Modern Radio Essentials

HATHAWAY

MODERN RADIO ESSENTIALS

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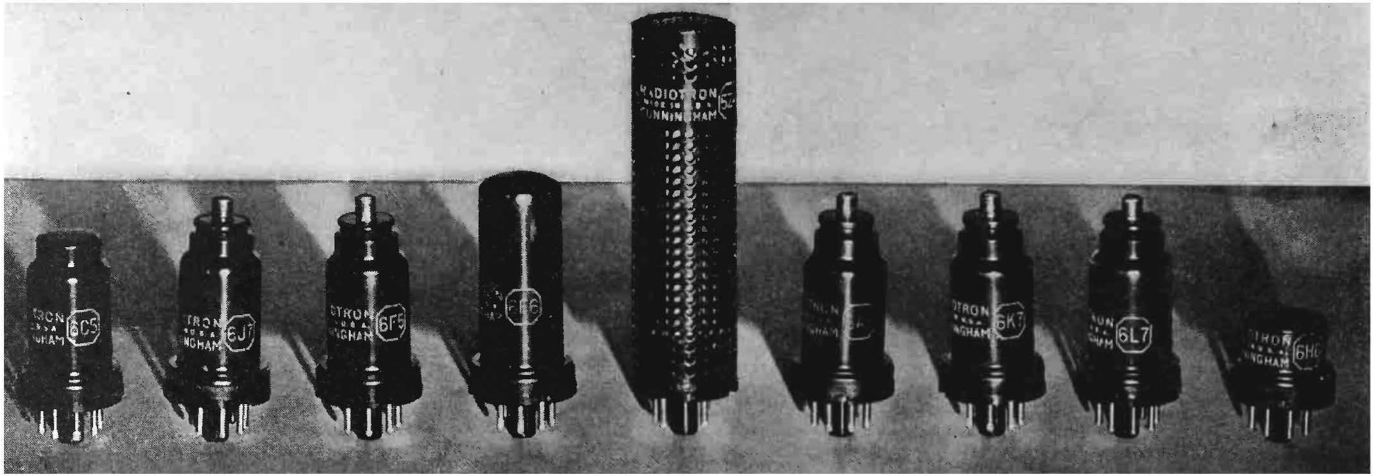

METAL TUBES

The Metal Tube, a radical departure in vacuum tube design, was developed in the Laboratories of the General Electric Company. The tubes shown here are as follows: 6C5, Detector Amplifier Triode; 6J7, Triple-Grid Detector Amplifier; 6F5, High-Mu Triode; 6F6, Power Amplifier Pentode; 5Z4, Full-Wave Rectifier; 6A8, Pentagrid Converter; 6K7, Triple-Grid Super-Control Amplifier; 6L7, Pentagrid Mixer Amplifier; 6H6, Twin Diode.

Courtesy of RCA Manufacturing Company

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INTRODUCTION

IN the preparation of this book, the author has confined his treatise to those elements of electricity that are related directly to the operation of devices designed to receive, amplify, detect, and reproduce radio signals.

The text embodies data that will be of service to those who wish to know the fundamentals of radio for their own enlightenment, those who are entering upon the study of radio, and those who are engaged in the maintenance of radio devices.

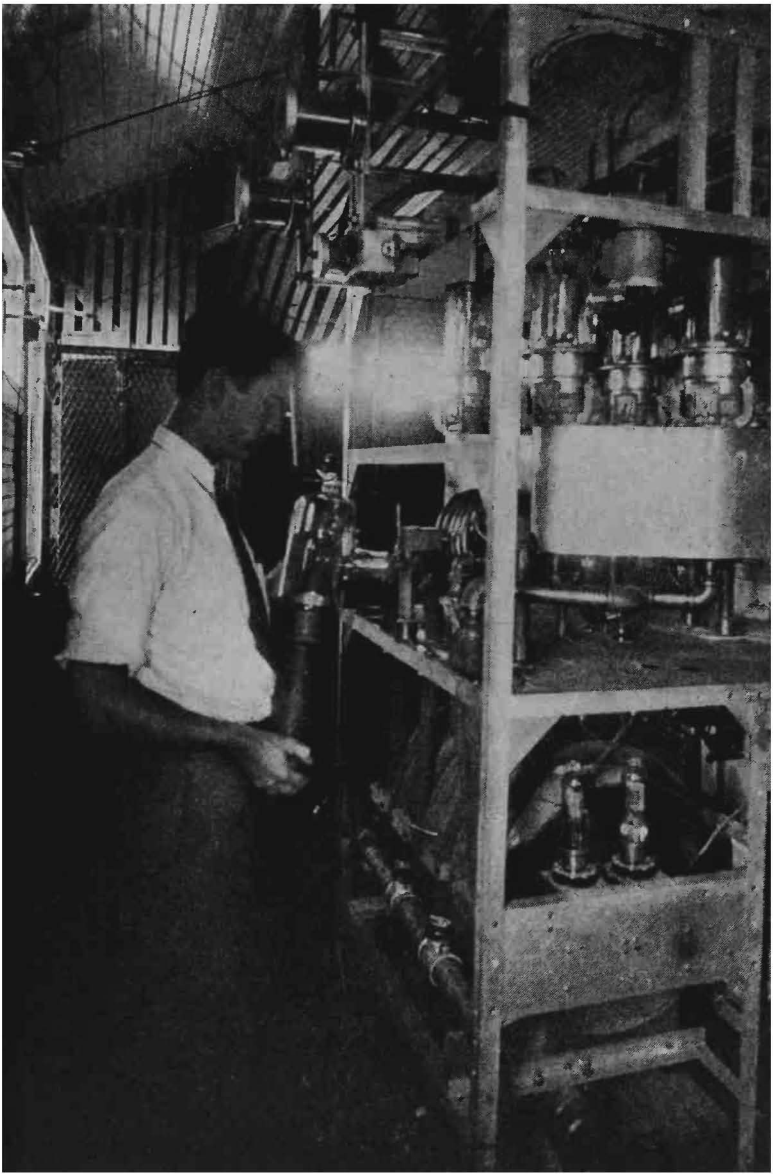
The discussion is general in every respect, avoiding completely the use of existing apparatus or devices for explanatory purposes. An attempt has been made, too, to show the causes of certain phenomena, either by analogy or by a complete explanation.

