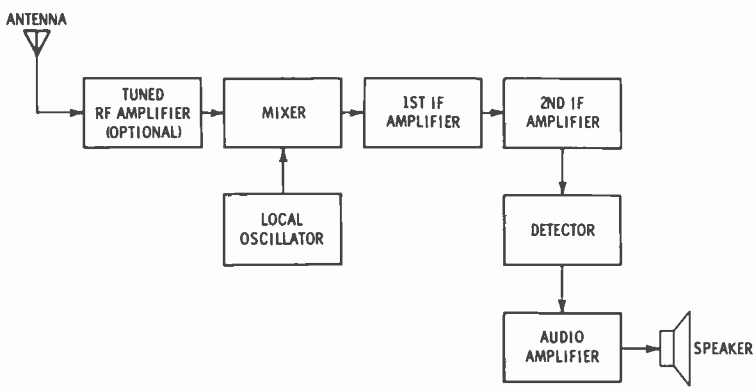


Fig. 2-19. Block diagram of a modern superheterodyne radio.

signal, for example 1,100 kilocycles, is *mixed* with this local oscillator frequency. When two different frequencies are added together, they produce a sum frequency and a difference frequency (they add and subtract). It is the difference frequency that is usually used, and the oscillator is adjusted when the set is tuned so that this difference frequency is always the same. (The difference frequency is usually 455 kc in the U. S., although 262 kc, 456 kc, 465 kc, and other frequencies are also employed.)

The 455-kc signal is called the *intermediate frequency* (IF). Whenever two radio signals are mixed or beat together this way, the action is called *heterodyning.* The term superheterodyne is derived from this and this kind of radio is called a *superheterodyne receiver*, or just *superhet.*

The same tube is usually used for oscillating and mixing, and this combined tube is called the *converter*. The name is very appropriate, since it converts the incoming radio signal to a modulated intermediate frequency, which can be handled by the radio much more easily than the raw radio wave.

The next two sections (each section is called a *stage*) are the *IF amplifiers*. An amplifier takes a weak signal and increases it to a useful level, and this is just what the IF amplifier does. In this case, it does not amplify everything that is fed into it—just the intermediate frequency of 455 kc and the *sidebands*, which carry the audio signal.

The two IF stages are virtually identical—they use the same type of tube, the same kind of transformer and the same kind of resistors and capacitors. Why two of them? Usually there is just one and the second stage is omitted but, in this receiver, additional amplification is needed so the second IF amplifies the signal further before it goes to the *detector*. The detector is a special tube and circuit that separates the audio signal from the intermediate frequency. The action of this circuit is very much like the rectifying action in the power supply.

The audio is detected and filtered and then once again must be amplified, this time by an *audio-amplifier* stage. In most superhet radios the detector and first audio amplifier are in the same glass envelope—really two tubes in one package. If you count the two-in-one functions of tubes in a five-tube radio, you find that it is the equivalent of at least a seven-tube set since it has two dual-purpose tubes.

Output and Speaker

The audio amplifier drives an *output transformer*, which, in turn, operates a speaker. The speaker is simply a paper cone with a coil of fine wire at one end that is pulled and pushed through the field of a permanent magnet as the signal voltage on this *voice coil* changes. When the paper cone is pushed forward, it compresses the air in front of it, creating a sound wave. This sound wave is very similar to the one that caused the diaphragm in the microphone to vibrate at the radio station.

Power Supplies

A very important and frequently neglected portion of every radio is the power supply. In portable sets this simply consists of the battery. In other types of radios it is a special section that converts the 110-volt alternating current from the wall socket into voltages that can be used by the radio.

Most vacuum tubes require a relatively high DC (direct current) voltage to operate. The power supply must provide several different DC voltages for various circuit points. The basic power supply consists of a rectifier—either a tube (diode) or a semiconductor rectifier such as selenium or silicon. This is followed by a filter which smooths out the ripples in the rectified alternating current providing a relatively smooth DC.

This is the basic radio, but there are other parts of the circuit that are important. One of these parts is the *automatic volume control* (AVC). This is a circuit that compensates for changes in the signal that would cause certain kinds of fading. The circuit is what is sometimes called a *feedback* circuit, and what it does is tell the converter and the IF amplifiers to increase their amplification when the signal starts to fade.

Another special circuit is the *volume control.* It is simply a method of raising or lowering the signal voltage to adjust the sound volume coming out of the speaker. This can be done several ways, but the method usually used is to make a small change in the amount of signal coupled to the audio amplifier stage.

Chapter 3

ANTENNAS AND TUNED CIRCUITS

An antenna in a radio receiver is actually part of a tuned circuit. Tuned circuits are usually of the parallel type in AM radios. They are made up of a coil and a capacitor connected in parallel, as shown in Fig. 3-1. The arrow across the capacitor means that it is adjustable, and this variability is necessary for changing the resonant frequency of the circuit.

Resonance is the frequency at which the most signal will be developed across the tuned circuit. As the frequency changes, the signal developed across the circuit falls off until it is effectively zero, as shown in Fig. 3-2.

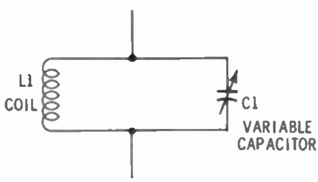


Fig. 3-1. Parallel tuned circuit with variable capacitor.

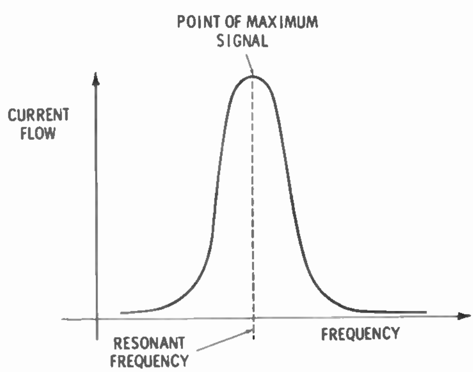


Fig. 3-2. Graph showing maximum signal developed across inductor at resonance.

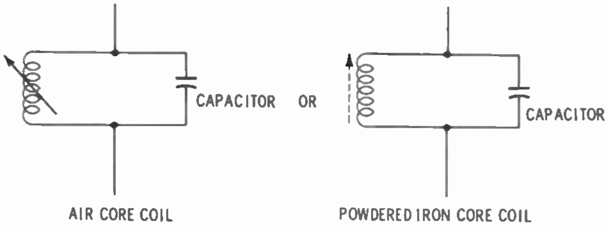


Fig. 3-3. Two types of tuned circuits used in radio.

The resonance point of tuned circuits can be changed by altering the value of either the coil or the capacitor. While it is easier to vary the capacitor, some circuits, such as IF transformers and RF amplifiers and oscillators in automobile radios, use *slug tuning* in which the circuit value of the coil is changed (Fig. 3-3).

ANTENNA CIRCUITS

The antenna is coupled to a capacitor, and the two together form a tuned circuit which is changed by varying the capacitor. The antenna itself is an inductor (coil) which acts very much like the second electromagnet described in Chapter 1. Remember that in that case, the varying magnetic field of the first electromagnet induced an AC current flow in the second coil.

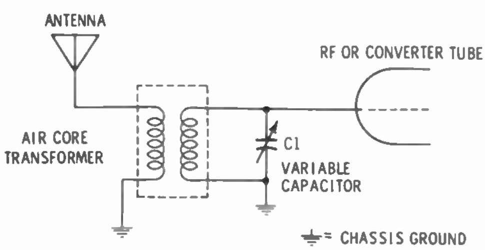


Fig. 3-4. Coupling antenna to first RF tube by inductive coupling.

The electromagnetic field strength at the antenna of a radio receiver is very weak when compared to the field between the two electromagnets. But it is strong enough to induce a very feeble flow of current in the antenna wire.

This weak current is enough to operate a radio receiver. In the early crystal sets the antenna current was all that was used. When a strong enough radio signal was available, these receivers could produce a usable sound in a pair of earphones.

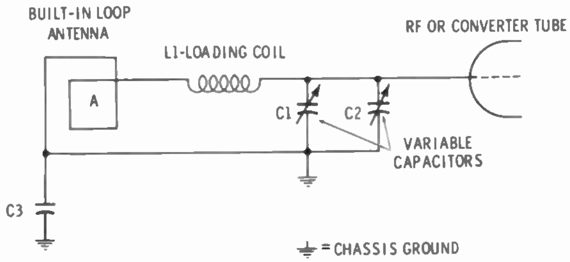


Fig. 3-5 Method of directly-coupling the antenna to first RF tube.

But today's radio must produce more output—enough to drive a speaker—and therefore the "self-powered" crystal set is not used. Tube-type radios also can pull in weaker radio stations than a crystal set can.

There are several ways of coupling the antenna to the input circuits of a radio. One method is by *inductive coupling*, as shown in Fig. 3-4. This is simply an air-core transformer of the type that is frequently used in radio circuits.

Another method (and cheaper) is *direct coupling*, as shown in Fig. 3-5. Here, the antenna signal goes through a *loading coil* directly to the control grid of the first tube. The tube can be either an RF amplifier or a converter tube, depending on the design of the set.

The flat loop antenna usually does not have a high enough inductance (a measure of its magnetic value in a circuit) to match the capacitors that are wired in parallel to it. Fig. 3-5 shows that this antenna circuit is actually a tuned circuit; it is tuned to the resonant frequency of the radio station being tuned in.

Capacitor C1 is one of the sections of the tuning capacitor (Fig. 3-6) that is used to tune in a radio station. Capacitor C2 is a

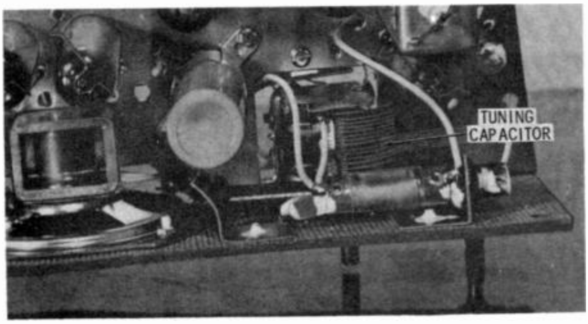


Fig. 3-6. Variable tuning capacitor.

trimmer, a small, mica-insulated adjustable capacitor that is used for making fine frequency adjustments at the factory and when the receiver is repaired or aligned.

The antenna loop (A) and coil (L1) (Fig. 3-5) are in series, and their total inductance forms the inductive (coil) half of the tuned circuit. By using a loading coil, many types of antenna loops can be incorporated into the circuit.

LONG-WIRE ANTENNAS

The classic type of antenna for broadcast transmitters and receivers is the single long wire. Back in the early days of radio, a long outdoor wire antenna was absolutely necessary because of the insensitivity of the home receivers. If the incoming signal is very weak, such as a transmission from a foreign station or a

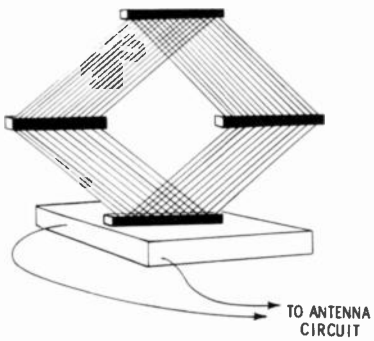


Fig. 3-7. An early loop antenna.

radio amateur, an outside antenna is necessary even today. But for picking up the superstrong signal from a local broadcast station, an indoor (usually self-contained), antenna will do the job.

Early types of indoor antennas were variations of the long wire, usually several loops of wire on a large open frame that would sit on top of the radio (Fig. 3-7). While the length of wire used was not the optimum length (quarter wave) in all cases, this type of antenna had a fairly good ability to "trap" the radio signal. This trapping ability is called *gain* and is a measure of the efficiency in operation of the antenna.

When a long wire is used outdoors, its gain can be increased by running a second wire alongside the first, separated by insulators (Fig. 3-8). This type of antenna is called a *doublet* and is still in common usage for short-wave and foreign broadcast enthusiasts. Of course, you need a long back yard or roof to set up an antenna of this kind, but it does have the advantage of greatly increased gain over indoor and single-wire types.

The favored type of built-in antenna for many years was the flat loop that was built into the back cover of most table-model radios. A representation of this type appears in Fig. 3-5. This antenna has a reasonably high gain for receiving local broadcast stations and is highly directional; that is, it produces the strongest signal when the radio and the antenna are facing in one particular direction. This is both an advantage and a disadvantage. When the radio is turned in the appropriate direction, the antenna has a great deal of gain. The disadvantage is that when changing

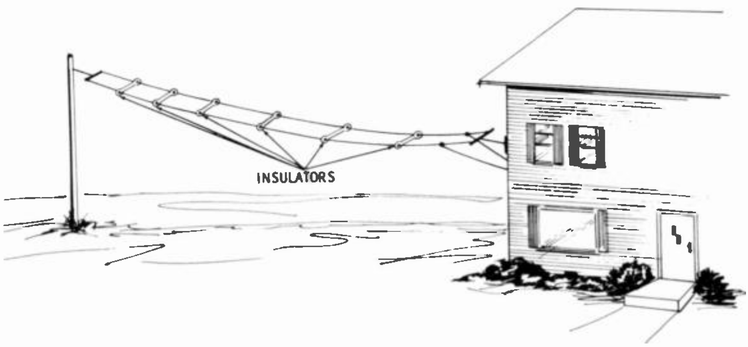


Fig. 3-8. Doublet antenna.

stations the antenna may not be facing in the proper direction, and constant rotation of the radio to get the best signal can be a nuisance.

FERRITE ANTENNAS

One of the most recent developments in AM antennas is the ferrite rod, or *loopstick* as it is sometimes called. This is a very high-gain antenna consisting of a coil of closely wound wire wrapped around a rod or bar of powdered iron (ferrite). In addition to having excellent gain, it is highly directional and much smaller in size than the flat-loop antenna. As a result, the large fiber back of table-model radios which formerly held the antenna is no longer necessary and the size of the radio can be reduced considerably. The tiny pocket-size transistor radios use a ferrite antenna, with the rod squeezed flat to take up even less space. A ferrite antenna is shown in Fig. 3-9.

An additional advantage of the ferrite antenna is its high inductance when compared to a flat loop. This high inductance means that the loopstick can be connected directly into the an-

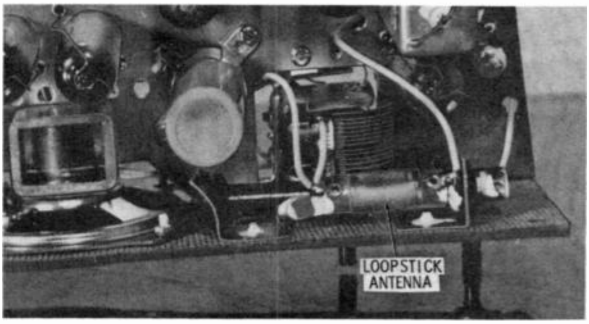


Fig. 3-9. Ferrite-core loop antenna.

tenna circuit without the need for a loading coil. A typical loop-stick circuit is shown in Fig. 3-10.

A variation on the long-wire type of antenna is called the *whip* antenna. This is the type usually used in autc ɔbiles. Compared

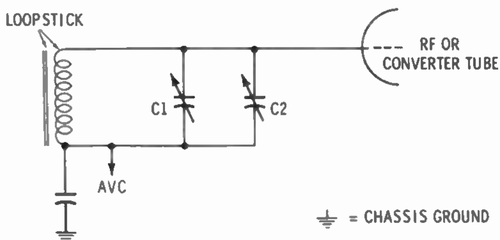


Fig. 3-10. Circuit using ferrite-core loop antenna.

to the loop or ferrite variety, this type has much higher gain, since its length is closer to a true quarter-wave antenna and it cuts through many more lines of radiation from the transmitting station. It also has the advantage of being nondirectional—a very

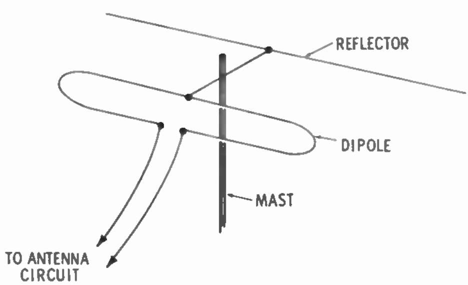


Fig. 3-11. Folded dipole with reflector.

important feature for a moving motor vehicle that is constantly changing its direction.

Another type of antenna is called the *folded dipole*, frequently shortened to dipole (Fig. 3-11). The folded dipole, because of inherent design characteristics, must be cut to a quarter wavelength, a size that makes this antenna feasible only for higher frequencies, such as used for television and FM. Many familiar rooftop TV antennas are quarter-wave folded dipoles. The dipole is really a kind of squashed circle—flattened so that each of the two flat arms is a quarter-wavelength long. The gain of the dipole is increased by placing a reflector behind it. This consists of a single aluminum tube somewhat longer than a quarter wavelength. Some of the broadcast signal that gets past the dipole strikes the reflector rod and bounces back to the rear of the dipole element, thereby increasing the signal at the dipole and to the receiver input.

Chapter 4

POWER SUPPLIES

Power supplies do just what the name implies—they provide power. They may take many forms, such as batteries of various sizes, huge power transformers with bulky rectifier tubes and filters, or they may be small semiconductor rectifiers with miniaturized filters.

In one respect, they are all the same—they must provide a constant flow of direct current (DC) to operate the tubes or transistors in a radio or other electronic equipment. All tubes and transistors require DC. Some transistors can operate from a couple of 1.5-volt penlight batteries. Tubes require much higher voltages, commonly anywhere from 40 to 400 volts. Some tubes may require more, some less.

The power available at the wall receptable is usually not DC. It is 117 volts alternating current in the United States. This is an average figure. Actually, it varies from about 110 to 125 volts and may fluctuate during the day because of varying demands for electrical power. Some parts of the country may have DC instead. This is especially true in some of the older districts of New York City, where Edison built his first power plants before the turn of the century and before the advantages of AC were fully understood. For this reason, many appliances are made for operation on both AC and DC. This is true of the common table-model radio. It is *not* true of any devices using transformers or electric motors. A transformer cannot be used on DC. Most motors are designed for use either with AC or with DC, not both. If you have ever tried using a DC motor on AC or vice versa, the cloud of smoke after you plugged it in should be ample proof of this.

BOILING ELECTRONS

The first vacuum tube, the Fleming valve, was what we today call a *diode*. A diode is a two-element tube (Fig. 4-1) and consists of a *cathode* and an *anode*, usually called the *plate*.

In an elementary diode (Fig. 4-1), the *filament* and the *cathode* are the same. Basically, the filament is similar to the filament in an electric light bulb. It is made of very fine tungsten wire and glows when enough electric current passes through it. The difference between a light-bulb filament and those used in vacuum tubes is that a light bulb is designed to give off light. The filament in a vacuum tube is designed to give off heat, and in this case, electrons.

Electrons are always in motion. When the temperature of the material increases, the electrons move much faster, and if they are made to move fast enough, some of them will break away from the atoms at the surface of the material. Electrons that break away in this manner are said to be "boiling" off the tungsten filament—much the same way that water molecules boil off when a pot of water is heated on the stove.

A special coating on the tungsten filament helps it to give up electrons even more freely. This coating has a greater number of free electrons than the tungsten, and it boils them off more easily. All these electrons boiling off the filament must have some place to go. A second element, the plate, is inserted into the tube and connected to the positive side of a battery, as shown in Fig. 4-2.