The author has given complete explanations of certain functions separately, after which they are combined to form circuits to serve definite purposes such as the generation of signals, the amplification of the minute electrical impulses, the detection of radio signals, the controlling of volume level, the amplification of voice frequencies, and the conversion of electrical energy into sound.

The subject of automobile radio is touched upon fundamentally, but is not discussed at length due to the variable factors involved, such as, for example, the changing design of motor vehicles.

The subject of vacuum tubes is discussed from the fundamental standpoint and no differentiation is made between tubes that are encased in glass envelopes and those that are enclosed in a metal container. Any variations in the physical design of apparatus in which tubes of whatever nature are used will be due to engineering development. Such variations will not be caused by deviations from the fundamental theory of operation governing vacuum tubes.

In this text will be found a complete and thorough explanation of the principles of radio, written in plain and understandable language for the novice as well as for the man who is engaged in any one of the technical phases of radio.



A POWER AMPLIFIER IN A SHORT-WAVE RADIO TRANSMITTING STATION
A rubber hose is used to connect the cooling water supply to the radio tubes and thus prevent them from overheating.
Courtesy of General Electric Company

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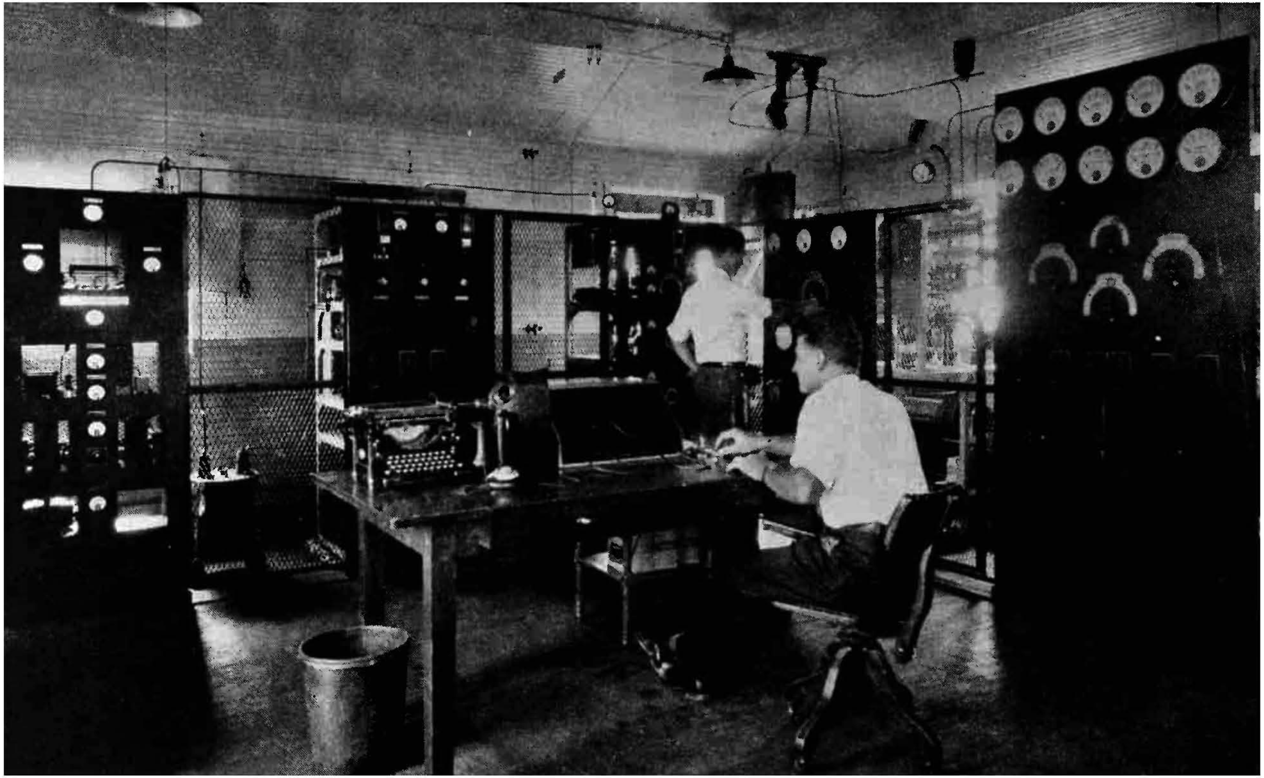


A GENERAL VIEW OF A SHORT-WAVE RADIO TRANSMITTER
Courtesy of General Electric Company

MODERN RADIO ESSENTIALS

CHAPTER I

INTRODUCTION

Radio is the art that deals with the use of electromagnetic waves to convey signals of communication. Generally speaking, there are two classes of radio communication—radio telegraphy and radio telephony—both of which depend upon the radiation of electromagnetic waves by means of which the signals are transmitted. The fundamental principles involved in the transmission and reception of radio telegraph and radio telephone signals are identical.

Radio telegraphy employs as signals a sequence of combinations of "dots" and "dashes," similar to those used in wire telegraphic communication; which, when translated into the letters for which they stand, form words and sentences. Radio telephony, otherwise known as the radiophone, provides facilities with which to carry on a telephone conversation, even over long distances, by means of electrical devices that function without the use of physical connecting apparatus.

Radio Broadcasting, the world's greatest medium for mass communication, is the most widely used and the best known of the numerous applications of the radiophone. In fact, it would be difficult to find a person who has not heard of radio or listened to radio programs, and the greater portion of homes in the United States have radio receiving sets for bringing in the regularly broadcast programs.

A study of radio broadcasting and radio-broadcast reception involves certain phases of acoustics, the science of sound, in addition to a consideration of the engineering principles underlying the functioning of the component electrical apparatus. In fact, broadcast transmission and reception utilize two conversion processes, both of which involve acoustics and radio engineering. First, the sound waves striking a sensitive element of the microphone set up electrical impulses that have a definite relationship to the variations in sound —referred to popularly but erroneously as the conversion of sound into electrical impulses of a varying nature. Second, in the receiver, the electrical impulses, fluctuating in accordance with sound pressures striking the sensitive element of the microphone, cause the vibration of physical substances to create disturbances of the air, thereby producing sound waves.

The science of acoustics holds a prominent place in the design of the studio in which broadcast programs originate, and again in the design of the cabinet in which is placed the reproducing device, commonly called the *loud speaker*. In the first instance, the problem is one of sound absorption—prevention of echoes and other extraneous noises. In the second, the problem is a matter of sound projection, and devising methods to prevent the "blocking" of sound waves caused by their colliding with one another.

It is quite probable that radio has had a greater influence on the development of acoustics than has any other science. The absolute necessity for acoustic or sound-proof treatment of walls, and the need for proper and effective control of sound waves, led to extensive research; and, as never before, students of acoustics have been given practical facilities for conducting their experiments outside of laboratories, where the conditions were already established and well known.

Radio broadcasting should be looked upon as a valuable service in the home and elsewhere. It enables the American family to have entertainment of a variety of types—dramas, operas, comedies, dialogues, comic strips, and news reports. It furnishes frequent market reports, especially valuable in the rural communities, directly from the exchanges where farm products are sold. Radio brings play-by-play reports of sporting events to "fans" who cannot attend the affairs. Religious and educational programs hold an important position in radio broadcasting, and programs for the public schools, conducted by prominent educators, are regular features. Last, but by no means least, radio broadcasting enables the executives of our government to talk direct to the citizens of the entire country at any time—a particularly valuable assistance in times of national emergency.

Radio broadcasting, as it is commonly considered, is carried on within certain specified limits of wave lengths or frequency channels 200 meters to 550 meters or 550 to 1,500 kilocycles. These terms are common in the average American home. However, the engineers have made great developments in the use of the short waves as a medium for radio broadcasting. In view of the fact that the principles involved in the engineering design and the functions of integral parts of a short-wave receiver are identical with those in a receiver designed to operate in the regular broadcast band, there is no attempt to discuss short-wave transmission and reception in particular in the following pages.

RCA THEREMIN MACHINE BEING OPERATED BY PROFESSOR THEREMIN, THE INVENTOR AND DESIGNER
Courtesy of Radio Corporation of America

MODERN RADIO ESSENTIALS

CHAPTER II

ACOUSTICS

Acoustics Is the Science of Sound. According to the physiologist or the psychologist, sound is a sensation produced in the ear. But according to the physicist, sound is a disturbance of the air—a motion of the air in the form of waves which, if they strike certain parts of the ear, create the sensation of hearing. The physiologist and the psychologist emphasize the presence of the ear as necessary to the existence of sound, while the physicist believes that sound can exist even if there is no ear to hear it.

Sound is produced usually by the vibrations of a material body—as, for example, the vibrating string of a musical instrument. It may also be produced by one substance striking another as, for instance, a stone striking a pavement. When a drumhead is struck by a drum stick, the resulting vibrations create a different sort of sound.

Sound travels in waves that can best be described as similar to those resulting from throwing a stone into a pool of water. The water, disturbed at the point of impact, forms in ripples circling out-

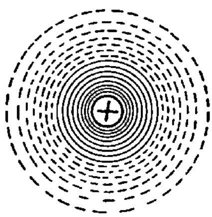


Fig. 1. Sound Waves from a Bomb Bursting in Mid Air

ward from the stone. A bomb, when exploded in the air, instantaneously releases a quantity of gas under high pressure, thereby condensing the air immediately surrounding the point of explosion, as shown in Fig. 1. The air at normal pressure rushes in as rapidly as its pressure will permit, to fill the rarefied space caused by the condensation; but the pressure in the space immediately surrounding the condensed area is far below the normal. The wave of condensed air strikes the eardrum, causing it to be pressed inward; and when it reacts outward almost instantaneously to the rarefied area (that below normal pressure), the movement of the eardrum, through the mechanical lever system of the middle and the inner ear, causes the sensation which we know as "hearing"—in this case producing a "crack" or a "boom."

Sound, then, may be defined as a *wave motion* consisting of areas of more or less than normal pressure (condensations and rarefactions), which are produced by a vibrating body and transmitted through an elastic medium.

Practically all substances are elastic—air, metals, wood, and water. When a piece of metal is struck with a hammer, the impact causes the displacement of molecules which, in turn, strike those next to them, and so on, so that the sound is transmitted through the metal.

The speed of sound is rated according to the distance it travels in still dry air (there is no sound in a vacuum, because there is no air to be disturbed) at about 1,100 feet per second. This means that nearly five seconds elapse between the time we see the steam emitted by the whistle of a locomotive a mile away, and the time we hear the sound—in still air. However, if the wind is blowing from the direction of the locomotive, the sound will reach us in a shorter time; and, conversely, if the wind is blowing toward the locomotive, a longer time will be required for the sound to reach us.