The positive charge on the plate attracts the negatively charged electrons boiled off by the filament. Remember that like charges

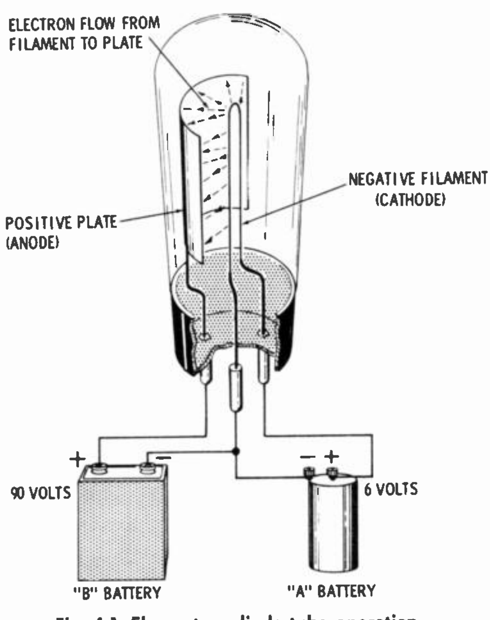
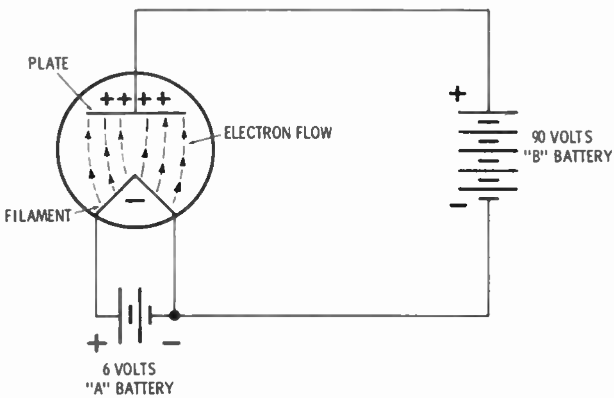


Fig. 4-1. Elementary diode tube operation.

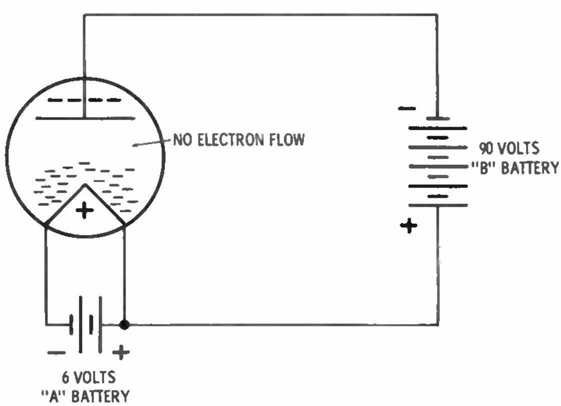
repel each other, and opposite charges attract each other. Since the electron is negatively charged, it is attracted to the positive plate, and a current flows through the tube.

This is all fine as long as there are electrons to be boiled and as long as the plate remains positive. But if the plate is connected to the negative side of the battery, then electrons are repelled and no current flows through the diode.

This type of action is very much like the action of a valve in a water pump. When the pump handle is raised, as shown in Fig. 4-3A, the valve assembly travels down the pipe, the valve is forced open, and water flows into the valve chamber. When the pump handle is lowered, as in Fig. 4-3B, the valve chamber is raised,

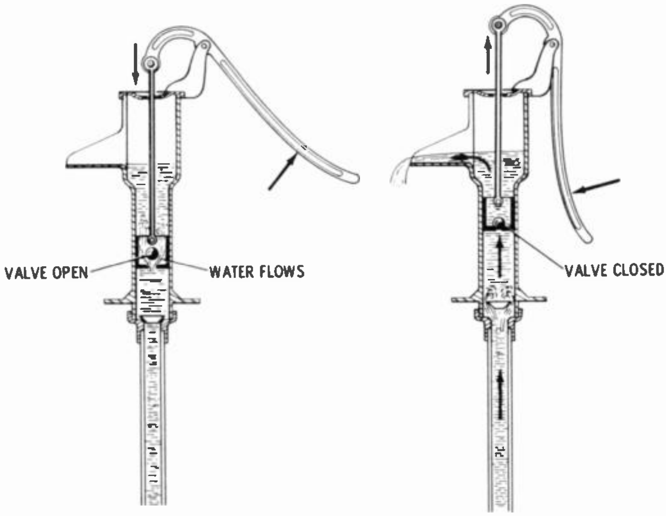


(A) With positive charge on the plate.



(B) With negative charge on the plate.

Fig. 4-2. Electron flow in a diode tube.



(A) Valve open. (B) Valve closed.

Fig. 4-3. Water pump valve analogy.

the valve is closed, and no water can escape back into the well but instead is forced out through the pump spout.

The diode acts in much the same way. When certain conditions are met—electrons boiling off the filament and a positive plate—current will flow. Change these conditions by making the plate negative and no current will flow. Because of this similarity to a valve in a fluid system, the first vacuum tubes were called *valves* and they still are in Great Britain and other English-speaking countries outside the U.S.

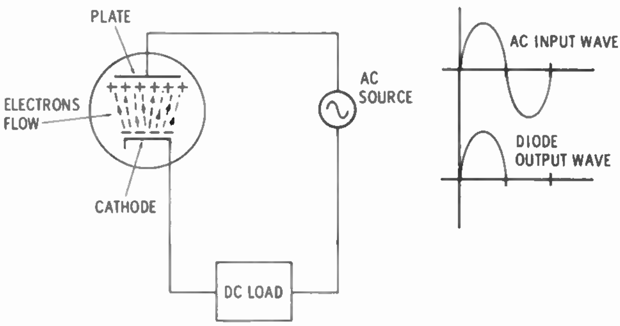
Because a filament boiling off electrons is not always the most efficient and effective way of obtaining electrons for operating the tube, another method is usually used. Instead of coating the filament with a special alloy, another element, called the *cathode,* is placed next to the filament. This cathode, when heated by the filament, boils off electrons.

When the filament boils off the electrons, it is also called a cathode, since any negative anode (element) that supplies electrons in a tube is called a cathode. The filament-cathode is called a *directly heated cathode* and is usually found only in certain types of rectifier (diode) tubes and miniature tubes designed for portable radios.

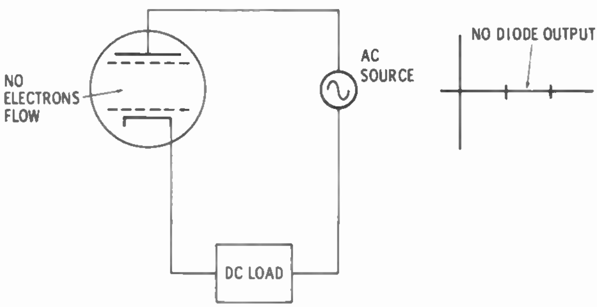
The separate cathode is called an *indirectly heated cathode;* whenever it is used, the schematic drawing is simplified by omitting the symbol for the heater (another name for the filament in this type of tube). Fig. 4-4 shows a rectifier tube in which the heater symbol has been eliminated for simplicity. This method is used throughout this book, since it is standard practice and makes the schematics easier to understand.

RECTIFICATION

If, instead of connecting the diode terminals to a battery, an alternating-current source is used, the diode will control the direction of flow of this current. Remember that in the battery situation, when the plate was positive, current flowed. The same thing is true here during the positive half cycle of the alternating current. Fig. 4-4A shows the condition of the tube (conducting) and the output waveform.



(A) Positive half cycle of AC—electrons flow.



(B) Negative half cycle of AC—no electrons flow.

(C) Pulsating DC output from rectifier.

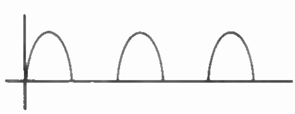
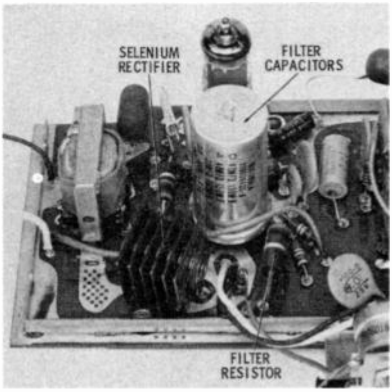
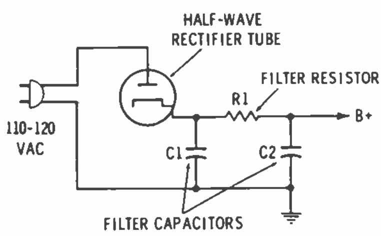


Fig. 4-4. Operation of a half-wave rectifier tube.

When the alternating current goes to the negative half cycle (Fig. 4-4B), the plate becomes negative and the diode does not conduct. This gives zero output voltage, as shown in Fig. 4-4B. When the AC swings positive again, once more the tube will conduct. The output of this type of tube is shown in Fig. 4-4C. The current is all flowing in one direction, but it has pulses and gaps in it. This is *rectified* AC which is also called *pulsating DC*. It is called DC because it always flows in the same direction and is called pulsating because it is not a straight-line DC of the kind that you get from a battery. A diode that rectifies one-half of the AC wave this way is called a *half-wave rectifier*.



(A) Power supply, filter capacitors and resistor.



(B) Schematic of rectifier and filter circuit.

Fig. 4-5. Practical rectifier circuit with filters.

After the AC has been rectified, it must be filtered. Filtering is the process of smoothing out those mountains and filling in the valleys. A filter circuit is shown in Fig. 4-5. This circuit uses capacitors to help smooth out the bumps. A capacitor can take a charge of electrons much the same way that you can charge up a plastic comb by running it through your hair. When an electric current flows across a capacitor, it charges up until that current stops flowing or until the capacitor is fully charged. When current stops flowing, the capacitor can discharge if there is some place for the stored-up electrons to go.

In a radio, the place for these electrons to go—called the *load*—is the rest of the circuit of the radio itself.

Filter capacitors are in parallel to the load; they charge up during the half cycle that current is flowing and discharge when the current drops off. The resistor (R1) in Fig. 4-5B helps

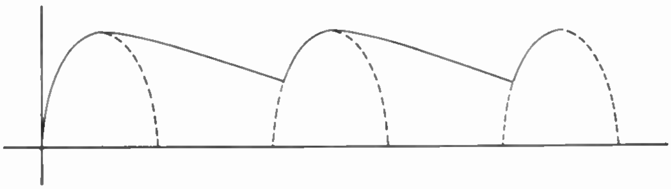


Fig. 4-6. Rectified and filtered DC voltage.

prevent the surges of current from going directly to the load (radio), giving the capacitors a chance to charge up.

The rectified and filtered voltage is shown in Fig. 4-6. It is almost a perfectly flat DC, but there is still a little *ripple,* a slight wavering of the line. This ripple can be heard as *hum* when the set is turned up very loud or if the radio is rather old and the filter capacitors have begun to deteriorate.

FULL-WAVE POWER SUPPLIES

If more power is needed with better filtering than is possible with a half-wave power supply, a full-wave supply may be used. The full-wave supply requires a power transformer and a full-wave rectifier tube. This is the same as the half-wave rectifier, except that it has two plates (Fig. 4-7).

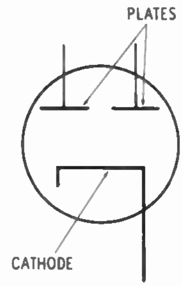
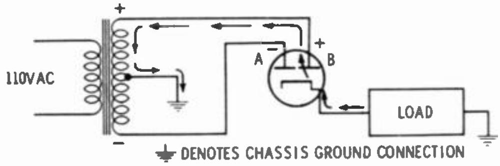


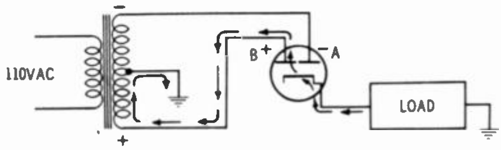
Fig. 4-7. Full-wave rectifier tube.

The transformer is necessary for two reasons. First of all, when a set uses a full-wave rectifier, it usually has higher power requirements than the ordinary AC/DC radio, and the transformer steps up the voltage to a higher level. The other reason is that its secondary coil (Fig. 4-8) has a center tap that provides a center balance point in the circuit to ground.

What this means is that the current flowing from either plate of the rectifier tube returns to ground—the same common point, which is the metal chassis of the radio. The arrows in Fig. 4-8



(A) First half cycle of AC.



(B) Second half cycle of AC.

Fig. 4-8. Current in a full-wave rectifier.

show this current flow from the plates. Fig. 4-9 shows the full-wave pulsating DC that comes out of this type of rectifier. Notice that the valleys between the mountaintops here are not as wide as they were for the half-wave rectifier because each half cycle is rectified. This type of waveform is easier to filter and the output has much less ripple than does the half-wave power supply.

When an alternating current is applied to the full-wave rectifier tube, first one plate is positive and the other is negative, as shown in Fig. 4-8A. Current flows from the load, across the rectifier tube to the positive plate, through the upper half of the transformer secondary coil, and to the ground connection. Then the current reverses. The plate that was positive now be-

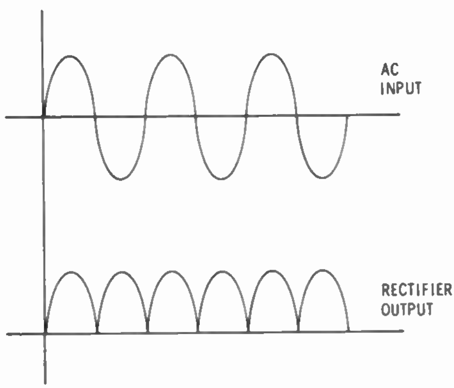


Fig. 4-9. Current output from a full-wave rectifier.

comes negative; the plate that was negative now becomes positive; current flows once again, this time to the other plate (Fig. 4-8B).

As far as the filter and the load are concerned, the current is still flowing in the same direction, toward the rectifier tube, and eventually to the ground connection.

Ground in a radio is simply the metal chassis. It is used as a common connection, just as if it were one big wire going to each ground point shown in the circuit. If a wire were actually run to each ground point, the underside of the wired radio chassis would be much more complicated than it is now. However, printed-circuit boards have no metal chassis, and they must have just this sort of arrangement. Of course, when a printed circuit is used, the ground foil is much more orderly and easier to follow than individual wires to each ground point on a hand-wired chassis would be. Printed circuits are covered in more detail in Chapter 9.

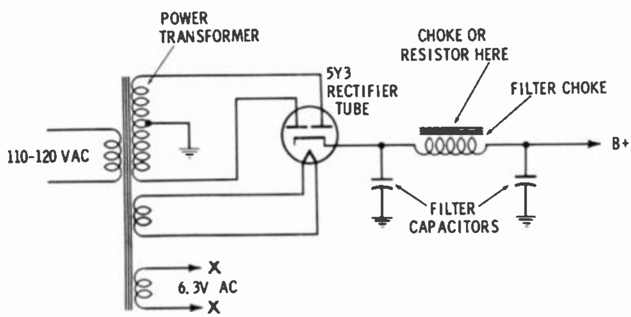


Fig. 4-10. Schematic of a complete full-wave power supply.

The power takeoff point shown in Fig. 4-10 (marked B+), is the positive high-voltage DC output from the power supply. The negative point, sometimes called B−, is the chassis ground. Ground is the common negative point for all circuits.

There are two other secondary windings shown on the power transformer. One is a 5-volt (AC) winding designed to power the 5-volt filament of the rectifier tube. The other winding provides 6.3 volts (AC) and powers the filaments of all the other tubes in the set. The filament winding outputs are marked X since this is shown as the filament points for the tubes. This method is less confusing than actually showing the connections for the filaments on the schematic. Another method is to leave the filaments off the rest of the schematic entirely, showing them connected to the filament winding itself. This type of arrangement is shown in Fig. 4-11.

FILAMENT VOLTAGES

Tubes have various types of filaments requiring different voltages, depending on the size and type of the tube. Most tubes made for use with transformer power supplies have 6.3-volt filaments, and they are wired in parallel, as shown in Fig. 4-11. A slight variation is the 12-volt tube, such as the 12AX7 shown in the parallel filament string in Fig. 4-11. This tube has a 12.6-volt filament with a center tap so that it can be used as a 12-volt tube or a 6-volt tube. The connections made in the illustration are for 6-volt operation. Tubes for AC/DC radios are wired in series

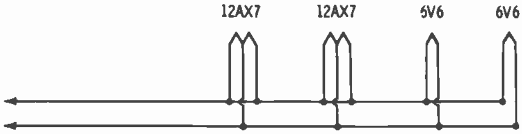


Fig. 4-11. Parallel connected filament circuit.

(Fig. 4-12). Since the radio is designed for 117-volt operation, the total of the filament voltages should equal this 117 volts, or come very close to it. Each filament drops a portion of the voltage; that is, it reduces the line voltage by an amount that is the same as the voltage required to operate the heater of the tube.

The first number in a tube designation usually indicates the filament voltage. Thus, a 6V6 has a 6-volt (really 6.3-volt) filament. Other typical 6-volt tubes include the 6AL5, 6X5, 6L6, 6BQ5, etc.

A 50C5 is a common power output tube used in AC/DC radios. This has a filament that drops 50 volts. A lineup of the

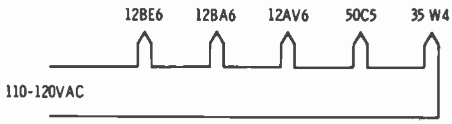


Fig. 4-12. Series filament string.

five tubes commonly used in an AM table-model radio might be: 12BE6, 12BA6, 12AV6, 50C5 and 35W4. If you add the first numbers of each tube, the total voltage drop is 121 volts. This figure is close to the 117-volt *average* line voltage that is normally available; the tubes will be wired as shown in Fig. 4-12. This is a series string, and if the filament of one tube burns out, all the tubes will stop working, since an open filament breaks the circuit and no current can flow. This is why, if all the tubes are dead in an AC/DC set, the trouble is most likely an open filament in one of the tubes. A burned-out filament is the most common kind of tube trouble. In some sets, if only four tubes are used, or if the filaments do not add up to 115 or 120 volts, a *filament dropping resistor* may be connected in series with the tube filaments to drop the remaining voltage. The five tubes in an AC/DC set are designed as a group, specifically for use in this type of radio, mainly because of the filament problem. Because of this grouping of the tubes, there is little variation in the basic circuit design from one five-tube radio to another. Because of this similarity, these sets are generally very easy to repair.

To be sure there are more expensive versions on the market with circuit and design refinements. And these improvements naturally add to the performance, but they usually consist of such things as better built-in antennas and higher-quality components in general. There may be static (noise) suppression circuits and perhaps a separate tone control. Other sets, by the addition of a selector switch and one or two additional tuned circuits in the input, can provide one or two short-wave bands in addition to the regular AM broadcast band. But, basically, the design of all these five-tube sets is the same.

SEMICONDUCTOR RECTIFIERS

Tubes use up a lot of current and generate heat; they are prone to failure, especially burned-out filaments. Because the rectifier tube is a high-power device, it is even more prone to failure than the other tubes in the set. If any single tube is going to be eliminated, it obviously should be the rectifier. Some set manufacturers do this by substituting a semiconductor rectifier for the power-supply tube.

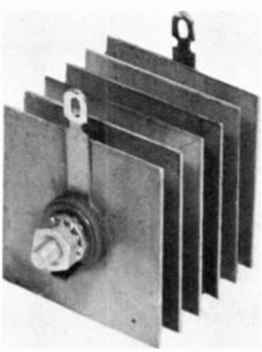


Fig. 4-13. Example of selenium rectifier.