Amplitude. Amplitude is the degree of loudness or volume, and is determined by the velocity with which the particles of the transmitting medium are condensed. For instance, a bomb in which the gas is at high pressure (either because of the method of manufacture or because of high temperature), if exploded in midair, would cause a much greater rush of air than a similar bomb in which the gas pressure was lower (due to the method of manufacture or because of low temperature). The amplitude of the sound of the first bomb would be greater than that of the second one; but the speed with which the sound of the two explosions traveled through the air would be the same, because the speed of travel of a sound wave is dependent upon the elasticity of the medium which, in turn, is dependent upon temperature and other natural phenomenon.

When the air is heavy or moist, sounds will appear to be much louder than when the air is dry, because moisture increases the density and elasticity of the atmosphere. This phenomenon explains why, on some evenings, we can hear the sound of a bell plainly, although we would not notice it when the air is dry.

Water is very elastic, and conducts sound waves with greater speed and greater intensity than air. The sound of a gun which is fired from offshore into a body of water is heard by a person standing on the bank as two distinct sounds (the second is often mistaken for the echo). The first sound is carried by the water—the second one through the air. Sound travels about four times as fast in water as in air.

Also, a tapping on a piece of wood, inaudible through air, can be heard distinctly by placing the ear to the wood at quite a distance from the point where the tapping is done.

Music and Noise. If the successive condensations or high-pressure areas and the rarefactions or low-pressure areas occur at regular intervals, the sound created is called a *musical note* or *sound.* However, if the condensations and the rarefactions are irregularly timed, the resulting sound is usually called a *noise.* A string on a musical instrument will vibrate so that it produces disturbances that are timed equally, creating a musical tone. The shuffling of feet, on the other hand, produces irregularly timed disturbances and, therefore, is a noise. Some noises are used to advantage in combination with the playing of musical instruments and, as an accompaniment, blend in with the regularly timed waves that create music and so become a part of the music itself.

Production and Transmission of Sound. Since we are concerned primarily with sounds of a musical nature (which include the human voice), we will consider chiefly the production of musical sounds.

A tuning fork is carefully made so that the length and mass of its prongs determine the number of vibrations it will produce per second. If one prong of a tuning fork is tapped, the condensations and rarefactions of the air between the prongs cause the other prong to vibrate in unison.

When the tuning fork is struck against an object—for example, a table or the palm of the hand—the prongs begin vibrating as shown by the dotted lines in Fig. 2, and their movement sets up a disturbance

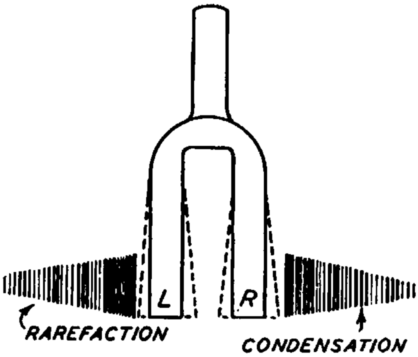


Fig. 2. Sound Waves from a Tuning Fork

of the surrounding air particles. Following the action from a state of rest, we see the result more readily. As prong *R* moves to the right, it produces a movement in the air to its right which causes that air to assume a pressure higher than normal. This is called a condensation. As the prong springs back to its normal position, the pressure in the space directly behind the condensed area is below normal. When the prong reaches its normal position, it does not stop but continues moving to the left until its momentum has been overcome, reducing the pressure in the area through which it has been passing, causing a rarefaction. Then, from the extreme left-hand position, it swings once more to the right, again causing a condensation of the air particles. The peaks of the two condensed areas (maximum pressure) may be termed the "crests" of the sound waves; the rarefied space between them may be termed the "valley" of the wave.

The particles of air thus set in motion by the prongs of the tuning fork do not move any appreciable distance. On the contrary, they transmit their movement to other particles of air, which likewise move only slightly, and in turn cause other particles to move. Thus, the particles at any given position vibrate back and forth in accordance with the movement of the prongs of the tuning fork. As the waves continue moving outward from the tuning fork, each successive wave is weaker than the one immediately preceding, because of friction losses, etc., until finally the pressure is equal to the normal air pressure, after which, there is no movement to produce sound.

Similarly, the prongs of the tuning fork gradually lose their motive force and come to rest, so that there is a gradual tapering off of the amplitude of the sound wave. However, the frequency of vibration remains the same so long as the prongs are vibrating, so that, although the pressure in the condensed areas may be gradually lowered, the distance between each pair of crests remains constant. As a result, the sound that is "heard" is produced by the same number of vibrations per second, although its amplitude is steadily decreasing.

Although the waves set up by the tuning fork create sound that can be heard in all directions, the greatest intensity of the sound is directly in front of the flat portion of the prong, and the area of least intensity is directly opposite the side of the prong.

Reflections and Echoes. Sound follows the same natural laws as light, so far as reflection is concerned, but it is much more difficult to demonstrate the law, because of our inability to confine disturbances of the air particles. It has been determined, however, that sound waves are reflected from an obstruction and, as with light,

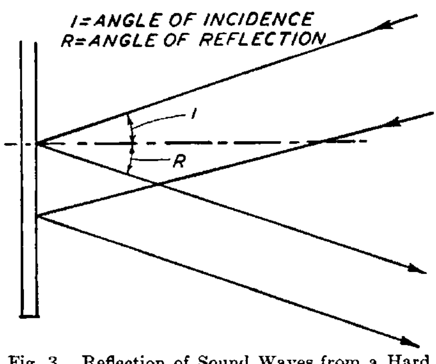
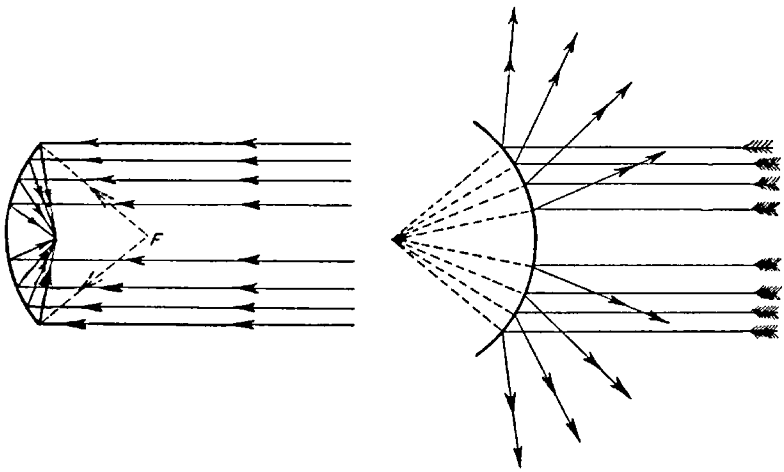


Fig. 3. Reflection of Sound Waves from a Hard Smooth Plane Surface

that *the angle of incidence equals the angle of reflection.* The angle of incidence is the angle between the perpendicular to the obstructing surface and the direction of the wave at the point of reflection, as shown in Fig. 3. Concave or convex reflectors either carry the sound to a focal point or spread it, as also shown in Fig. 4 at (*A*) and (*B*), respectively.

A sound wave projected against a flat wall or other surface will be reflected from the surface, and the sound may be heard more than once—a phenomenon that is called an *echo*. If the wall were so close to the listener's position that the echo wave reached him before the original sound had died away, the echo either would not be heard, or else would be heard as a rumble. The hard, smooth wall surfaces of improperly designed lecture halls or auditoriums cause reflections



(*A*) (*B*)

Fig. 4. Reflection of Sound Waves from Curved Surfaces

of sound waves that make it difficult, and in many instances impossible, to understand the speaker.

An analysis of conditions in such a hall would show that, while the sound passes from the speaker directly to the listener, another part of the sound wave is reflected from a wall surface; and since it travels a greater distance represented by two sides of a triangle, the reflection of the first sound reaches the ears of the listener at the same time that another and different sound—that of another syllable or another word—reaches the listener. The two sounds combine to create a jargon of unintelligible sounds. Hence, in improperly designed halls—provided they are not treated acoustically—only those persons who occupy the first few rows ahead of the reflection area can hear clearly the words of the speaker.

Prevention of Sound Reflections. The prevention of sound reflections can well be termed sound control. Materials and substances that have the property of absorbing or diffusing sound, will prevent or break up the reflections so that their effect is negligible. When radio broadcasting began, it was common practice to drape the walls of the studios with heavy cloth, such as velvet. The floors, too, were heavily padded, and the ceilings were covered with flowing drapery. More recently, however, wall materials have been developed that eliminate the need for such drapings.

Commercial acoustic materials—such as felt, velvet, gypsum, burlap, cork, hair, and other fibrous substances—are used for treating walls, floors, and ceilings of rooms so as to give them sound-absorbing properties. Substances that appear to be hard on the surface may prove to be efficient acoustic materials because of their porosity, such as spun glass. One of the commercial acoustic wall blocks consists of spun glass particles embedded in a binding substance.

An empty auditorium does not usually possess the same acoustic properties that it has when the seats are occupied. The clothing on the people in the seats serves to absorb the sound waves and so prevent the reflections that are cast by seats with bare wooden backs or non-sound-absorbing upholstery. Hence, it frequently happens that the first attempt to install radio or public-address equipment in a hall or auditorium will not be entirely successful, and that in certain places the reflections will be so pronounced as to require additional adjustment, because of the acoustical changes that occur when the seats are occupied.

General Musical Sounds. Musical sounds have three differing characteristics—pitch, amplitude, and quality—which provide the means for the production of melodies and other harmonious tunes.

The *pitch* of a tone is determined by the number of vibrations produced per second. A note that is produced by 400 vibrations per second is said to have a higher pitch than one which is produced by 200 vibrations per second.

The determining factor in *amplitude* is the impression on the auditory system of the individual. An impulse that may sound loud to one person may not be so loud to another. However, *intensity* of sound is a definite quantity, measured as the rate of the flow of energy through a cross section normal to the direction of propagation. *The intensity of sound waves is inversely proportional to the square of the distance from the source.*

Musical sounds have *quality* as the result of blending a number of simple tones of different but related wave frequencies, any one of which alone would not appear to be musical or pleasant. The lowest of the related tones is called the fundamental; all others are called overtones. Practically all musical instruments produce sounds that are abundant in *overtones*, which serve to give what might be called a "richness" of sound. Quality is often referred to as *timbre*.

Harmonics. An overtone whose frequency is an integral number of times the frequency of the fundamental tone is called a *harmonic*. Thus, if a string on a musical instrument vibrates 200 times per second, it may, and probably will, produce also an overtone—a harmonic—of 400 vibrations per second. Similarly, if the string vibrates 400 times per second, it may produce an overtone—again, a harmonic—of 800 vibrations per second. In the first instance, harmonics at 600 and 800 vibrations per second may be present also; and in the latter case, there may be additional harmonics of 1,200 and 1,600 vibrations per second.

The term "harmonic" should not be confused with "octave." Harmonics are overtones having an integral number of times the frequency of the fundamental, but a tone an octave higher is always twice the frequency of the original tone. Thus, an octave above middle C (256 vibrations per second) is also "C," having 2×256, or 512 vibrations per second. Two octaves above middle C would be $2\times(2\times256)$, or 1024 vibrations per second—again "C." Or, the tone produced by 400 vibrations would be an octave above the

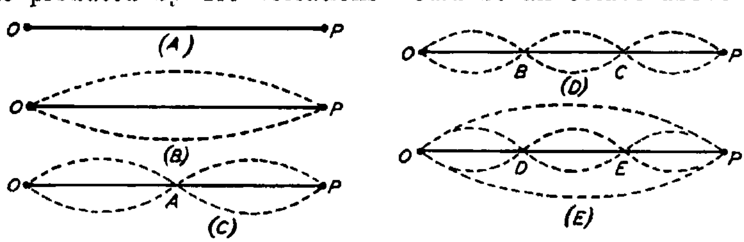


Fig. 5. Diagram Showing How First and Second Harmonics and Overtones Are Produced

fundamental of 200 vibrations per second, and two octaves above the fundamental would be a tone produced by 800 vibrations per second.