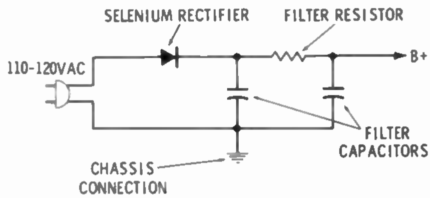
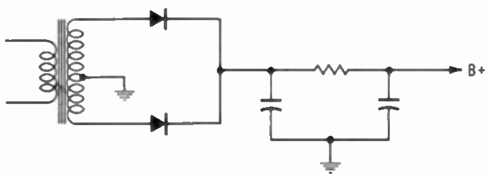


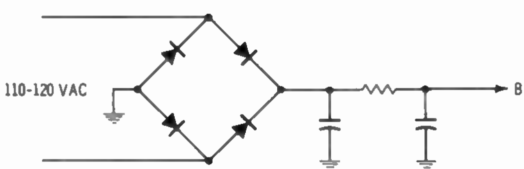
Fig. 4-14. Schematic of selenium half-wave rectifier circuit.

A semiconductor is a special material of the kind that is used for making transistors. The semiconductor rectifier and diode were in general use long before transistors were invented. A common rectifier of this type is the *selenium* rectifier. Selenium is the name of the active material that gives the rectifier its diode action. It is common practice to call these rectifiers by name of the principal material used in them. Thus, there are also copper-oxide rectifiers, silicon rectifiers, and germanium diodes.

The selenium rectifier consists of a metal plate coated with selenium on one side. Because of the properties of this combination, electric current is allowed to flow only in one direction between the connections made to the face of the metal plate and to the selenium. When an alternating current is applied across a selenium rectifier, only one half of the wave is able to flow—the other half is lost—just as it is in a half-wave, vacuum-tube rectifier. Usually, a single plate is not sufficient to handle the higher voltages that are used in radios, so several plates are stacked together, forming the finned structure shown in Fig. 4-13.



(A) Transformer powered full-wave circuit.



(B) Transformerless full-wave bridge rectifier circuit.

Fig. 4-15. Schematic of full-wave selenium-rectifier circuits.

Newer, more compact rectifiers used in radios may simply be a featureless cube with two wires protruding from opposite sides. When some of the newer semiconductor materials are used, there is really no commonly used shape or size for the rectifier. It is entirely up to the individual manufacturer. A selenium-rectifier power supply (half wave) is shown in Fig. 4-14.

Like the vacuum-tube rectifier, semiconductor rectifiers can be used for full-wave operation. A transformer-powered, selenium, full-wave power supply is shown in Fig. 4-15A. Another way of obtaining full-wave rectification, but without the use of a power transformer is the rectifier bridge. This circuit is shown in Fig. 4-15B. While it is possible to use this type of circuit with vacuum-tube rectifiers, it means using two full-wave tubes. Selenium-rectifier stacks can be *tapped* and stacked in such a way that one unit forms the bridge, as shown, with terminal points conveniently located on the selenium stack. This method has the advantages of lower power consumption than the vacuum-tube rectifiers, smaller space requirements, and the selenium units generate far less heat. The semiconductor rectifier very seldom goes bad, so its use considerably reduces servicing problems.

Chapter 5

THE RF AMPLIFIER

The tuned circuit is one of the most important single circuits in the radio receiver. Because of its characteristics, it is used to select certain frequencies and to reject all others.

The basic spark loop that Heinrich Hertz constructed was one type of tuned circuit. It certainly was not as sophisticated as the ones used in present day radios, but it served essentially the same purpose.

Tuned circuits, also called *tank circuits*, can be varied. Their resonant frequency can be changed either by altering the inductance of the coil or by changing the value of the capacitor. Both methods are used in radios in different sections of the circuit.

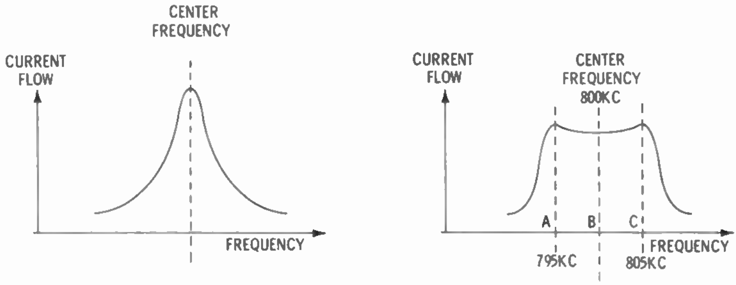
BANDWIDTH

When the coils of two tank circuits are coupled as in an IF transformer (Fig. 5-1), the coupling response of the two circuits can be varied. A single tuned circuit, not coupled to another, usually has a resonance point that looks something like that in Fig. 5-2A.

(A) Slug tuning. (B) Capacitance tuning.

Fig. 5-1. IF transformer circuits.

Coupling two tank circuits, each tuned to a slightly different frequency, can produce a response within a larger span of frequencies, as shown in Fig. 5-2B. This bandwidth is important, since all radio waves are complex and contain many frequencies other than the radio-frequency carrier.



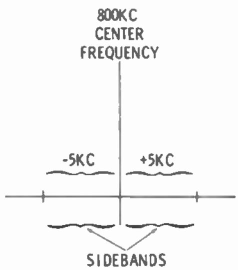
(A) Single tuned circuit. (B) Inductively coupled circuits.

Fig. 5-2. Current flow in tuned circuits.

When coupled tuned circuits are equally sensitive to a broad range of frequencies, they are said to be *broadband* or wide-bandwidth circuits. The band of frequencies passed by the circuit in Fig. 5-2B is 10 kilocycles—the distance from point A (795 kc) to point C (805 kc). This is the band of frequencies passed by the circuit.

This bandwidth is necessary because the carrier frequency of the radio transmitter (800 kc) is modulated by an audio-frequency signal. While this audio signal does not change the broadcast frequency, it does create *sidebands* (Fig. 5-3). Sidebands are information-carrying frequency bands that always exist in voice communications. They are created at the transmitter when an audio frequency modulates an RF carrier.

Fig. 5-3. Sidebands created by modulation.



As long as there is an unmodulated single-frequency carrier, such as 800 kc, this is all that is transmitted and received. When the carrier is amplitude modulated, the amplitude changes at an audio-frequency rate. The effect of this is that the audio frequency is added to and subtracted from the frequency of the carrier.

Since a sine wave is both positive and negative, the modulating audio signal will both add and subtract frequencies. An 800-kc RF with modulation of ±5 kc has a frequency variation from

795 to 805 kc. This represents a bandwith of 10 kc and is the same as the bandwidth shown in Fig. 5-2B.

The bandwidth in an AM radio depends on the desired quality of the sound to be reproduced. A very wide band, such as ±10 kc, would give high fidelity if a good quality signal were being broadcast from the transmitter. This ±10 kc would mean a bandwidth of 20 kc for the transmitter. If the carrier is 800 kc, then the total band space occupied by the station would be from 790 to 810 kc (Fig. 5-4).

If you are going to have such clear channels or high-fidelity stations on AM, then there will be room enough only for a very few such stations in the standard broadcast band. Ordinarily,

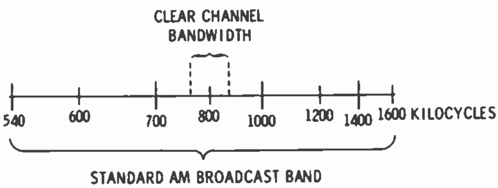


Fig. 5-4. Example of AM station bandwidth.

typical bandwidth for an AM station is usually not more than 10 kc. This limits the frequency response of the station to ±5 kc—certainly not high fidelity.

If enough space is to be made on the broadcast frequency band (540 to 1600 kc), the bandwidth of the individual stations must be kept very narrow. This is to prevent interference with other AM stations. Since low-frequency AM signals can travel great distances by bouncing off the Heaviside layer at night, this interference with distant stations can become a very serious problem, and often does.

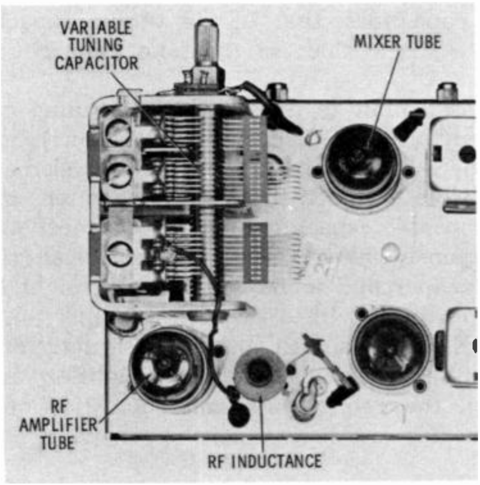
For this reason, AM station bandwidths are kept very narrow to avoid interference in the broadcast spectrum. This usually does not cause any great hardship, since the average AM listener is not too concerned about high-fidelity reception.

AMPLIFYING THE SIGNAL

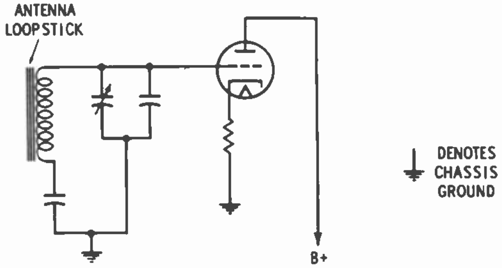
A circuit at the antenna that is designed to amplify (build up) the feeble radio signal being picked up is called an *RF amplifier*. The tube is an ordinary amplifier tube that has a broadband tank circuit at its input. The tuned circuit (Fig. 5-5) for this stage is easy to construct since the inductance is already present in the radio. It is the ferrite loopstick antenna.

The RF amplifier simply boosts the level of the carrier and its sidebands, such as the band from 795 to 805 kc shown previously. While the RF amplifier stage is not used on most AC/DC radios, it does appear in a few of them and is frequently used in automobile radios and the more expensive radio-phonograph consoles. Its use gives the receiver greater *sensitivity*—the ability to pull in weak or distant stations.

Some early vacuum-tube radios were simply several RF amplifiers strung together feeding a detector (diode) and an audio amplifier. The trouble with these "TRF" receivers was that each stage had to be individually tuned, and the overall *selectivity* was not too good. Selectivity is the ability of a receiver to select just the station frequency wanted and to reject all the rest.



(A) RF amplifier stage.



(B) Typical RF amplifier circuit.

Fig. 5-5. Typical RF amplifier circuit.

The reason for this is that the components in the RF tank circuit must be able to pass the 10-kc bandwidth over a wide range of frequencies from 540 kc to 1600 kc. To do this, the tank circuits must be variable over this range and, as a result, will lose some of their selectivity.

If a tank circuit is designed to pass only one frequency band and does not have to be retuned each time the station is changed, then it can be adjusted for the best possible selectivity. This is what is done in superheterodyne receivers.

The TRF (tuned radio frequency) receiver, which became popular in the days before the superheterodyne circuit was invented, was simply several stages of RF amplifiers coupled by tuned circuits. Each of these had to be adjusted each time the station was changed (Fig. 5-6). These were usually tuned by *ganging* the capacitors; that is, the tuning capacitors were all mounted on a single shaft so that one knob could change the station.

But there is a limit to the number of tuning capacitors that can be ganged this way (usually three or four), and because of small differences in the fabrication of circuit elements, it became almost impossible to match these ganged sections precisely. Also, a four-gang variable capacitor for the TRF receiver was cumbersome and expensive. Very frequently, in an effort to make the TRF radio cheaper and more workable, it might have had two tuning controls, each with a two-section capacitor.

The last RF amplifier was coupled to a detector which drove the audio amplifiers. The circuit was straightforward and simple, but it lacked the refinements and sophistication expected in present day radios, and it was more expensive.

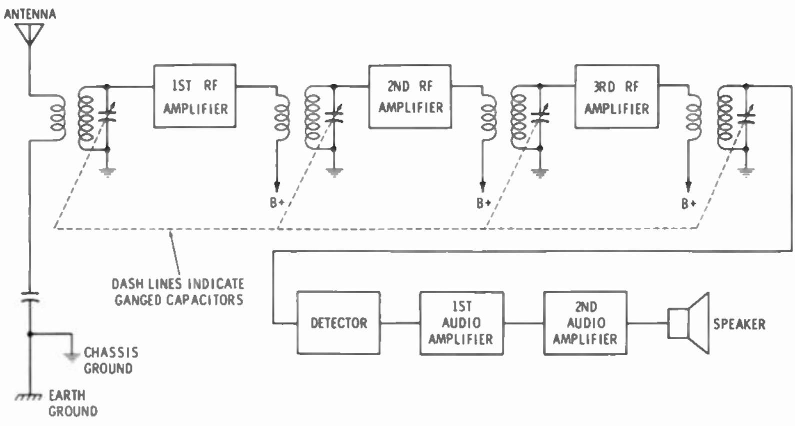


Fig. 5-6. Block diagrams of a TRF receiver showing ganged tuning.

TRIODE ELECTRON TUBES

In Chapter 4, it was shown how a vacuum tube could direct the motion of an electrical current, changing it from AC to pulsating DC.

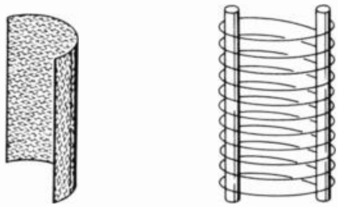
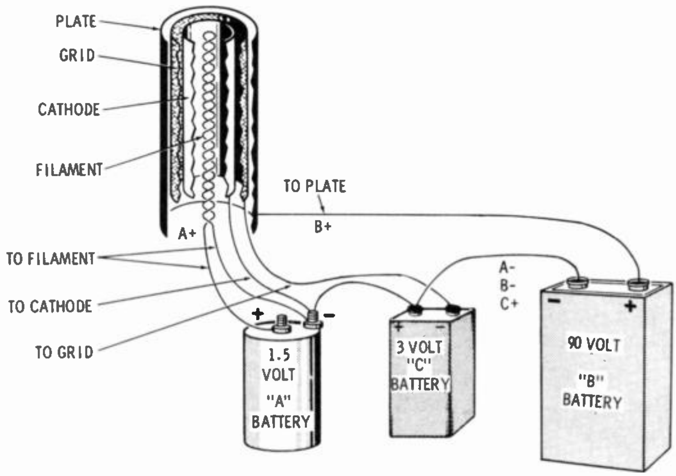
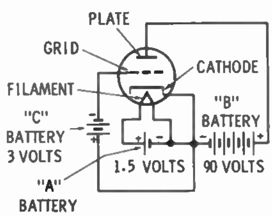


Fig. 5-7. Construction of grids in a vacuum tube.

But an electron tube is a very versatile device and can change electric currents in a variety of ways. If you take the diode tube and insert another element in it called the *grid,* it becomes a three-element tube called a *triode.*



(A) Construction of practical triode.



(B) Schematic of a typical triode circuit.

Fig. 5-8. Triode vacuum tube.

The grid can be a woven wire mesh like a window screen or a series of closely spaced wires, as shown in Fig. 5-7. The grid in a vacuum tube acts as a kind of traffic policeman, telling the electrons when to stop and go.

It does this in much the same way that a diode does—by electrostatic attraction. If a triode is connected as shown in Fig. 5-8, there will be a negative charge on the grid and many of the electrons boiled off the cathode will be repelled and turned back by the grid.

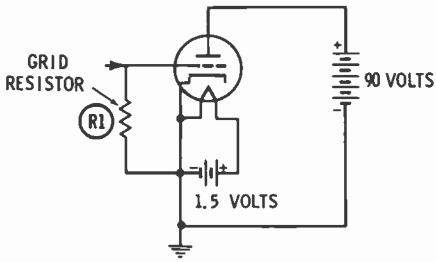


Fig. 5-9. Triode amplifier with grid bias resistor.

If the grid is made less negative more electrons will flow through it to the plate. Conversely if the grid is made more negative fewer electrons will flow through it to the plate. Remember, these electrons do not touch the grid—they flow through the holes in the mesh or between the wires.

A resistor is usually substituted for the "B" battery of Fig. 5-8 as shown in Fig. 5-9. The incoming signal flowing through this resistor produces a voltage drop across the resistor which serves as the grid voltage. It is quite easy to change the grid voltage. One way of doing this is by changing the value of R1 (Fig. 5-9). As R1 is decreased in value, the grid becomes less negative, or to put it differently, it becomes more positive. This grid is generally not referred to as actually going positive, because if this does

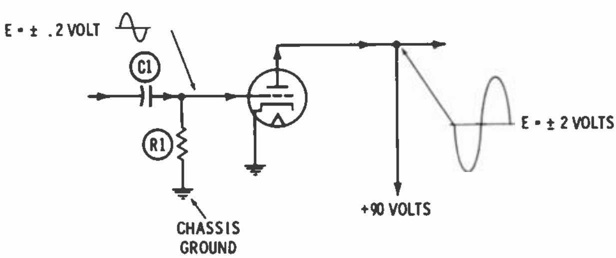


Fig. 5-10. Circuit showing control of plate sine-wave voltage by the grid.

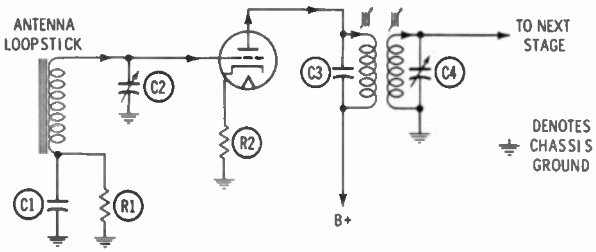


Fig. 5-11. Schematic of triode RF amplifier circuit.

happen, the free electrons from the cathode are attracted to the grid instead of to the plate.

So the grid becomes less negative, and as it does, it repels fewer electrons and more electrons are able to flow through to the plate. This voltage which is the voltage difference of electrical potential between the grid and the cathode is called the grid *bias*.

THE TRIODE AMPLIFIER

If a signal, such as a sine-wave alternating current, is applied to the grid of the triode (Fig. 5-10), the voltage on the grid will change according to the changes in the sine-wave voltage.

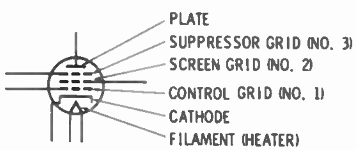
The amplified voltage that appears on the plate of the tube is displaced by a half cycle. Notice that when the input voltage reaches a maximum, the output voltage reaches a minimum peak, and vice versa. The two signals are said to be *out of phase* with each other, because one cycle of a sine wave occupies 360° like a complete circle, one half of a cycle is 180° out of phase or opposite.

The triode tube takes a weak input signal and produces a much stronger signal. The weak input can control large amounts of power, just as a man turning a valve on a pipeline can control the flow of large amounts of oil (or other liquids) through the valve. A triode connected as an RF amplifier is shown in Fig. 5-11.

ADDITIONAL ELECTRODES

Triodes are not frequently used in high-gain circuits, since their amplification is limited. For various reasons that will not be

Fig. 5-12. Diagram of a pentode tube.



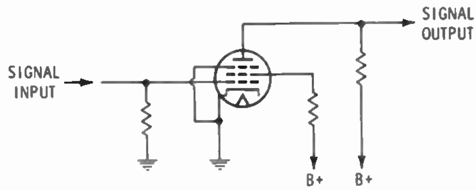


Fig. 5-13. Simplified schematic of a pentode amplifier circuit.

detailed here, it is often convenient to add two more grids to the triode, making it a five-element tube called a pentode (Fig. 5-12).

The pentode operates basically the same as a triode, but it is much more efficient. The control grid is the same as the control grid in the triode. The filament, cathode, plate, and control grid are connected as before.

The screen grid is usually connected to a resistor, which, in turn, is connected to the positive high voltage (B+), as shown in Fig. 5-13. The suppressor grid is almost always connected directly to the cathode. In fact, in many pentodes, they are connected inside the tube itself.

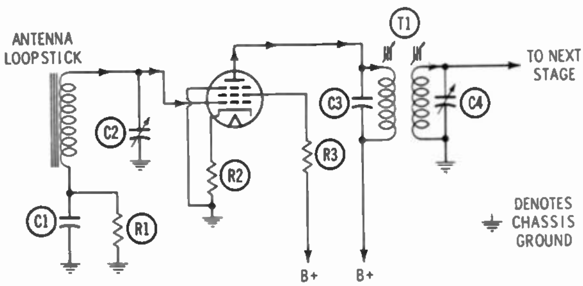


Fig. 5-14. Complete schematic of a pentode RF amplifier.

The control, screen, and suppressor grids are frequently called grids number 1, number 2, and number 3, as indicated in Fig. 5-12.

When the pentode is connected as an RF amplifier, it will look like the circuit in Fig. 5-14. You can see by comparing this to Fig. 5-11 that the two schematics show that substituting the pentode for the triode has not really changed the circuit at all. It has simply required the addition of two components (screen-dropping resistor R3 and screen-bypass capacitor C5) which are not in the signal path.

Chapter 6

THE CONVERTER

The converter is usually the first stage in most AC/DC radios, although some do use an RF amplifier first.

The converter stage is actually two tubes in one package—the local oscillator and the mixer. In any block diagram of an AM receiver (Fig. 6-1), the converter is shown as two separate stages, the oscillator and mixer.

MIXING RADIO WAVES

One of the jobs the converter does is mix two radio signals together. It combines the incoming RF with the signal from the local oscillator. When these two frequencies are combined this way, the result is two different output frequencies—one equal to

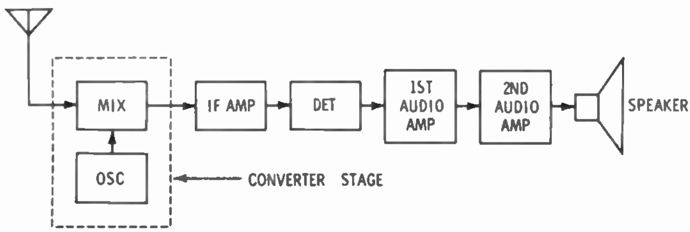


Fig. 6-1. Block diagram of a simple superheterodyne receiver.

the sum of the two inputs and the other to their difference. These outputs are called *beat frequencies*, and the mixing action that produces them is called *heterodyning*.

If two frequencies—call them A and B—are heterodyned as shown in Fig. 6-2, there will be two widely different beat frequencies, 2500 kc and 500 kc. Both output frequencies would be available at the output of the mixer, but we want only one of them to use in the radio.

In actual practice, the output frequency is usually 455 kc. This is the *intermediate frequency* (IF) used in most AM standard broadcast receivers. It is the job of the converter stage to take any input RF in the tuning range and change it to 455 kc with the modulation sidebands intact.

Some manufacturers may vary the IF and you might find sets with an intermediate frequency as low as 262 kc and as high as 465 kc. Since 455 kc is the most popular in the U. S., it will be used in the examples in this book.

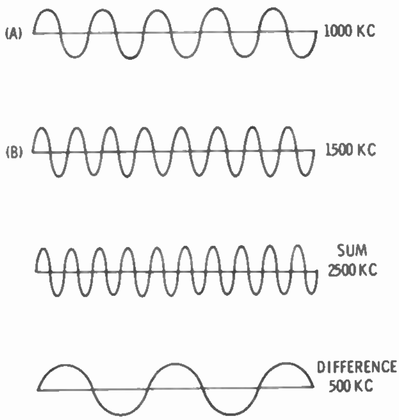


Fig. 6-2. Example of heterodyning two different frequencies.

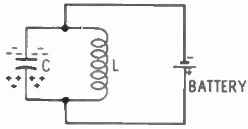
To obtain the proper beat frequency, the oscillator frequency is always kept exactly 455 kc higher than the incoming signal. Thus, if a station is broadcasting at 800 kc when the receiver is tuned, the oscillator will be putting out 1255 kc.

The 800 kc is then subtracted from the 1255 kc giving the 455-kc IF. If the station tuned is at 1600 kc, the oscillator will operate at 2055 kc, again giving the proper 455-kc output.

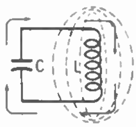
OSCILLATORS

In Chapter 1 an oscillator was described as an electronic circuit that generates radio-frequency alternating current. Just as an oscillator is used in a radio transmitter, it is also used in a receiver, this time to produce the 455-kc intermediate frequency.

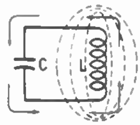
The basic element in any oscillator is the tuned circuit. In a typical circuit, such as in Fig. 6-3A, an external voltage charges up the capacitor (C). In the condition shown in Fig. 6-3A, the upper plate of C is charged negatively—it contains an excess of electrons.



(A) Capacitor charged.



(B) Capacitor discharging through inductance.



(C) Reversing of discharge through inductance.

Fig. 6-3. Principle of damped oscillations.

If the battery is removed, as in Fig. 6-3B, the excess electrons will rush through the coil (L), to the lower plate to equalize the capacitor charge.

While these electrons are in motion through L, the coil builds up a magnetic field. When the current stops flowing, the magnetic field collapses, its lines of magnetic flux cut the wires in L, and an electric current is generated, in the coil, flowing in the opposite direction, as shown in Fig. 6-3C.

Current will flow in the entire tank circuit, since electrons flow from the lower plate of C to replace electrons that move from L to the upper plate of C.

Now once more, the upper plate of C has an excess of electrons, and the whole process starts over again. This is not a perpetual-motion machine; the amount of current that flows decreases because of losses in the circuit (such as resistance and hysteresis), and eventually the current stops flowing entirely.

But what is created with this circuit? The current flows back and forth (*oscillates*) at the natural resonant frequency of the circuit. The waveform it generates is called a *damped oscillation,* since it diminishes to zero and looks like Fig. 6-4.

This is exactly the same kind of oscillation you would get if you pushed the pendulum of a clock that is not wound. The pendulum will oscillate—it will swing back and forth, a little less each time, until it stops. All this time it will still swing at its natural "frequency" of one complete swing each second. Again,

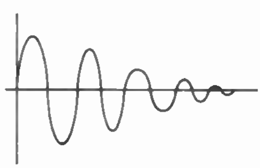


Fig. 6-4. Graph of damped oscillation waveform.

this is a damped oscillation, since there are losses in the mechanical system—friction this time.

But if you give the pendulum a little push each time, it will sustain the oscillation; you can give it this push by winding the spring.

The same is true of the tank-circuit oscillator in Fig. 6-3. Here you can provide the push with the energy from a power supply, and the timing of the "push" can come from a vacuum tube connected to the circuit.

A basic oscillator circuit is shown in Fig. 6-5. The plate is inductively coupled to the input through coils L1 and L2. Any small instability in the circuit will start the tube oscillating; these small instabilities occur constantly.

When current flows in the plate circuit, some of the signal goes back to the grid through the inductive coupling between L1 and L2. The tank circuit (L2-C1) will begin oscillating at its resonant frequency, feeding this signal to the grid of the tube through capacitor C2. Resistor R1 provides the grid bias.

Useful output can be taken from the oscillator directly from the plate and through coupling capacitor C3. Remember, capacitors pass alternating currents and block direct currents.

There are many different types of circuits that can be used with a triode to produce controlled oscillation. The one thing that all must have is a tank circuit of one kind or another. It is possible for a circuit to oscillate without the tank circuit, but only if the tube is operated beyond its normal limits. Then it will not be a controlled oscillation at a specific frequency.

The tuned circuit always determines the *precise* frequency of oscillation. The *general* frequency range of operation is determined by the characteristics of the tube being used.

The basic design used in most AM radios is the Hartley oscillator shown in Fig. 6-6. This circuit does not use the separate inductively coupled coils used in Fig. 6-5. Instead, the plate is connected to the lower half of coil L1. The tap on the coil goes to

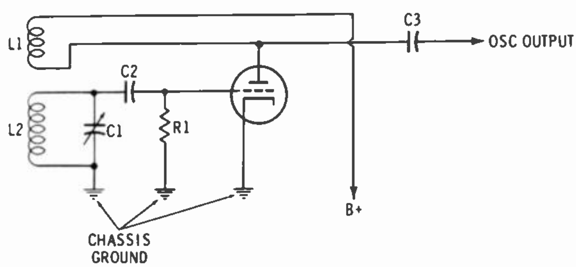


Fig. 6-5. Basic triode oscillator circuit.

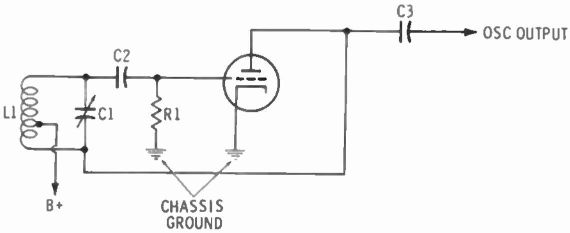


Fig. 6-6. Schematic of basic Hartley oscillator circuit.

the high-voltage supply (B+), providing positive voltage for the plate.

Even though the two sections of the coil are really the same coil with a tap, they act as if they are separate, inductively-coupled coils. The lower portion induces a current in the upper section, which is part of the tuned-circuit grid input. Again, C2 provides coupling to the grid, and R1 is the grid-bias resistor.

Another Hartley oscillator is shown in Fig. 6-7. In this circuit there is no direct coupling between the plate and grid. The obvious question is how does it work?

Remember that for plate current to flow, electrons have to come from somewhere, and they come from the cathode. Because of this, the cathode current will be the same as the plate current (varying at the same rate), and since the cathode is connected to the tap on L1, it provides the necessary coupling to the grid. Again, R1 provides the grid bias.

The Colpits oscillator (Fig. 6-8) is an alternative type sometimes used in radio receivers. The plate is coupled directly through L1, and it uses a tap at the center (common) point of two capacitors instead of a tapped coil as does the Hartley. This circuit has a tendency to 'overproduce"; that is, it produces such powerful oscillations that secondary, unwanted *parasitic* oscillations may occur. Using L2 in place of the resistor normally located at this point helps prevent unwanted oscillations.

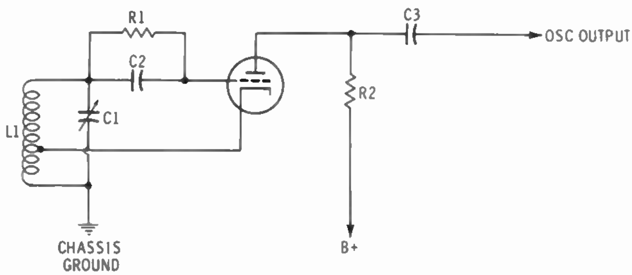


Fig. 6-7. Schematic of a practical Hartley oscillator.

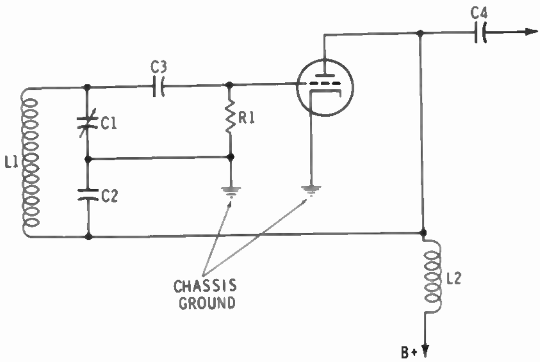


Fig. 6-8. Schematic of a Colpitts oscillator.

MIXING THE SIGNALS

If an oscillator, such as the Hartley, is connected to an RF amplifier circuit taken from Chapter 5, the resulting circuit will be something like Fig. 6-9.

The two stages shown are inductively coupled by L1 in the cathode circuit of the mixer, picking up the local oscillator frequency from tank coil L2.

With this arrangement the cathode current available in tube V1 varies with the oscillator output. If there were no RF signal

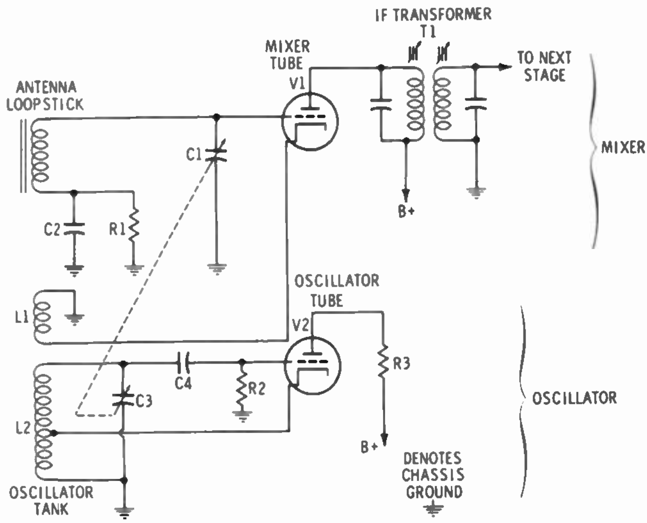


Fig. 6-9. Schematic of separate triode oscillator and mixer.

at the grid of V1, then just the local oscillator frequency would appear at the mixer plate.

Once there is an RF signal on the grid, heterodyning takes place. The difference signal is selected by the tuned circuits in IF transformer T1 and is passed on to the next stage.

THE CONVERTER TUBE

Using two triodes in this manner is very cumbersome. In most AC/DC sets a combination tube, called a *pentagrid converter,* is used. This tube has five grids, and the general wiring is shown in Fig. 6-10.

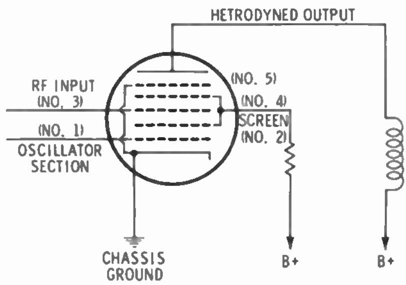


Fig. 6-10. Diagram of a pentagrid converter tube.

The tube is not as complicated as it looks at first glance; it has the conventional suppressor grid connected internally to the cathode although now this is grid number 5. There are two screen grids, numbers 2 and 4, tied together inside the tube and conventionally connected to the high-voltage supply through a resistor like the pentode.

The first control grid (grid number 1) is connected to the oscillator input while grid number 3 is coupled to the RF input signal.

Fully wired as a converter stage, the pentagrid tube looks something like Fig. 6-11. Fig. 6-12 is a photo of the same stage as it appears in a conventional AM radio.

Starting from the left of Fig. 6-11, the incoming radio station signal is picked up by the loopstick antenna, which forms part of a tuned circuit with capacitors C1 and C2. C1 is one of the sections of the tuning capacitor, while C2 is a small *trimmer* capacitor used to make adjustments at the factory and by technicians servicing the set. Bias for grid No. 3 is provided through R1, which is not a single resistor but really several resistances in the circuit. For all practical purposes, there is a single resistor (R1) at that point.

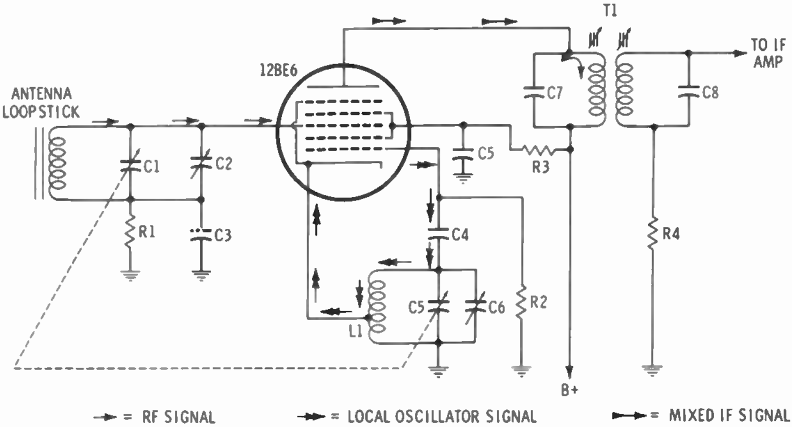


Fig. 6-11. Schematic of a fully wired pentagrid converter circuit.

The lowest section of the tube, the cathode and grids No. 1 and No. 2, acts as a separate tube. The screen grid is much more positive than the cathode and attracts electrons the same way a plate would. These electrons develop a voltage across the oscillator tank circuit (L1 and C5); C6 is a trimmer capacitor. The signal then passes through the tap on the coil to the cathode. Notice that the conditions are exactly the same as for the conventional triode Hartley oscillator explained previously. The tube oscillates, with more than enough of the oscillator output leaking through

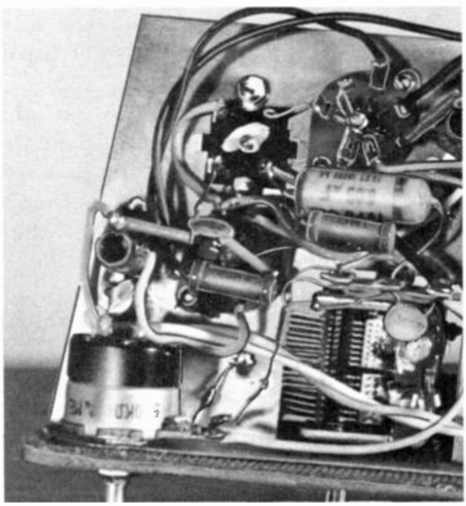


Fig. 6-12. A complete converter stage.

grid No. 1 to the rest of the tube. In operation, just enough grid current flows in grid No. 1 to maintain the oscillation. The rest of the energy travels through the other grids to the plate.

The electron stream, varying at the oscillator frequency, is further altered by the changes in grid voltage on grid No. 3. This is the second control grid and the signal there is the incoming RF from the antenna. This is where the heterodyning action takes place, and the signal that arrives at the plate is a composite of the two beat frequencies.

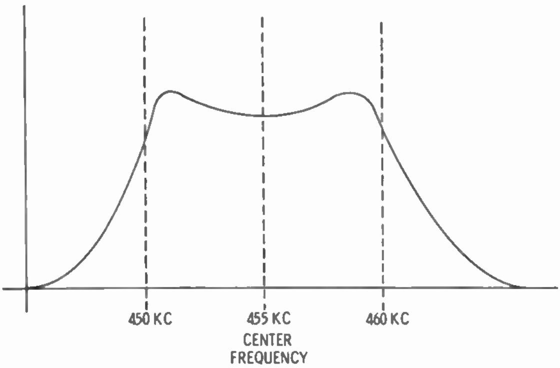


Fig. 6-13. Bandpass characteristic of an IF transformer.

THE IF TRANSFORMER

Transformer T1 is called an IF transformer and is really made up of two tank circuits that are inductively coupled. The capacitors in this transformer are fixed, but the inductance of the two coils can be varied with screwdriver adjustments in the transformer can. This process is known as *alignment* and is one of the last steps taken when the radio leaves the factory. Either the inductance or capacitance can be varied for alignment but in actual transformers only one is made variable.

The transformer tank circuits are tuned for the 455-kc IF. All other frequencies except those very close to 455 kc will be rejected—they just will not be able to pass through. Only the sidebands contained in the composite IF are allowed to pass. The frequency bandpass characteristic of the properly adjusted IF transformer is shown in Fig. 6-13.