On some musical instruments, a single string may produce several overtones in addition to the fundamental. As an example, take a string on the musical instrument shown in Fig. 5(A). When at rest, the string creates no sound. But if held tightly at points *O* and *P*, and plucked at any point along its length, the string will vibrate as shown in Fig. 5(*B*) in which the outer edges of the oval represent the limits of maximum vibration.

If, after the string has been plucked and caused to vibrate, the finger or a piece of soft rubber is placed exactly midway between *O* and *P*—at point *A*—the string will vibrate in two units, as shown in Fig. 5(*C*). There will be no movement at the midway point, and each half of the string will vibrate as a unit. Since *OA* (or *PA*) is one-half of *OP*, it will vibrate at twice the frequency as the string *OP*, with the result that the first harmonic will be created.

Going one step farther. If the string is touched at *B* (one-third the distance from *O* to *P*), it will vibrate in three segments, thereby creating the second harmonic. Touching the string one-fourth the distance from *O* to *P* will make four segments and create the third harmonic; and so on.

While, in general, overtones and harmonics create quality, some of the higher harmonics create discord because of their interference with other harmonics and overtones. Consequently, musical instruments are so designed that the string will be struck or plucked at a selected position in order to prevent setting up high harmonics that would detract from the quality of the tone. For instance, the strings of a piano are struck about one-seventh of the distance from one end, so that that point on the string will be in motion and cannot become a node. Nodes are the points of no vibration—as *A*, *B*, *C*, and *D*, in Fig. 5—(*A*), (*B*), (*C*), and (*D*) which limit the number of harmonics that the string is capable of creating.

It should be understood, however, that while the string on a musical instrument is vibrating to create harmonics, at the same time it is also vibrating as a single unit, as indicated in Fig. 5 (*E*). Herein lies the creation of overtones other than harmonics—tones that are definitely related.

In Fig. 5(*E*) note that there are two frequencies, the fundamental and the first harmonic. Another frequency of vibration is established through a combination of the two shown; that is, the frequency of the fundamental is added to the first harmonic to create a disturbance of the air; and even though the string does not itself establish the disturbance, a third sound, related to the two sounds created mechanically and harmonious with them, is produced. For instance, if the fundamental frequency of vibration were that of middle C (256 vibrations per second), the first harmonic would be 512 vibrations per second—one octave higher than the fundamental. The sum of 256 and 512 is 768, a frequency of vibration which the ear would hear in addition to the fundamental of 256 vibrations per second, and the harmonic 512 vibrations per second. Both of the latter frequencies are harmonics, but only one of them is produced mechanically. Reference to the major diatonic scale (invented by Bach), would show that a vibration of 768 times per second is the tone described as G, or, in terms of the scale, "sol," in the second octave above middle C, the fundamental tone in this illustration. An overtone is not necessarily a harmonic, but may be a tone related to the fundamental and its harmonics. The calculations carried out here could be applied to a sound due to any specific frequency of vibration.

Pitch. Since *pitch* is determined by the number of vibrations produced per second, it is evident that melodies or tunes can be produced by varying the pitch as desired. Vocal sounds, too, are rated according to the pitch—bass, baritone, tenor, also, soprano, and so on, up to 1,000 vibrations per second. Some bass singers, however, can sustain notes as low as 60 vibrations per second; and some soprano singers have been reasonably accurate around 1,300 vibrations per second. Musical instruments also have pitch limits, with the piano and the organ covering the greatest span of vibration frequencies. The lowest tone produced by a piano or an organ is about 27 vibrations per second; the highest note on the ordinary instrument is about 4,100 vibrations per second.

Other instruments cover only certain portions of the above-mentioned range of pitches as shown in Table I (ranges according to the major diatonic scale).

The pitch of some wind instruments is determined by the amount of air permitted to pass through the air column, and the length of the air column. Bass horns have a much longer tube than horns that are pitched higher. The pitch of the tones emitted by a pipe organ is determined by the length of the pipe which governs the number of condensations and rarefactions of the air within a given length of time. Vibrations of the air column in a clarinet are set up by a reed on the mouthpiece. The length of the air column determines the pitch, which is varied by opening apertures through which air is deflected and instantaneously changes the number of times the air particles are disturbed. The valves on the cornet and similar wind instruments act to lengthen or shorten the tube through which the air passes, and thereby change the pitch. The tones produced by string instruments are created mechanically by either striking or plucking the strings.

TABLE I

Range of Pitches According to the Major Diatonic Scale

Instrument	Low	High	Type of Instrument
Banjo	288	768	String
Bassoon	60	480	Wind
Bass Tuba	42.67	341.33	Wind
Bass Viol	40	240	String
Cello	64	682.67	String
Clarinet	160	1536	Wind
Flute	256	2304	Wind
French Horn	106.67	853.33	Wind
Guitar	80	640	String
Kettle Drums	85.33	170.67	Percussion
Mandolin	288	1536	String
Mandolin Cello	64	256	String
Piccolo	512	4068	Wind
Trombone	80	480	Wind
Trumpet	160	960	Wind
Violin	288	3072	String

The method of combining different kinds of instruments, as well as the selection of instruments to be combined, determines the type of musical ensemble that results. For instance, a military band differs from any other kind of band (a brass band, for example) because of its different combination of instruments. Similarly, a concert orchestra differs from a dance orchestra. The objective of the director of the band or orchestra is the governing factor in determining the type of instruments to be used and the number of each. His selection is based upon the effect he wishes to produce.