Chapter 7

THE IF AMPLIFIER

As the name implies, the purpose of the IF amplifier is to amplify the intermediate frequency. The single tube used in this stage is a high-gain pentode that takes the 455-kc input signal from the secondary of the IF transformer, boosts it, and feeds it to the detector transformer (which is usually a duplicate of the IF transformer).

The IF transformer is normally mounted in a metal can, as shown in the photo in Fig. 7-1. Inside the can are capacitors C1 and C2, that are shown schematically in Fig. 7-2. These are fixed capacitors selected to give the resulting tank circuit a resonance at 455 kc. While the two capacitors in this example are not adjustable, the inductance of the transformer coils is. The coils are usually adjusted with a screwdriver or other long-shaft tool that

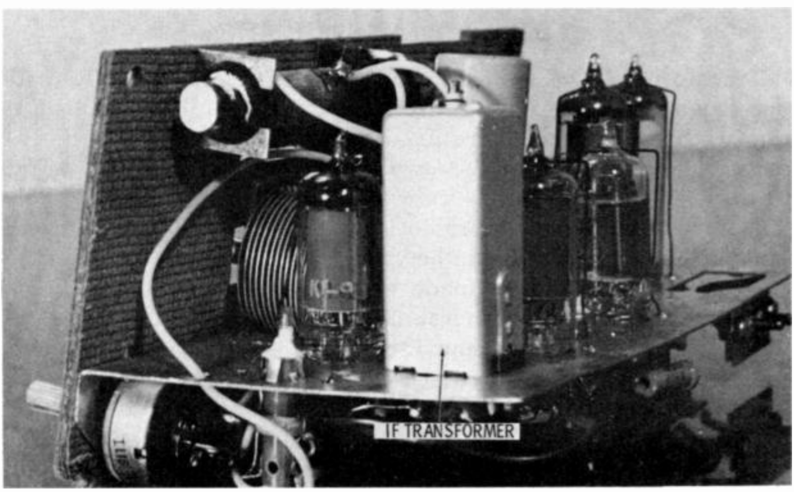


Fig. 7-1. IF transformer is enclosed in metal can.

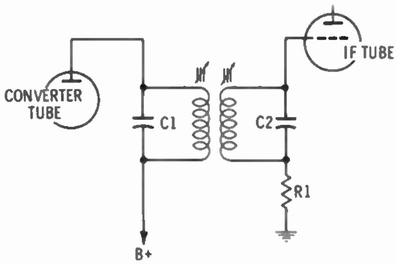


Fig. 7-2. IF transformer is made up of two adjustable tuned circuits.

can fit through the hole in the top and bottom of the IF transformer can.

The changes in coupling that can be made are shown in Fig. 7-3. The narrow peaked curve shown in the figure results from improper adjustment of the coils. This type of response does not pass enough of the sidebands through the transformer. On the other hand, the wide, flattened-out curve with the 10-kc bandwidth shows good coupling. As indicated in Chapter 5, a radio becomes cumbersome when it is made up only of RF amplifiers, and in addition to this, there is the difficulty in selecting component parts that match from one stage to the next, the reduced selectivity of the TRF receiver, and the much higher cost encountered with such a radio.

In the superheterodyne radio a single IF amplifier tube with sharply tuned tank circuits in its input and output networks can provide more than enough selective amplification in a carefully fixed bandwidth. The IF transformers are factory assembled for the standard intermediate frequency and sidebands, and then the resonant frequency is adjusted to the precise frequency in the radio. Also, the IF transformers each contain two tuned circuits—a total of four such tanks for the one 455-kc frequency. By the time

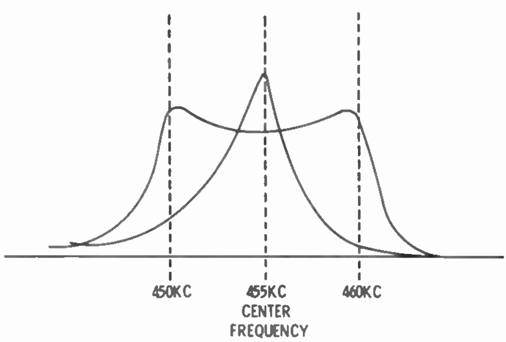


Fig. 7-3. Improperly coupled IF transformer gives sharp peak. Properly coupled unit has flattened response.

the signal passes through these circuits, it is virtually impossible for any other spurious frequencies to be mixed with it.

A typical IF stage is shown in Fig. 7-4. The dashed lines in Fig. 7-4 indicate that the capacitors are inside the transformer cans. Thus, capacitors C1 and C2 are encased with T1, and C3 and C4 with T2.

Resistors R1 and R3 are not actually single resistors, but represent several resistors in series in a special circuit called the *automatic volume control* (AVC). This circuit is covered in the

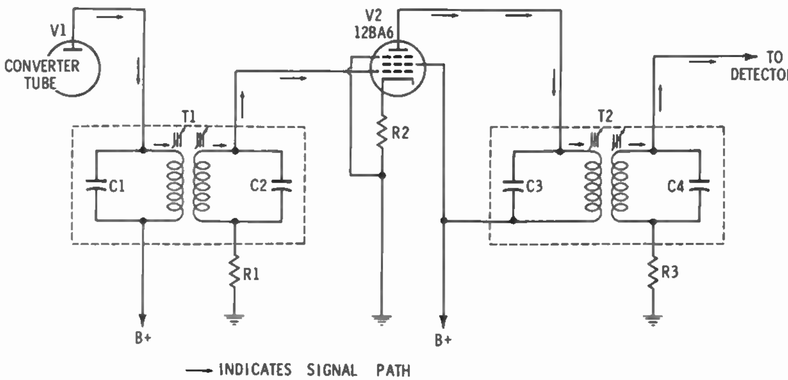


Fig. 7-4. IF amplifier stage uses single amplifier pentode and two IF transformers.

next chapter. For the present, R1 and R3 should be regarded as single resistors that provide grid bias.

The cathode in the IF amplifier may be biased instead of being grounded, as it almost always is in RF amplifiers. In Fig. 7-4, R2 supplies the bias, but its value is so small that the positive DC voltage at the cathode is almost zero and, for all practical purposes, can be ignored. Resistance R1, on the other hand, is very large, causing a large voltage drop in the grid circuit. The grid thus remains more negative than the cathode.

Once the transformers are wired into the circuit, it is impossible for any frequency to pass through the IF amplifier, except the 455-kc intermediate frequency. When the transformers are properly coupled, they will also pass the sidebands. With this arrangement, four precisely tuned tank circuits are placed in the signal path assuring single-frequency operation, as opposed to the TRF receiver where there is always the possibility of passing other frequencies.

The suppressor grid (No. 3) in the pentode is usually grounded for best operation. In Fig. 7-4 this grid is connected directly to ground instead of the cathode. In other cases, it may be connected to the cathode.

The arrows above the transformers in the schematic diagram indicate that they are adjustable. This variable tuning can also be indicated by the use of other methods, as shown in Fig. 7-5. Very frequently, these arrows are omitted entirely.

Fig. 7-5. Some methods of indicating variable tuning in transformers.

The adjustment is usually accomplished by placing a movable core of powdered iron in the interior air space of the coils. When the core is moved up or down, the inductance of the coils is changed.

Another method that is not too frequently used, but appears in some older radios, is to adjust the capacitance in the tank circuit. Adjusting the capacitor changes the resonant-frequency characteristics of the coil and capacitor—the same as adjusting the coil.

Chapter 8

DETECTOR AND AUDIO

The detector stage and first audio amplifier are usually combined in the same glass tube. Like the converter tube, this is a dual-function device. A typical detector-amplifier tube is shown in Fig. 8-1. It is made up of a diode and a triode section, using the same cathode for both.

Fig. 8-1. Schematic symbol for detector and audio amplifier tube.

DEMODULATING THE CARRIER

Remember that at the radio transmitter, an audio signal (voice, music, etc.) is impressed on the RF carrier. This audio signal modulates the carrier, changing the carrier amplitude at an audio frequency rate. In the receiver, the frequency of the carrier is lowered to the 455-kc intermediate frequency. This IF still carries the audio modulation (Fig. 8-2), and now the problem

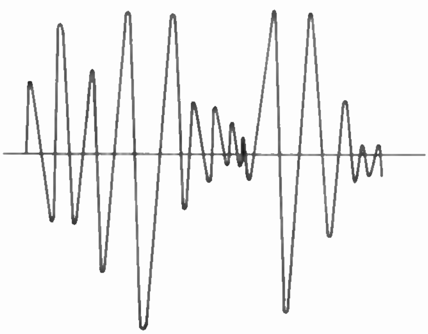


Fig. 8-2. Modulated IF signal.

is separating the audio from the IF. The problem was the same with crystal sets and TRF receivers. The only difference in them was that the RF itself instead of the IF, was demodulated—simply a case of the carrier of modulation being at a higher frequency.

The crystal set used a crystal diode for a detector. The modern AC/DC receiver uses a vacuum-tube diode, but both types perform the same function, rectification of the signal.

In the simplified circuit shown in Fig. 8-3, the IF signal is taken from the tank circuit (L1-C1), which is the secondary of the second IF transformer, sometimes called the detector transformer.

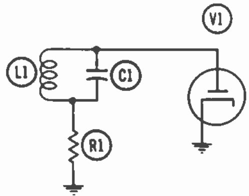


Fig. 8-3. Basic detector circuit.

The signal is applied to the plate of the diode, and during the positive half-cycles, when the plate is positive, electrons will flow from the cathode to the plate. In the chapter on power supplies this action was called rectification, and it is no different here, except that the frequencies are much higher. The result of this rectifying action is a waveform that is cut in half, as shown in Fig. 8-4. Look familiar? It is pulsating direct current. When pulsating DC was in the power supply, it ran through a filter to smooth out the pulsations, and exactly the same thing can be done here. But now there is a difference: there are two kinds of pulsations, at the IF rate and at audio frequencies.

The audio frequency variations are the ones to keep while the 455-kc pulsations must be smoothed out. This can be done by selective filtering. The size of a capacitor (that is, its capacitance) determines how it will behave in a circuit. The larger the capacitor, the lower the frequencies it will handle, while smaller capacitors will handle higher frequencies. When a capacitor passes

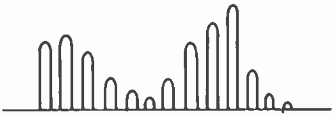


Fig. 8-4. Signal at plate of detector diode.

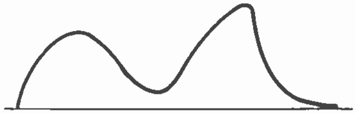


Fig. 8-5. Detected audio signal after filtering.

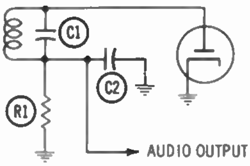


Fig. 8-6. Detector circuit with filter.

an AC voltage, it is actually charging up and discharging at the frequency rate of the signal applied across it.

If the value of a filter capacitor is made high enough, it fills in the valleys in the DC that is pulsating at the 455-kc frequency, but it will not affect the audio pulsations. This results in a pure audio signal, as shown in Fig. 8-5.

A detector circuit is shown in Fig. 8-6. Capacitor C2 does the filtering and the audio output appears across resistance R1. R1 is actually several resistors in the circuit, which are described later.

AUDIO AMPLIFICATION

Now that an audio signal has been obtained, it must be amplified to a level high enough to operate a speaker. The 12AV6 tube shown in Fig. 8-1 is a dual tube. The same glass bulb contains both the detector and a triode. The detector is actually made up of two plates. The reason for this is that some manufacturers will introduce circuit refinements that depend on having two plates available, but it is common practice to tie the two together, as shown in Fig. 8-7.

After filter capacitor C2 has finished with the signal, the newly detected audio is coupled through capacitor C3 to the grid of the triode section of the tube, the first audio amplifier.

The arrows in Fig. 8-7 show the path that the signal follows. If it looks as though the rectified signal (pulsating DC) is flow-

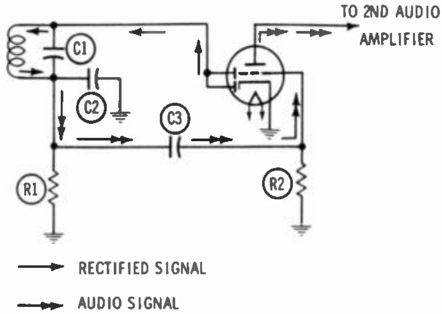


Fig. 8-7. Detector circuit coupled to first audio amplifier.

ing backward, remember that current in the tube goes from the cathode to the plates. The IF signal voltage appears at the diode plates, causing diode current to flow when the plates go positive. This pulsating DC then goes back through the tank circuit, is filtered by C2, and is then coupled to the first audio amplifier.

An audio amplifier is basically the same as an RF or IF amplier—it takes a weak signal at the grid and delivers a boosted (amplified) signal to the plate. Of course, the actual design of the tube is somewhat different inside, making it more suitable for use at audio frequencies.

Volume Control

At this point in the circuit, radio manufacturers usually insert a variable resistor. This is used as a volume control for the radio. A volume control is shown in Fig. 8-8. As control R2 is varied,

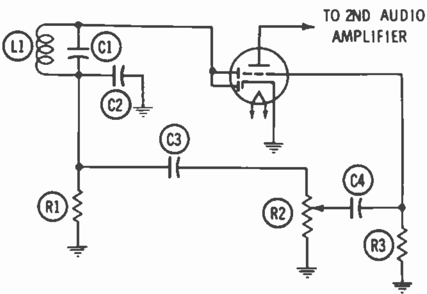


Fig. 8-8. Detector circuit, first audio amplifier and volume control.

it changes the amount of resistance in series with the signal. As this series resistance increases, the signal strength at the movable contact (which is coupled to the tube via C4) is decreased. All this does is lower the volume coming out of the speaker. Conversely, as R2 is varied in the opposite direction, it decreases the series resistance to the audio signal and increases the signal coupled to the grid, causing an increase in the plate current of the audio amplifier. This increases the volume.

Automatic Volume Control

Not to be confused with the volume control just discussed, the automatic volume control (AVC) is an important circuit used in most AM receivers. To understand why this circuit is necessary, go back to the antenna circuit for a moment.

When a radio-frequency carrier strikes the antenna, it induces a current flow in the antenna. This current flow, which is the radio signal, depends on the strength of the RF field at the antenna. RF fields are seldom constant in strength, except when they are very close to the transmitter. Changes in atmospheric conditions cause variations in field strength. The fields actually move so that a high-strength point may strike the receiving antenna and then move on, leaving the antenna with a field that is much weaker. This causes *fading* of the received signal.

The AVC circuit is added to avoid this fading. It samples the strength of the signal at the detector and develops a signal voltage proportional to the field strength. If there is a strong signal at the detector, then the AVC signal will be strong. This signal is coupled to the grids of the preceding stages (the converter and the IF amplifier) and is called *feedback* (Fig. 8-9) and lowers the gain of the radio.

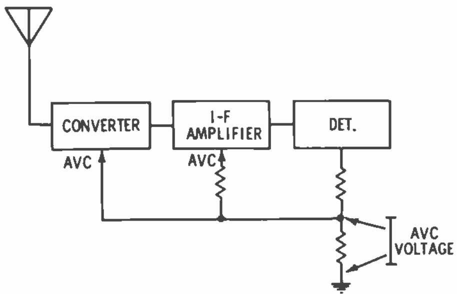


Fig. 8-9. AVC voltage is applied to converter and IF amplifier.

What this feedback does is increase the grid bias on the first two stages whenever the signal strength at the detector output increases. This makes the grids more negative, and they conduct less, thus cutting down the signal strength. It works in reverse, also. As the signal strength at the detector decreases, the AVC voltage decreases the grid bias, permitting more amplification.

The AVC does not vary with varying audio amplitude—this would make very low musical passages as loud as an orchestral crescendo. It just compensates for fading caused by changes in the RF field strength.

The connecting points for the AVC network are shown in Fig. 8-10. The AVC voltage appears at point A in the detector circuit, and is coupled to the RF and IF amplifiers via resistor R2. C5 serves as a filter capacitor to remove any RF variations from the line.

One resistor and capacitor is all it takes to add AVC to a radio, although sometimes manufacturers may place an additional resistor and capacitor in the line between the converter and IF amplifier for isolation.

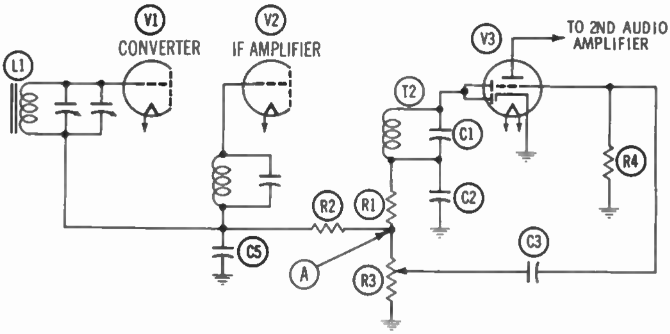


Fig. 8-10. Circuit connections for AVC.

More Amplification

Although the triode section of the detector-audio tube amplifies the audio signal, this still is not quite enough to operate a speaker. So the triode is coupled through a capacitor to the second audio amplifier, a high-power pentode (Fig. 8-11). The cathode of the pentode is isolated from the chassis by a small resistor R3. Cathode bias is provided by the electrons flowing upward through this resistor to the tube. R2 provides the usual grid bias and R4 is the screen grid dropping resistor.

The high voltage for the plate is applied through the primary coil of transformer T. This is the *output* transformer, and it has two main functions. First of all, it steps down the voltage, and by doing this, steps up the current since the speaker needs a lot of current to drive it.

The second job the transformer does is called *impedance matching*. Impedance is a special kind of resistance that a coil has to alternating current, and the voice coil in the speaker has a specific impedance that must be matched by the same amount of impedance in the transformer secondary. This matching provides maxi-

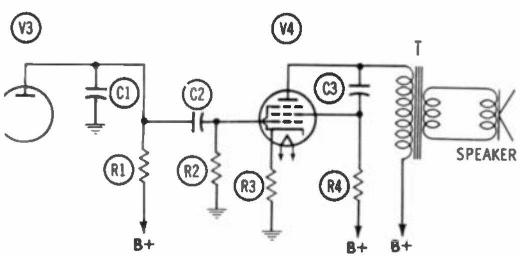


Fig. 8-11. Second audio amplifier, output transformer, and speaker.

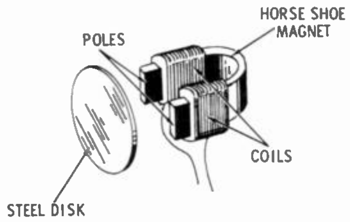


Fig. 8-12. Elements of an earphone.

mum coupling with very little loss of power between the transformer and speaker. It also cuts down distortion.

The Speaker

The final step in this long chain of electronic events is converting the audio signal voltage into audible sound. The classic method, first invented by Alexander Graham Bell, is the earphone, and this method was used with crystal receivers since they could not develop enough power to operate anything larger.

An earphone consists of two basic parts—an electromagnet and a metal diaphragm (Fig. 8-12). A horseshoe-type permanent magnet is usually used, and coils are wound around the two legs of the magnet. When an audio signal is applied to the coils, they build up magnetic fields that either partially cancel (buck) or boost the already existing fields of the magnet. This causes the magnet to pull or push the iron disc which is the diaphragm of the earphone. The disc vibrates at an audio rate and reproduces the sound that was first converted to an electric current when it struck the diaphragm of the microphone described in Chapter 2 and shown in Fig. 2-10.

An earphone is not the most effective way of converting electrical energy to sound; it has the main disadvantage of limited volume. Some early attempts to obtain more volume from the earphone involved using a curved megaphone, as shown in

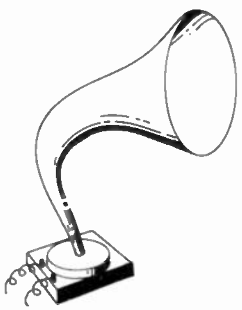


Fig. 8-13. Earphone with megaphone on early TRF receiver.

Fig. 8-13. These "loudspeaking" earphones were frequently used with TRF receivers before speakers were perfected.

The speaker as we know it today went through several periods of development. The electrodynamic type shown in Fig. 8-14 was popular in the 1930's. This type of speaker had a coil of wire cemented to the cylindrical rear portion of the paper cone. This coil was free to move in the field of a powerful electromagnet. The electromagnet was usually electrically connected in the power-supply filter circuit, where it acted as a choke coil. At the same time, this arrangement provided DC for the electromagnet.

When an audio voltage is applied to the voice coil, the magnetic flux generated around the coil interacts with the flux of the electromagnet, causing the voice coil (and the entire speaker cone) to move in and out of the magnetic field, vibrating at an audio rate. Because of the flexibility and resiliency of the paper cone, it can reproduce sounds much more accurately than the metal diaphragm in the earphone. And perhaps more important, it can produce room-filling amounts of sound.

The introduction of the permanent magnet speaker provided major improvement. This speaker (Fig. 8-15) uses a powerful *Alnico* magnet to provide the field. Aside from this, the basic operation is the same but this change has given the speaker much more flexibility. No longer must the radio power supply and speaker be designed together. The power supply operates completely independently of the speaker magnet. Sound quality has improved too, since the field is not disrupted by line voltage ripple. The permanent magnet also means that a speaker can be moved relatively far from a radio if necessary, and thus makes it possible to add extension speakers—additional speakers attached to the same radio or amplifier.

An added advantage of the PM (permanent-magnet) speaker is its wide variety of possible sizes and shapes. They are made

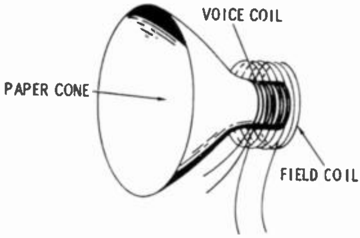


Fig. 8-14. Construction of electrodynamic speaker.

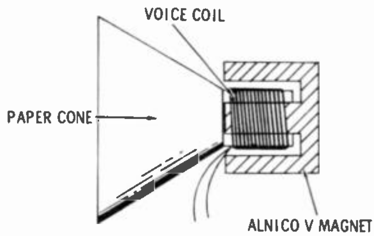


Fig. 8-15. Construction of a permanent-magnet speaker.

in oval shapes for automobile radios, in miniature for pocket-size transistor sets and in enormous sizes for theater sound systems. Further refinements in speaker design along with a better understanding of audio reproduction have led to highly specialized and carefully produced speakers that form the core of high-fidelity sound systems.

Chapter 9

THE COMPLETE AM RECEIVER

Now that all the separate sections of the AM receiver have been discussed, it is time to put them together (Fig. 9-1). The first element is the antenna where the broadcast-station signal is picked up by the radio. It can be one of several types, but the most commonly used antenna today is the ferrite loopstick.

POWER SUPPLY

The antenna feeds a series of vacuum-tube circuits (Fig. 9-2), and all of these stages require specialized types of electrical power, most important of which is high-voltage direct current. The 110-volt AC house current must be changed to DC for the high-voltage supply. This is done with a rectifier tube (or semiconductor rectifier) and a filter circuit.

The rectifier tube changes the AC to pulsating DC, and the filter smooths this into straight-line DC. The positive high voltage, called B+, is usually about 110 volts DC in five-tube AC/DC sets.

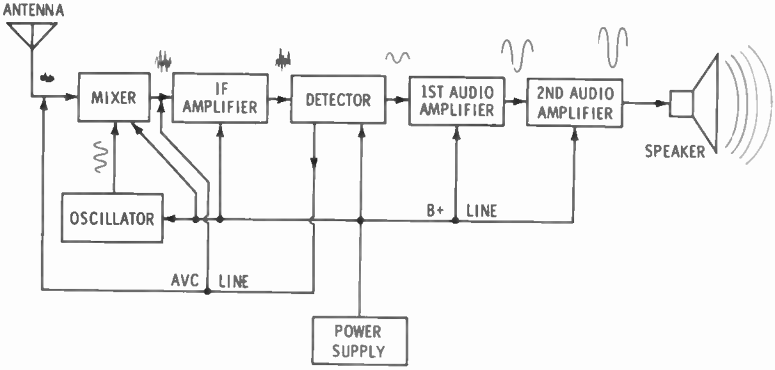


Fig. 9-1. Block diagram of the complete AC/DC radio.

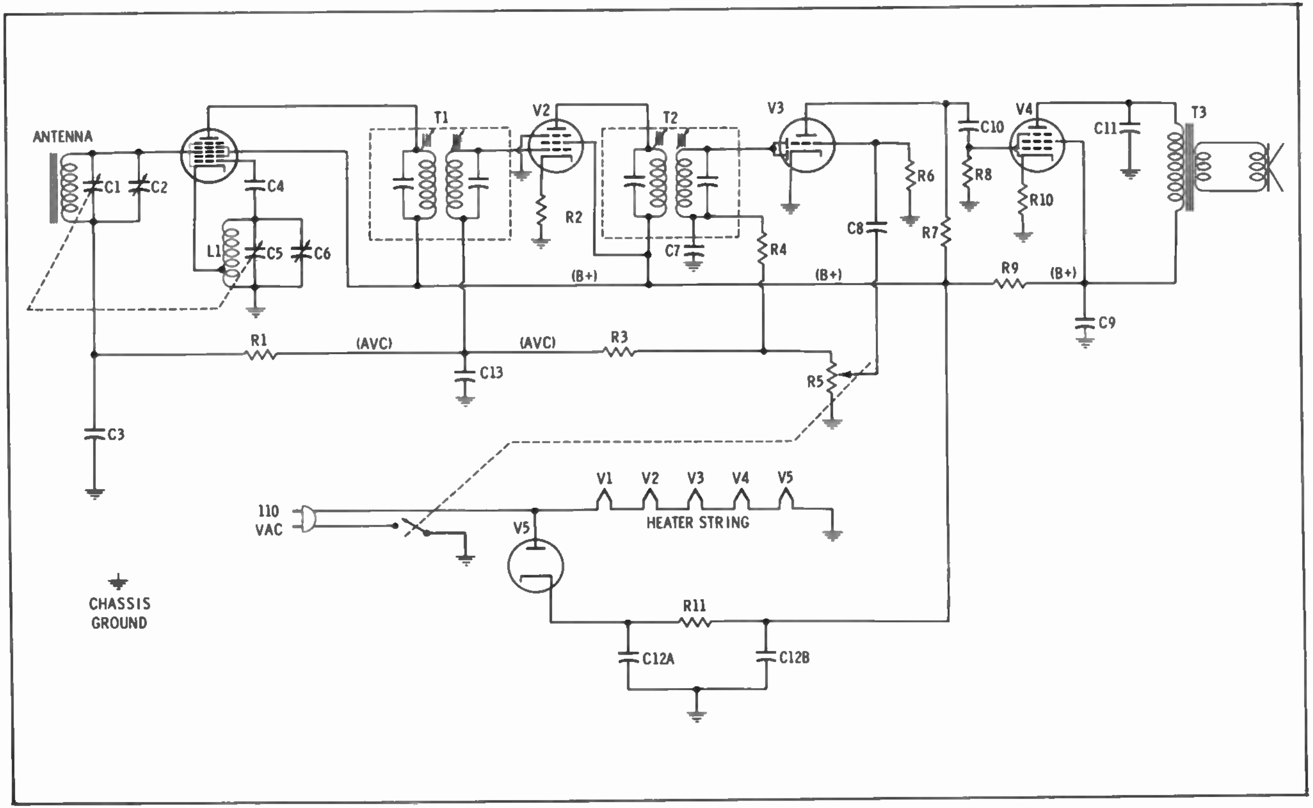


Fig. 9-2. Schematic of an AC/DC radio.

Line dropping resistors lower this to about 90 volts for some circuits. The B− is connected directly to the metal chassis which becomes the common negative, or *ground*, point for the entire radio receiver.

HETERODYNING ACTION

The RF signal from the antenna circuit is mixed with a signal from the local oscillator. The local oscillator is one section of a pentagrid (five-grid) tube known as the converter (V1). The cathode and grid No. 1 act as a separate tube, oscillating at a frequency exactly 455 kc higher than the RF input. The oscillator and RF signals are mixed electronically in the tube (V1), and the output is two different beat frequencies, the sum of the two signals and their difference. The difference signal is the intermediate frequency, 455 kc, and it is selected by the tuned circuits in the first IF transformer.

The first IF transformer also couples the converter to the IF amplifier stage. The amplifier (V2) boosts the 455-kc signal and its sidebands, and the output is coupled to the next stage through another IF transformer. The two IF transformers provide a total of four tank circuits which effectively restrict the signal to only the intermediate frequency and its sidebands. These circuits are tuned to the intermediate frequency by the adjustment of the coils. This adjustment is known as *alignment*. The proper adjustment will allow sufficiently wide sidebands to pass through the transformers to carry the complete audio signal. This bandwidth is usually about 10 kc.

The IF amplier is transformer-coupled to the detector stage, which is one half of a dual-function tube (V3). The coupling transformer is the second IF transformer. The secondary tank circuit of this transformer is connected to the plates of the diode section of the detector tube. Rectified (pulsating) DC appears across the tank circuit, pulsating at both the 455-kc intermediate frequency and the audio frequency.

The signal is then filtered by capacitor C7 (Fig. 9-2) which is a value selected to filter out the 455-kc IF pulsations while leaving the audio pulsations intact. The audio output signal appears across resistors R4 and R5. A portion of this signal is selected by the setting of variable resistor R5 (the volume control) and coupled via C8 to the grid of the audio amplifier section of the tube (V3).

The amplified audio signal is coupled through capacitor C10 to the second audio amplifier (V4). This is a high-gain tube, frequently a type known as a beam-power pentode because of special beam-forming electrodes in the tube that concentrate the stream of electrons.

The output of the beam-power tube (V4) goes to output transformer T3. The secondary winding of T3 matches the impedance (AC resistance) of the speaker voice coil. The high-current signal on the secondary of T3 drives the speaker, thus producing audible sound.

Adjustments in the radio include the two normal front-panel controls—tuning and volume. The tuning is done by varying capacitors C1 and C5—the RF tank-circuit capacitor and the local-oscillator capacitor. These two variable capacitors are ganged, as indicated by the dashed lines connecting them. The volume control R5 is ganged with on-off switch S1, indicated by dashed lines connecting the two.

The power supply consists of rectifier tube V5 and the filter network (C12A, C12B, R11, R9, and C9). The sixty-cycle alternating current present at the plate of V5 causes current to flow from the cathode to the plate only during the positive half cycles. The resulting pulsating DC is filtered by the filter network capacitors. The capacitors charge up during the peaks of current flow and discharge when no current is flowing, thus smoothing the waveform of the current.

PRINTED CIRCUITS

The printed circuit was first introduced in electronics during World War II. At the time, it was very costly and was used only where such high cost was justified for miniaturization—mainly in proximity fuses for antiaircraft shells.

The technology of printed circuit production was not very far advanced by the end of the war, and printed circuits remained much too expensive to be used commercially for the first few years of the postwar period.

With the lowering of production costs, printed circuits (abbreviated PC) became very popular for use in consumer products, including home radios. Use of the PC board permits the manufacturer to automate his production facilities. Instead of the many hand-soldering operations, the PC board already contains all the wires in the form of narrow strips of copper foil (Fig. 9-3). Components are inserted through holes in the board and soldered to the foil.

This foil is bonded to a resin board that is a good insulator, and individual foil circuit paths can run very close to each other on the board without shorting to each other. The entire layout has a very neat and orderly appearance.

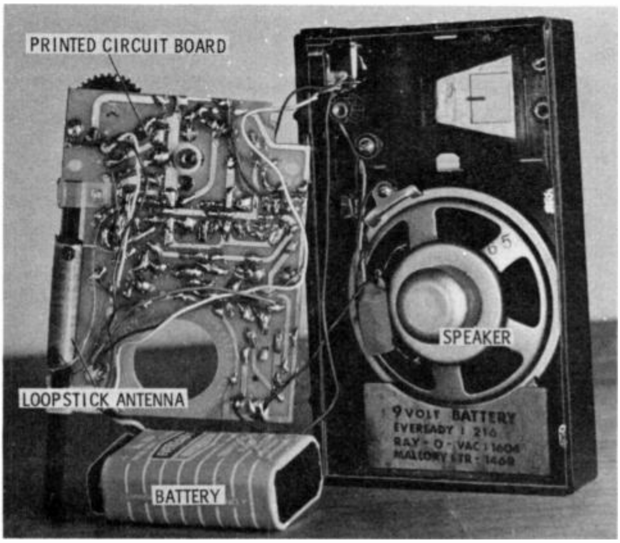


Fig. 9-3. Printed-circuit board used in transistor radio.

Usually the components are all mounted on the top of the board away from the circuits. The connections to the foil are made through holes drilled in the board (Fig. 9-4), and wires are dip-soldered to the foil in a single factory operation.

Because all the components are mounted above the board, it is not always as easy to trace the individual circuits, but the components will usually be grouped around the tube or transistor that they are connected to. Since there is no chassis to use as a ground point, additional circuit paths are needed for the common (B−) connections.

Miniaturization is the chief advantage of printed circuits and is the reason that they were first developed. Conventional components mounted on a PC board can be squeezed into a much

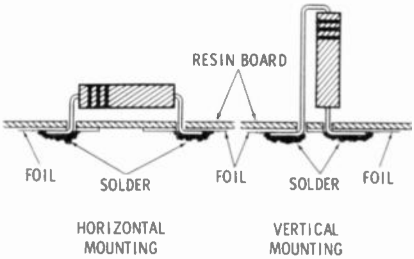


Fig. 9-4. Two methods of mounting components on printed-circuit board.

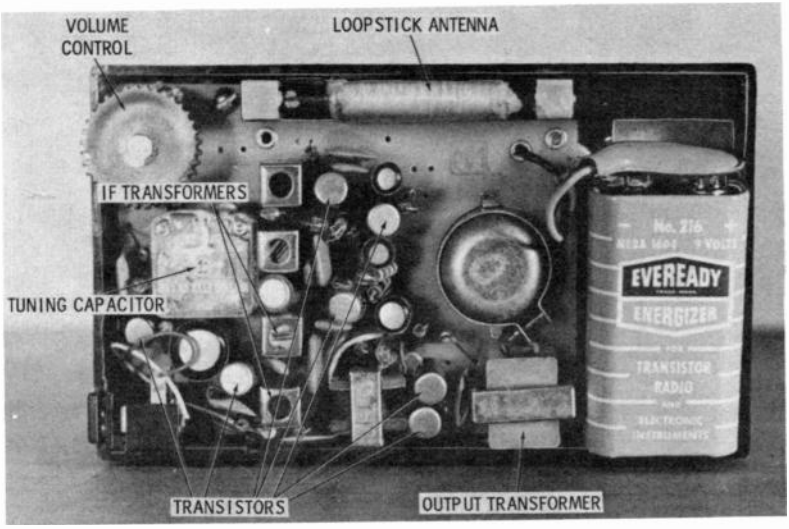


Fig. 9-5. Components are packed closely together in transistor radio.

smaller space than is possible on a hand-wired chassis. An example of this is the pocket-size transistor radio that is so common today (Fig. 9-5).

TRANSISTOR RADIOS

As a basic circuit element the transistor has already done almost as much to revolutionize the electronics industry as did the vacuum tube. Like the electron tube, the transistor operates with a kind of valve action, but unlike the tube, the electrons flow through a solid material instead of through a vacuum.

Transistors are fabricated from *semiconductor* materials. Typical materials used are germanium and silicon. When scientifically mixed with impurities, these semiconductors can be used to regulate the flow of electrons. An ordinary junction transistor

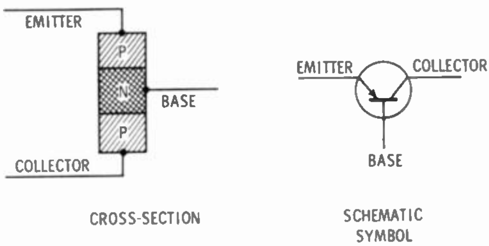


Fig. 9-6. Elements of a PNP transistor.

consists of a sandwich of positive and negative materials (Fig. 9-6). An arrangement of this type is called a PNP transistor. The top and bottom pieces have a shortage of electrons (because of the impurity mixing) and the center piece has a surplus of electrons. Thus there are positive and negative elements in the transistor.

In the simple amplifier circuit of Fig. 9-7 the input signal is applied to the base and the emitter is positively biased. The emitter injects *holes* (positive spaces that have a shortage of electrons) into the base. Because of the negative polarity of the collector, the holes travel through the base to the collector, and collector current flows. Of course there are many variations on this basic circuit, but the important thing is that it amplifies and it does this very well.

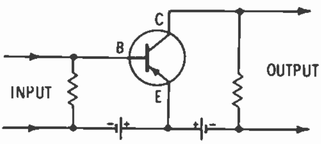


Fig. 9-7. Typical transistor amplifier circuit.

While transistors operate on much lower power levels than vacuum tubes most of the time, they can still do a tube-size job. Sometimes it will take several more transistors to do it, and sometimes the same number or less is required.

There are several advantages to using transistors. They operate on very low voltages (anywhere from 3 to 12 volts) which eliminates the need for the bulky B batteries used in portable tube radios. They are extremely small, making them ideal for miniaturization. Transistors draw relatively little current, which means long battery life, and they do not burn out the way vacuum tubes do. Transistors are frequently soldered directly into the circuit along with the other components. This is possible because of their long-life characteristics. Another plus feature is that they require no warmup time.

There are several conditions however that can ruin transistors. These are mainly excessive heat and voltage. If a transistor radio is properly constructed and is not subjected to temperatures near the boiling point of water (the battery will explode before the transistors are ruined), these incredible little semiconductor devices should last almost indefinitely.