The Siren. The siren is probably the best known illustration of sound creation by means of air particle disturbance. If a column of air is directed upon a disc in which regularly spaced holes have been drilled around a given radius (Fig. 6), and the disc is rotated, each time one of the holes comes in front of the air column there will be a rush of air, followed immediately by a rarefaction; another condensation at the next hole; and so on. If the column of air is directed to a series of holes spaced the same distance apart as the first row, but on another radius, and the disc is rotated at the same speed as before, the condensations and rarefactions will occur at different intervals, because the distance to be traveled differs from that shown in the first case, and so the pitch will be changed. If the second row of holes is nearer the center of the disc, their pitch will be lower; while if they are nearer the circumference, their pitch will be raised. Also, if the speed of the disc is increased, the pitch will be raised; while if the speed of the disc is decreased, the pitch will be correspondingly lower. The pitch of a siren such as that shown in Fig. 6 can easily

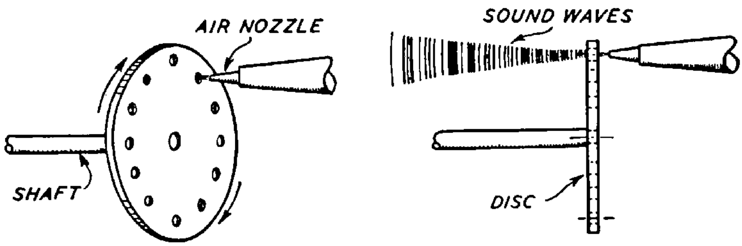


Fig. 6. A Siren

be determined by multiplying the number of holes in the disc by the number of revolutions which the disc makes per second.

It is evident that the action of the siren consists in the projection of puffs of air at regular intervals; and that the puffs, acting as condensations, register upon human ears as sound waves.

Another example of the creation of sound by means of disturbing the air is furnished by the propeller of an airplane. The sound coming from an airplane is caused by the propeller rotating in the air into which the plane is rushing and not, as is commonly believed, from the exhaust of the motors. We might say, then, that the electric fan should create a similar disturbance; but the fan is taking air at normal pressure, and increasing its speed only enough to create a breeze. A noise similar to the cracking sound made by an airplane propeller can be produced by blowing on the blades of an electric fan that is running. In fact, the speed of the fan blades is great enough to produce a musical note, if the air projected against them were of of sufficient and constant strength. In experimenting with the fan blades, note also that, although the intensity of the sound may vary with the same pressure of air, the pitch remains the same, no matter at what part of the blade the stream of air is projected. This is because the stream of air is being cut the same number of times each second, regardless of whether it is projected against the blades near the hub or near the circumference.

How We Hear. Hermann von Helmholtz, a German scientist, physiologist, mathematician, and physicist of the 19th century, advanced the thoery that the cochlea of the inner ear contains about 3,000 or more fibers; that each fiber vibrates in resonance with a given frequency of vibration, thus transmitting to the brain the effect of that particular impulse, and thereby creating the sensation of hearing. This theory appeared to clear up the mystery of the ability of the ear to hear a complexity of sounds—such as, for example, a fundamental frequency together with the first, second, and other harmonics; or a combination of more than one fundamental with their attending overtones striking the ear simultaneously.

Further, because of the ability of the human auditory system to respond to complicated sounds, the individual has the power to distinguish between different instruments by differentiating them from the "quality" standpoint.

Variations in Pitch. There are several standard musical scales, among them those known as the International and the Major Diatonic. Because of its simpler calculations, the Major Diatonic Scale is the one most commonly used in textbooks for the purpose of comparing vibration frequencies. However, although according to the Major Diatonic Scale, the first note on a piano or organ produces a tone of 26.67 vibrations per second, the piano may be tuned to produce a tone of more or less than that number of vibrations; and in that case, the other strings would be adjusted to produce tones higher than those specified in the Major Diatonic Scale. But since, in order that instruments may be played simultaneously and harmoniously, they must be tuned to the same tones or related ones, it is necessary for an orchestra to tune its instruments to the piano being used.

Most musical instruments are tuned according to the *tempered scale,* in which the vibration frequencies assigned to the notes differ slightly from those of the Major Diatonic Scale. A comparison of the frequencies for a single octave—beginning with middle C is given in Table II.

TABLE II

Comparison of Frequencies for a Single Octave

Note	Major Diatonic Scale	Tempered Scale	
		C=256	A=435
C	256	256	258.3
D	288	278.3	290.3
E	320	322.5	325.9
F	341.3	341.7	345.3
G	384	383.6	387.4
A	426.7	430.6	435
B	480	483.2	488.3
C	512	512	517.2

Range of Audibility. The normal range of audibility—that is, the range of vibration frequencies heard by the human being—is from between 15 and 20 vibrations per second to approximately 12,000 vibrations per second. Few people, in fact, can distinguish sounds produced by 12,000 vibrations; although some can hear as high as 15,000 vibrations per second.

There are also very few persons whose auditory system will respond with equal efficiency over the entire range of frequencies; some frequencies will register with greater intensity than others, and vice versa, which explains the differences of opinion regarding the quality of a particular type of reproduction.

MODERN RADIO ESSENTIALS

CHAPTER III

MAGNETISM AND ELECTRICITY

MAGNETS AND MAGNETISM

A thorough understanding of the principles of magnetism is a necessary foundation for subsequent analyses of electrical phenomena.

Bar Magnets. A *magnet* is a bar of iron or steel that has been subjected to electrical treatment, which has given it the property of attracting iron, steel, and certain other metals. The *bar magnet,* as it is usually called, also has the property of assuming a north-to-south position when suspended by a thread; for this reason, the ends of the magnet are commonly referred to as the *"north pole"* and *"south pole."* The north pole of a magnet is also called the *positive* (+) pole, and the south pole is known as the *negative* (−) pole.