One burgeoning use for transistors is in automobile radio. An auto radio of this type is shown in Fig. 9-8. This particular model has five transistors and three semiconductor diodes. Because of the low-voltage requirements for transistors, there is no power-

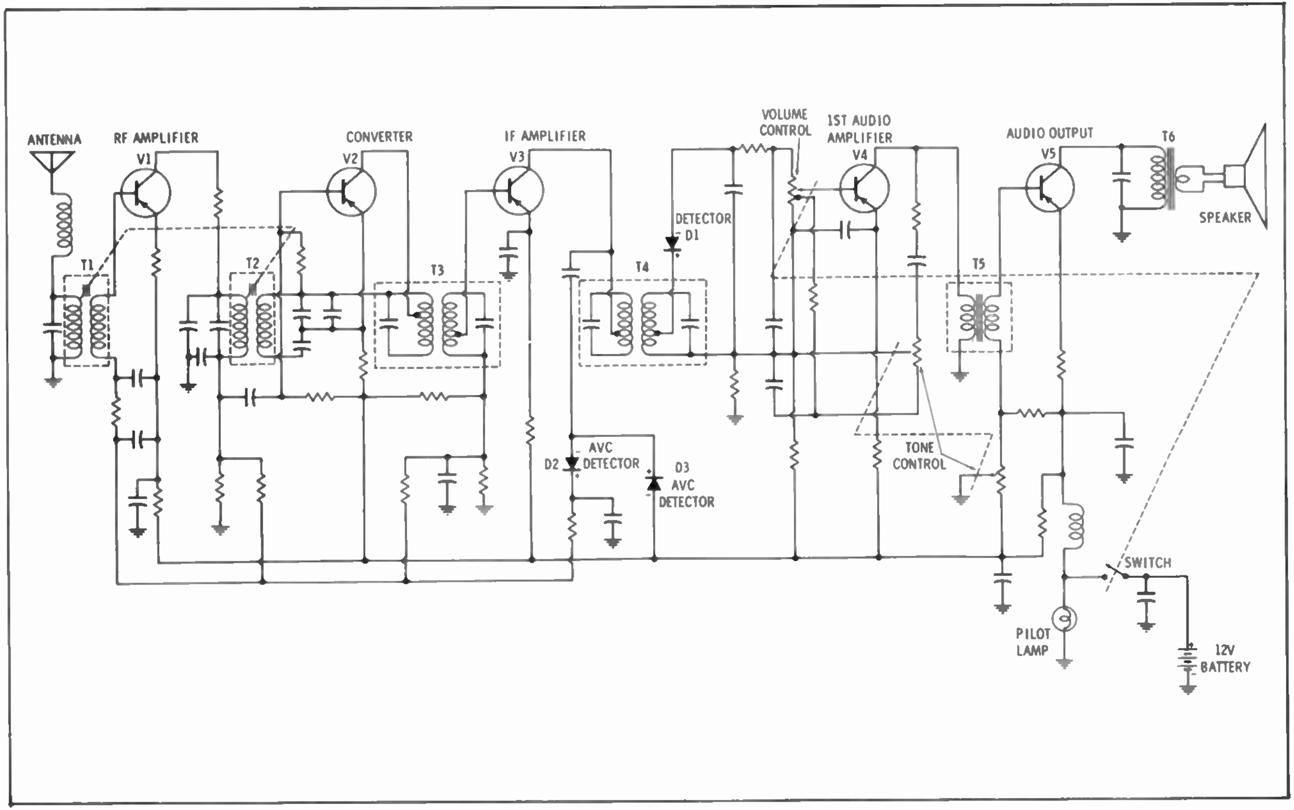


Fig. 9-8. Typical transistor automobile radio circuit.

supply section as such. Instead, the radio operates directly from the 12-volt battery in the car.

Starting from the left, V1 is the RF amplifier. The tuning in automobile radios is done by varying the inductance of the tank coils, instead of varying capacitors. This is called *slug tuning.* Note that the slugs of transformers T1 and T2 are ganged to the same tuning control.

T2 is the RF coupling transformer. Its secondary also forms the tank coil for a Colpitts oscillator. Transistors, even though they are analogous to triode vacuum tubes, can perform several functions at the same time. In this case V2 is both the oscillator and mixer—a converter stage all wrapped up in a single transistor. The base-emitter circuit oscillates, while at the same time, the incoming RF signal is applied to the base through the coupling transformer T2.

Transistor V3 is the IF amplifier stage; T3 and T4 are the IF transformers. D1 is a semiconductor diode and is the audio detector. V4 and V5 are the audio amplifiers and T5 is an audio coupling transformer. T6 is the output transformer. Transistor radios generally use transformers instead of capacitors for coupling because of the improved circuit matching characteristics.

The other two diodes, D2 and D3, are part of the automatic volume control circuit.

Chapter 10

FM RADIO

While AM radio is a very popular broadcasting medium, it has serious disadvantages. For one thing, the AM operating frequency range is so low that the transmitting station must have very narrow sidebands. If the bandwidth is limited to 10 kc, naturally high-fidelity transmission and reception is impossible.

Another disadvantage is interference. Virtually any kind of electrical equipment or machinery, notably fluorescent lights, motors, and doorbells, can create static on the AM radio. This type of interference rides on the crests of the amplitude-modulated carrier waves; and because of the way it attaches itself to these amplitude peaks, the interference is detected and amplified by the audio stages and is very noticeable in the speaker. In addition there is natural interference from electrical storms and occasional solar flares.

FM TRANSMISSION

FM radio offers a solution to both of these problems. It is transmitted commercially in the range of 88 to 108 mc, which is a high enough frequency to allow very wide sidebands—up to 200 kc wide. This bandwidth is more than ample for high-fidelity transmission, and the mechanics of FM are such that most electrical interference is eliminated.

Remember that the AM transmitter in Chapter 2 had a modulator section that made the amplitude of the carrier vary. This was called amplitude modulation. FM is an abbreviation for *frequency modulation*, and this means simply that the frequency is changed by the audio signal instead of the amplitude. Fig. 10-1 shows a comparison of the two types of modulation.

The change in frequency can be made in several ways. Basically, the modulator simply adds the audio signal to the output from the oscillator tube the same way the converter tube in the

AM receiver adds the incoming RF signal and the local oscillator output. But this time there is a difference—the audio signal, unlike the local oscillator, is constantly varying. Thus the sum of the two frequencies will be constantly varying. The output of such a tube is a carrier frequency that is constantly shifting its frequency—it is frequency modulated.

The other elements of the FM transmitter are similar to the AM transmitter except for the size and value of the components. They must be different in order to operate at higher frequencies. In addition, all operation must be on a broadband basis, since the carrier will vary over a very wide range of frequencies. As wide

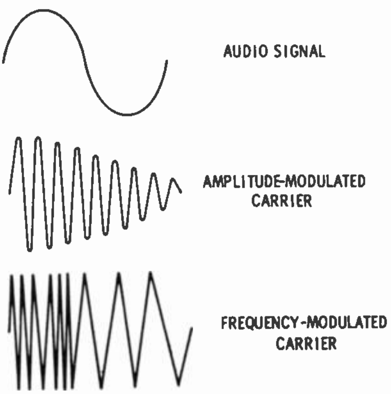
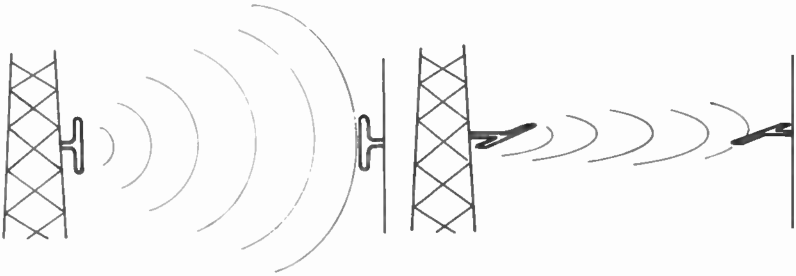


Fig. 10-1. AM and FM waves resulting from the same audio signal.

as the station bandwidth is, the percentage of modulation of the carrier frequency is so small (because of the high carrier frequency) that a single FM station occupies a relatively small portion of the broadcast spectrum.

Another aspect of the high frequencies used in FM is the fact that there is no reflection from the Heaviside layer. Virtually all of the transmitted signal that travels into the atmosphere keeps right on going. None of it is reflected. This means that FM transmission is effective only over line-of-sight paths just like television. Because of this limitation, the effective range of an FM station is seldom over 30 to 40 miles. An advantage of this limitation is the lack of interference with nearby stations on the same or close frequencies.

At VHF (very high frequency) radio frequencies (including the FM band) transmission patterns from antennas are extremely important. Unlike AM, which wastes a lot of output power by radiating in all directions most of the time, FM transmitting antennas are carefully designed to obtain the best possible coverage of the listening audience.



(A) Vertical polarization. (B) Horizontal polarization.

Fig. 10-2. Vertical and horizontal polarization of FM transmissions.

POLARIZATION

Another aspect of the FM antenna is *polarization.* Simply stated, this means that if the transmitting antenna dipole is mounted vertically, then the best signal will be obtained by a receiving dipole that is also vertical. The same will be true of horizontal polarization. Fig. 10-2 shows how the transmitted waves tend to stay in the same plane as the antenna itself.

In some parts of the world, television transmissions are vertically polarized, so all TV receiving antennas are mounted vertically in contrast to the horizontal arrangement that is used in the U.S. Of course, an antenna that is improperly polarized can still receive transmissions if there is enough signal strength.

Because television broadcasting frequencies occupy both sides of the FM spectrum, a TV antenna can be used for FM reception. It is cut to approximately one-quarter wavelength and is highly directional. But this directional property can be a problem if your locality has FM stations transmitting from several different directions. A solution to this problem is the omnidirectional FM antenna shown in Fig. 10-3. This is a modified dipole that has equal gain in all directions.

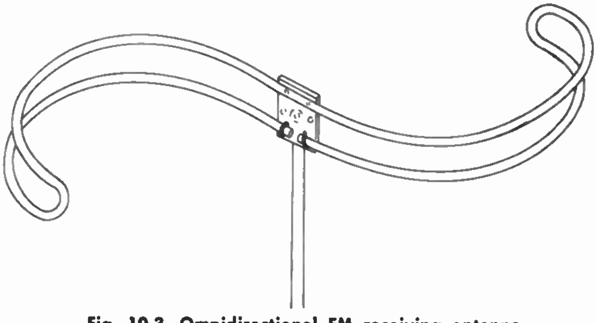


Fig. 10-3. Omnidirectional FM receiving antenna.

SIGNAL STRENGTH

In the early postwar days when there were not many TV stations on the air, a frequently heard phrase was "fringe area." This referred to the boundary line of the area in which a TV station could be received adequately. The cause of the fringe area is the necessity for high frequencies for TV transmission, and these same limitations hold true for FM radio.

AM broadcasts, because of their low frequencies, can be reflected from the Heaviside layer and received beyond the ground-wave reception area. This is not true for TV and FM. The high frequencies involved here make all transmission line of sight. Any receiver that is beyond the horizon will not be able to receive a clear signal. Another factor affecting transmission will be intervening obstructions such as mountains or tall buildings. If the line of sight is broken, a clear signal cannot be received.

PRE-EMPHASIS

The use of pre-emphasis in FM transmitters is universally used in the United States. What this does is simply to boost the amplitude of the higher (above 1,500 cycles) audio frequencies. The reason for this is that the pre-emphasis improves the *signal-to-noise ratio*. This ratio represents the amount of clean usable audio signal available at the receiver over and above the normal background noise.

Background noise that is not atmospheric interference or solar disturbance is caused by the equipment itself, sometimes called shot noise. It is caused by the electrons striking the plates of the vacuum tubes. If there is no audio signal being received and the volume control is turned all the way up, there will be a steady sound of electronic "hash." This is normal background noise, and it is important to keep the useful audio signal level far above this noise level.

The FM receiver contains a *de-emphasis* network which compensates for this boost in treble frequencies and the receiver then delivers normal audio output.

Chapter 11

THE FM RECEIVER

A frequency-modulated carrier is relatively easy to generate at the transmitter. Receiving it properly, however, is another matter. Since the purpose of FM is primarily static-free high-fidelity radio reception, high-quality receiving equipment should be used for best results.

This can bring about several schools of thought about FM. For the person who only wants unobstrusive background-type music and is not concerned about high fidelity, an inexpensive AC/DC table-model receiver will suffice. For that matter the needs of such a listener might be adequately taken care of by an ordinary AM radio.

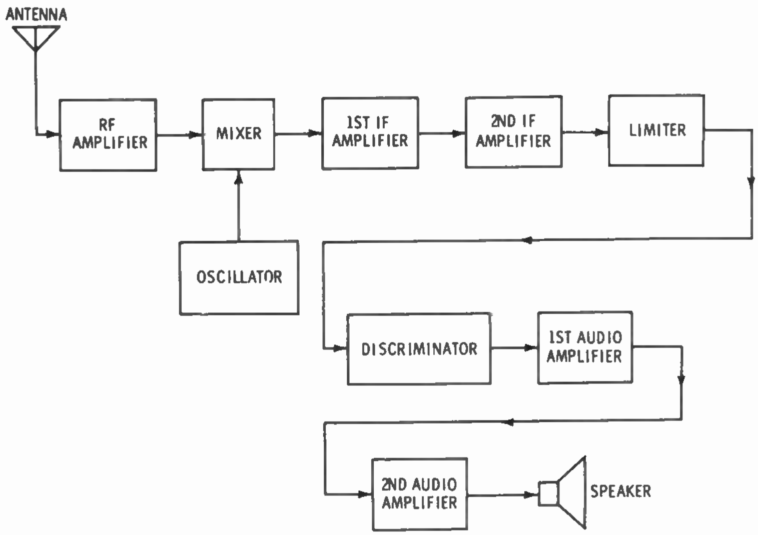


Fig. 11-1. Block diagram of a quality FM receiver.

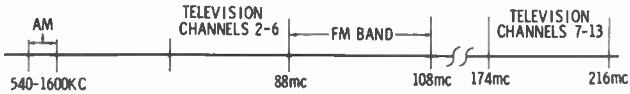
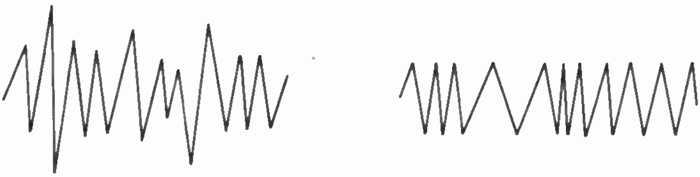


Fig. 11-2. Standard broadcast frequencies.

In many localities, the FM band offers stations and programs not available to AM listeners, although some stations broadcast the same programs on both their AM and FM outlets. Other stations broadcast two completely different programs, and there are some stations that are on FM only.



(A) Before limiting.

(B) After limiting.

Fig. 11-3. FM signal before and after limiting.

HIGH-FIDELITY RECEPTION

Since FM is aimed primarily at the high-fi enthusiast, the basic receiver should include all the stages and parts necessary for high-quality sound reproduction. A block diagram of an FM receiver of this type is shown in Fig. 11-1. Notice that it includes many more stages than a conventional AM radio.

First of all, there is the RF amplifier. Some AM radios have this stage but almost all FM sets have it. The reason for this is that the amount of signal strength made available to the mixer stage is much more critical than it is for AM. The main difference between this RF amplifier and one in an AM set is that it deals with much higher frequencies. Remember, the FM band covers the range of 88 to 108 mc, compared with 540 to 1600 kc for AM.

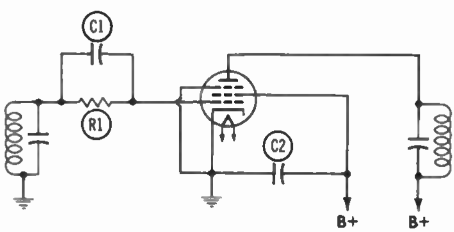


Fig. 11-4. Limiter stage in FM radio.

Fig. 11-2 shows the range of frequencies currently in use for commercial broadcasting.

The oscillator and mixer operate the same as in AM sets, except that the output frequency (the IF) in the FM set is usually 10.7 mc. FM receivers will frequently use two IF amplifier stages to provide greater amplification and receiver sensitivity.

The purpose of the limiter stage is to remove amplitude variations from the IF signal. All the information you want is contained in frequency variations, not amplitude variations. Any static riding on the crests of the carrier will still come through as noise, unless it is removed. Therefore the signal of Fig. 11-3A is put through the clipping action of the limiter, and it results in the clean frequency-modulated wave in Fig. 11-3B. It is this limiting action that makes FM free from most types of static and interference. A schematic of the limiter stage is shown in Fig. 11-4. The parallel resistor and capacitor (R1 and C1) in the grid circuit are the components that partly perform the limiting action. R1 and C1 effectively change the bias point of the grid when the amplitude varies, thus providing a kind of constant-level bias and the clipping action.

DETECTING THE AUDIO

Separating the audio from the carrier is not quite as simple as it is in AM radios; however, as in AM radios the detection circuits use diodes. Fig. 11-5 shows a basic *discriminator circuit*. The signal coming through the discriminator transformer (L1, L2, L3), is divided by the center tap in the secondary coil. The upper half of the secondary (L2) will respond to frequency changes below the IF. L3 will respond to frequency changes above the intermediate frequency. This will be true since they are each part of a tank circuit and are tuned to respond to these particular frequencies. These frequency deviations are passed on to the plates of the two diodes (V1 and V2). The more the frequency deviates from the carrier, the more one of the diodes will conduct, developing audio voltages across resistors R1 and R2. This audio signal then goes through the usual two stages of audio amplification or to a high-fidelity amplifier.

An alternative method of detecting the audio is with a circuit known as a *ratio detector*. Its operation is somewhat similar to the discriminator, but with a couple of differences. In the first place one of the diodes is reversed, as shown in Fig. 11-6. The ratio detector will not produce quite as good fidelity as the discriminator, and this is important when the FM receiver is used in quality high-fidelity systems. The ratio detector has the property

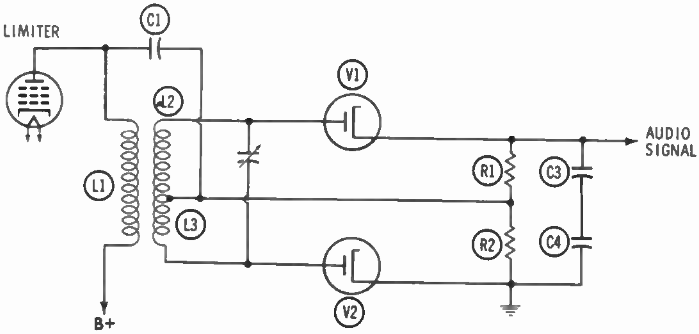


Fig. 11-5. Foster-Seeley discriminator circuit.

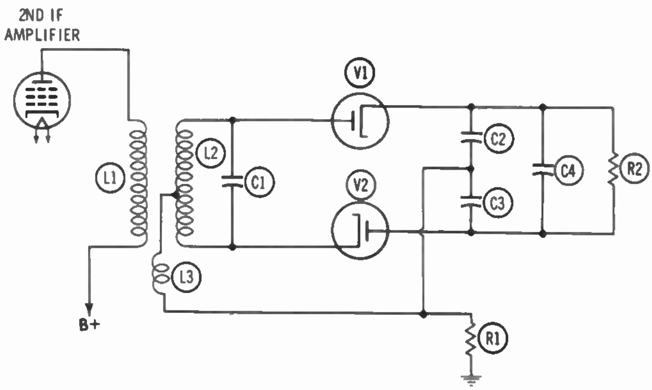


Fig. 11-6. Ratio detector circuit.

Courtesy Zenith Radio Corp.

Fig. 11-7. Typical FM radio.

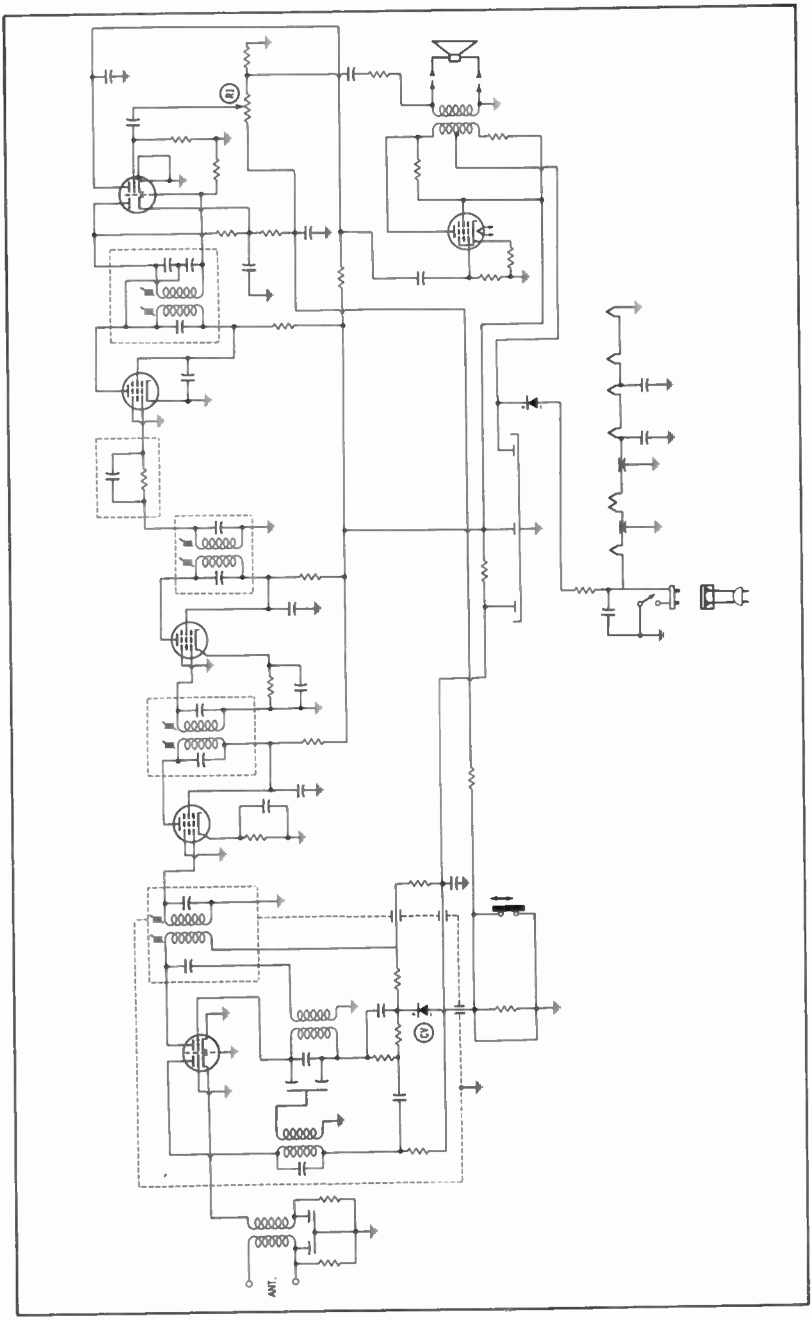
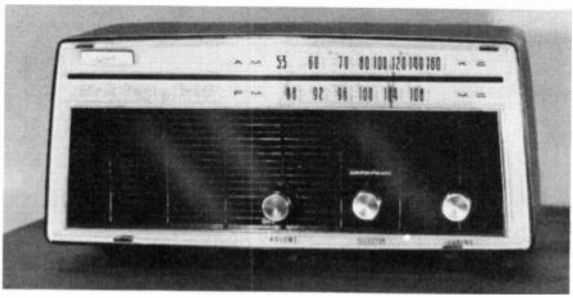


Fig. 11-8. Schematic of FM radio.

of being self-limiting, so no limiter stage is required. Because of this self-limiting action, the ratio detector is a very desirable type of circuit, and many refinements have been incorporated in it to improve the operation. As a result, it is being used more and more in FM tuners.

An FM tuner is a quality receiving instrument that contains all the elements of an FM radio except the audio amplifier stages and the speaker. Generally speaking, you can not take a table-model FM radio and make a tuner out of it, since the set design will make use of less critical components and circuitry than are used in a high-priced tuner. A typical table-model FM radio is shown in Fig. 11-7 and 11-8.

Some of the special features in Fig. 11-8 include *automatic frequency control* (abbreviated AFC). This is a special circuit that prevents the oscillator from *drifting* off the station frequency. This kind of drift occurs as the set warms up and the temperature-sensitive oscillator circuit values change slightly. The AFC signal is taken from the volume control (R1), which is in the grid circuit of the first audio amplifier. As the frequency drifts, some of the voltage change is fed through the AFC and the AFC diode (CV) to the oscillator circuit. There it provides feedback and keeps the oscillator "locked on" frequency.



Courtesy Lafayette Radio Electronics Corp.

Fig. 11-9. An AM/FM radio.

Use of AFC does have its disadvantgaes. The circuit robs the receiver of some of its sensitivity, and if a disabling switch is provided, switching the AFC on and off can sometimes cause a sudden frequency shift and the station must be retuned. Another method is to use carefully selected temperature-compensated components in the oscillator section. By doing this, if the characteristics of a coil in the tank circuit change by a certain number of cycles as it heats, the capacitor across the coil will have a frequency shift of the same amount in the opposite direction, thus

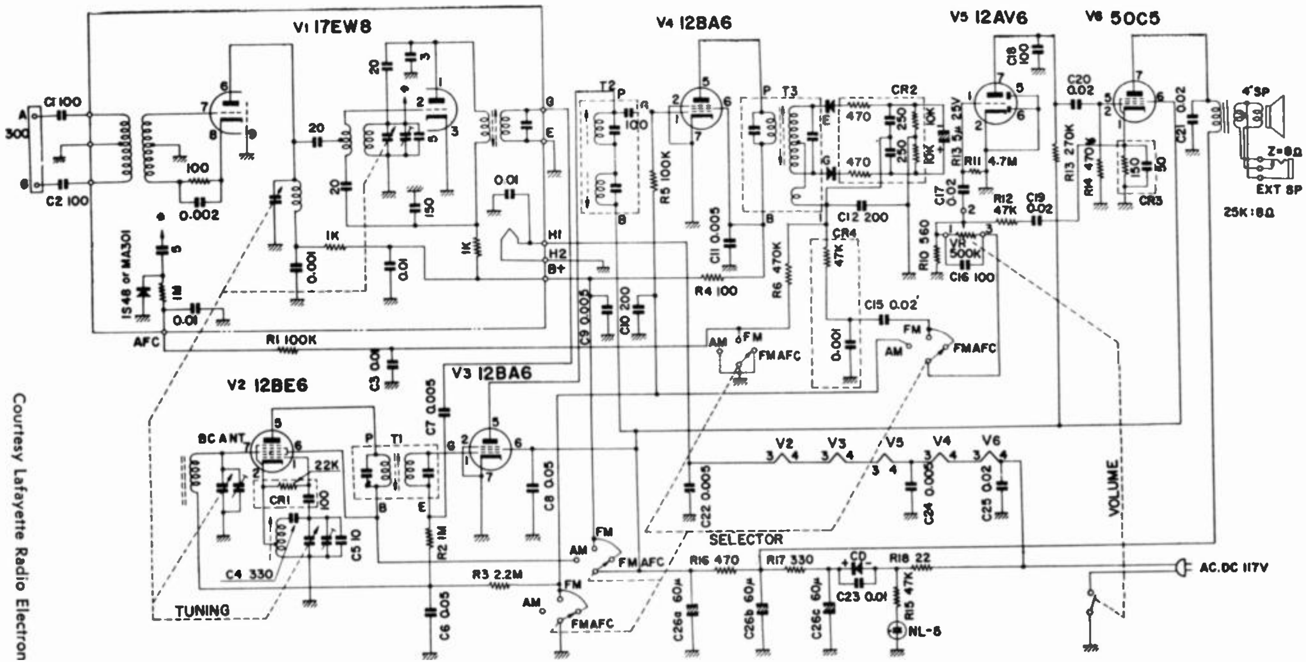


Fig. 11-10. Schematic of AM/FM radio.

Courtesy Lafayette Radio Electronics Corp.

cancelling out the effects of temperature change. Such a method is generally much more expensive than the use of the simple and effective AFC circuit.

AM/FM RECEIVERS

A typical AM/FM table model receiver is shown in Figs. 11-9 and 11-10. This set uses two separate "front ends" for AM and FM. In the upper left of the schematic is the FM antenna circuit, the RF amplifier (one-half of a dual-triode tube), and a triode converter tube. The IF (10.7 mc) leaves V1 and goes to V3, the first IF amplifier. From there, it goes to V4, the second IF amplifier through a ratio detector using semiconductor diodes (E and G) to audio stages V5 and V6.

The AM signal enters the set through the loopstick antenna at the lower left of the schematic (Fig. 11-10). V2 is the pentagrid converter, and this feeds the 455-kc intermediate frequency to IF amplifiers (V3 and V4), to the AM detector tube (V5) and then to the audio amplifier section. Notice that certain key components of the two sections of the radio are switched in and out by the selector switch.

Chapter 12

RECEIVING FM STEREO

Stereo adds a new dimension to high fidelity. Since you hear with two ears, stereo creates an illusion of the placement and position of musicians in such a way that your ears can tell just where these instruments are located.

This illusion is accomplished by using two separate recording channels. The basic system uses two microphones, which represent the listener's two ears. The outputs of these two microphones are recorded on separate stereo tape tracks, pressed in stereo recordings, and broadcast via FM stereo.

TWO STATIONS, ONE FREQUENCY

It has been shown how the single FM station can transmit high-quality audio for faithful reproduction in the home. When stereo enters the picture, two FM radio stations or an FM and AM station working together (Fig. 12-1) can be used. These methods were tried with some degree of success, for a number of years while the FCC was deliberating on the final type of system to use as the industry standard. The method of using two FM stations has certain obvious drawbacks. For one thing, it means tying up two different stations for the same program—not a very easy task, since these stations are in competition with each other most of the time. Another factor is the need for two separate FM receivers, usually not available in most homes.

AM and FM stereocasting also had its disadvantages. With this method the same station broadcasts both channels, one on AM and the other on FM. But the right channel being broadcast on AM naturally can not be high fidelity, and the total illusion of stereo suffers as a result. Again, two receivers are required, but many of the AM/FM tuners are actually two separate units in

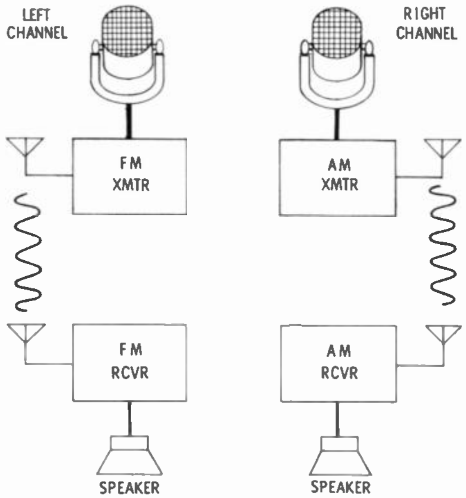


Fig. 12-1. Stereo broadcast using FM and AM for the two channels.

a single cabinet, thus making it possible to receive stereo broadcasts of this type with a single unit.

Ideally, both channels should be received on FM from the same station. The one way of doing this is known as *multiplex*. This is a method of adding the frequencies of one audio signal to the carrier well above the frequency range of another; thus, two different audio signals are transmitted on the same channel (Fig. 12-2). This method has been used by the telephone companies for years to send many telephone conversations over the same pair of wires simultaneously and is the method used for present-day FM stereo.

Fig. 12-2 shows an additional channel of audio riding on the main carrier but beyond the limits of the main channel. The main channel forms sidebands of 15 kc on each side of the carrier frequency. This represents the full range of hearing for the average

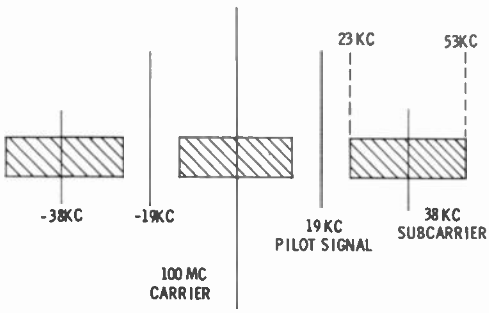


Fig. 12-2. Additional sidebands occupied by an FM multiplex channel.

human ear. Although some people can hear above this frequency, many have an upper limit that is closer to 10 or 12 kc. In any event, the multiplex channel starts well beyond the range of normal human hearing, and certainly beyond the reproduction capability of most speakers. The multiplex channel, even though it is called an audio channel, is inaudible, and if it is inaudible, as far as the listener is concerned, it just is not there.

This *subchannel* can, however, carry useful information with proper translating equipment at the receiving end. It can carry special programs of background music for restaurants, stores, and other public places that have piped-in music; in fact, this type of transmission is an important source of revenue for many FM stations.

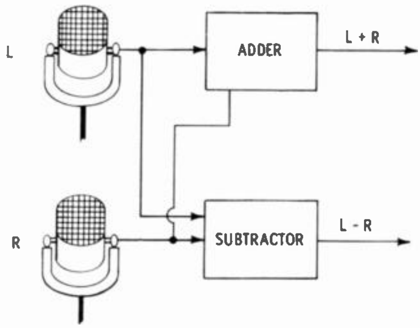
This subchannel can also be used to transmit a stereo signal. The simplest method is to use the main channel for the left and the subchannel for the right channel in a stereocast. But there is a disadvantage here also. The average person who has just conventional monophonic FM equipment will receive only the left channel and nothing from the right. This is also true with the FM/FM and FM/AM stereocasts. Half the signal is always missing. What is needed is some kind of compatible system that will permit equally good results on mono or stereo, depending on the kind of equipment available.

COMPATIBLE STEREO

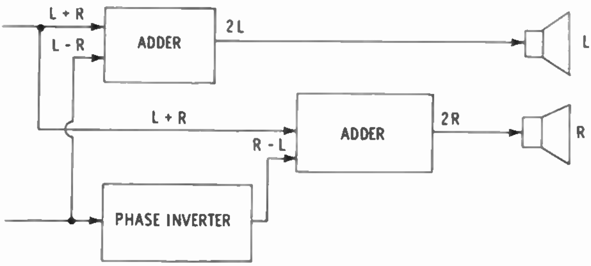
An ingenious system called a *matrix* is used to produce a compatible stereo broadcast. As shown in Fig. 12-3A, the L (left) and R (right) signals are both added and subtracted at the transmitter, thus producing two signals, L + R and L − R. The L + R is transmitted on the main channel and is received by mono receivers as a full monophonic program. In stereo receivers, the L + R and L − R signals are decoded by passing them through the decoding network as shown in Fig. 12-3B.

First the two channels are added together and the R's cancel each other, leaving 2L. Next, the L − R channel goes through a phase inverter. This is a circuit that has the same effect as changing the signs in front of the two stereo components, and the result is R − L. This is added to the L + R channel, the L's cancel each other, and the result is 2R. The decoding circuit takes the two composite signals and recreates the stereo information that was originally available at the transmitter.

This is a compatible stereo system. Monophonic FM radios receive a full mono signal (L + R), and listeners with multiplex equipment receive a full stereophonic program.

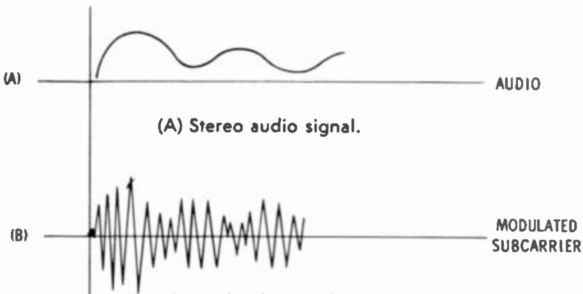


(A) At transmitter.



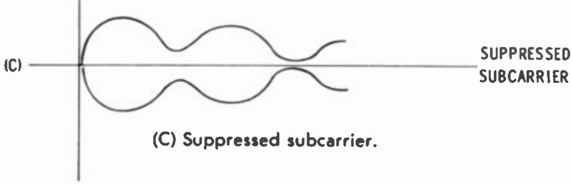
(B) At receiver.

Fig. 12-3. Matrix for FM stereo.



(A) Stereo audio signal.

(B) Amplitude-modulated subcarrier.



(C) Suppressed subcarrier.

Fig. 12-4. FM stereo signal.

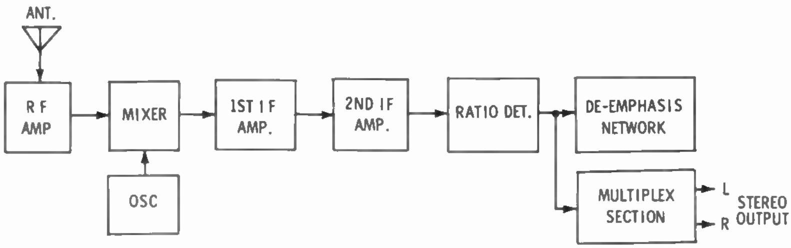


Fig. 12-5. Block diagram of FM tuner with multiplex adapter added.

MULTIPLEXING THE SIGNAL

At the FM transmitter, the L + R signal modulates the main carrier as it would in ordinary monophonic operation. The stereo signal (L − R) is treated in quite a different way. A local oscillator generates a pilot signal of 19 kc. This goes through a doubler, providing a 38-kc signal. This 38-kc signal is called the *subcarrier*.

The L − R signal (Fig. 12-4A) amplitude modulates the 38-kc subcarrier, as shown in Fig. 12-4B. Then the carrier frequency (38 kc) is suppressed, leaving just the sideband envelope (Fig. 12-4C). This sideband envelope is impressed on the main carrier in the reactance-tube modulator. Also acting on the modulator tube is the original 19-kc pilot signal. This is used as a reference frequency by the multiplex receiving equipment. It may also turn on automatically operated multiplex equipment that is tuned for the 19 kc signal.

THE MULTIPLEX RECEIVER

The composite signal must be removed from the discriminator or ratio detector stage before it reaches the de-emphasis network

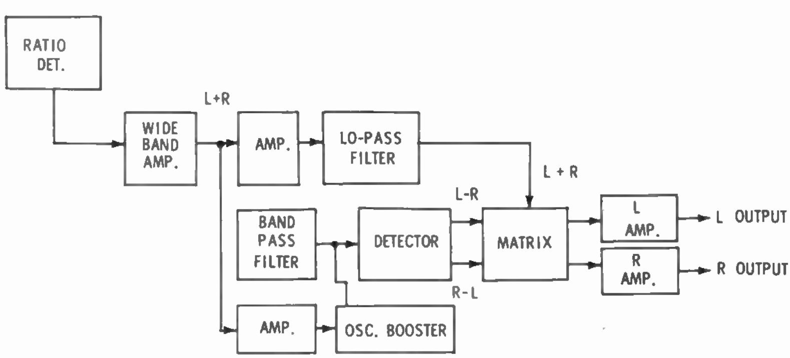


Fig. 12-6. Block diagram of multiplex section of FM stereo receiver.

(Fig. 12-5). Remember, the pre-emphasis at the transmitter boosts frequencies that are above 1,500 cycles. The de-emphasis network in the FM receiver attenuates (reduces) the higher frequencies, including the stereo information in the subchannel.

The multiplex unit can be in the form of an adapter that is added to existing FM equipment, or it can be a built-in section of an FM stereo receiver. Fig. 12-6 is a block diagram of the multiplex unit. It contains a local oscillator that generates a 38-kc signal. This 38-kc signal is injected into the L − R envelope after this signal has been picked off the main carrier. The stereo signal then goes through conventional detection and part of it goes to a phase inverter which changes the L − R to R − L. These two along with the main channel L + R signals are fed to the matrix circuit which performs the necessary additions. The two-channel output is further amplified and then goes to the stereo audio amplifier.

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