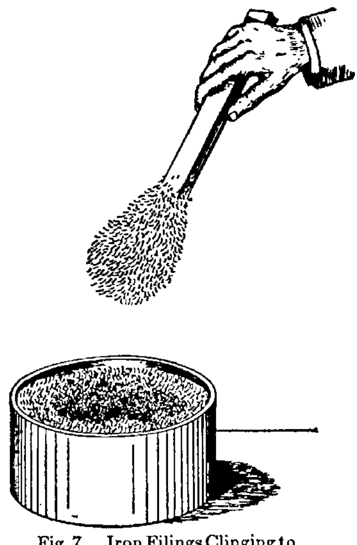


Fig. 7. Iron Filings Clinging to End of a Bar Magnet

If either end of a bar magnet is dipped into a pile of iron filings and then withdrawn, that end will be covered with the iron particles, as shown in Fig. 7. Investigation reveals that many of the particles are not touching the bar itself, but are clinging to other filings, showing that the filings also have become magnetized so that they, too, have the same magnetic properties as the bar. The property of attracting metal is called *magnetism.*

If the bar magnet were broken in two, it would retain its magnetism, Fig. 8. The north pole (*N*) would continue to function in that capacity, and the other end of the broken half would become a south pole (*S*). Similarly, the south pole (*S*) of the bar would be the south pole of its half of the bar, and the other end of the half would become a north pole (*N*).

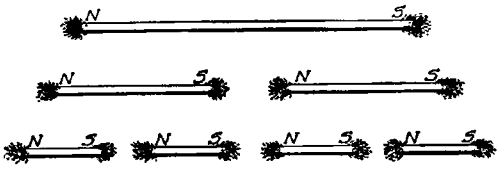


Fig. 8. Results of Breaking a Bar Magnet

Although magnets have the property of attracting and holding certain metals, they also have the property of repelling them, under proper conditions. For instance, if the north pole of one magnet is brought close to the north pole of another magnet, the two will tend to repel one another; on the other hand, if the south pole of one magnet is brought close to the north pole of the other, they will attract one another and cling together. This experiment demonstrates an accepted electrical law: "Like poles repel—unlike poles attract."

Horseshoe Magnets. A *horseshoe magnet* is bent in the shape of a horseshoe, as shown in Fig. 9. Its properties are identical with

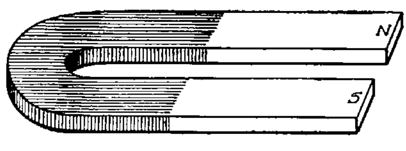


Fig. 9. A Horseshoe Magnet

those of the bar magnet. An iron or steel nail placed on either pole of the magnet will adhere to it and tend to be attracted toward the other pole, Fig. 10. If more than one iron nail is placed on either pole, the ends of the nails tend to repel one another, in accordance with the rule just explained.

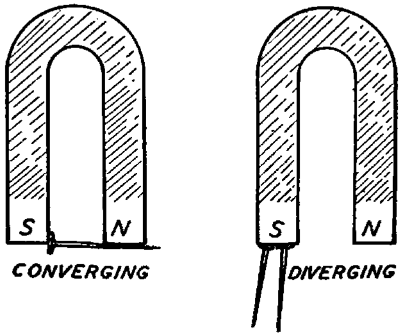


Fig. 10. Diagram Illustrating Laws of Attraction and Repulsion

Temporary and Permanent Magnets. A *temporary magnet* is one which holds its magnetism for a short period of time. A *permanent magnet* is one which retains its magnetism indefinitely. Soft iron is used for temporary magnets; but if a permanent magnet is desired, a piece of hard steel is placed inside a coil of wire through which direct current is passing. Such a magnet, if properly seasoned and cared for, will continue to hold its strength over a long period of years.

Electromagnets. An *electromagnet* is made by winding a coil of wire around a piece of soft iron and passing a current through the coil, as shown in Fig. 11. So long as the circuit is connected as shown,

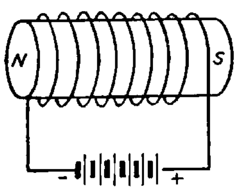


Fig. 11. An Electromagnet

the polarity of the magnet will be as indicated; but if the connections on the source of supply are reversed, the poles will be reversed also so that the one marked *N* (north) in the diagram will become the south pole, and the pole marked *S* (south) will become the north pole. Similarly, the polarity as indicated by the positive (+) and negative

(−) signs will be reversed. An electromagnet will attract iron and steel when electric current is passing through the coil winding, and will release the metal when the circuit is opened and current ceases to flow.

Magnetic Fields. A very interesting experiment can be conducted by placing a bar magnet under a sheet of paper and then sprinkling iron filings over the paper. The filings will take very definite positions with respect to the bar. Those directly over the ends of the magnet will adhere very tightly—bunched up, as it were, with a tendency to spread out in a fan-shaped design. Away from the ends of the magnet, the filings will line up parallel with the sides of the bar, assuming the design shown in Fig. 12.

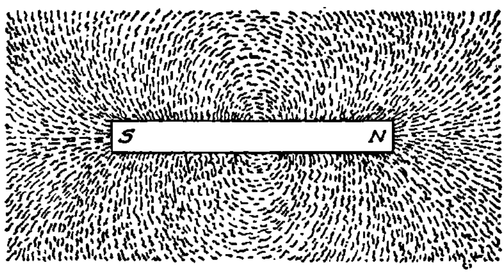


Fig. 12. Magnetic Field of a Bar Magnet

The same phenomenon holds true with the horseshoe magnet, except that the shape of the design differs because of the proximity and relative position of the two poles.

The iron filings clustered about the bar magnet demonstrate the presence of what is called the *magnetic field.* It can be shown just as graphically by moving a compass slowly along the length of the bar, and observing the movement of the needle.

Because of the proximity of the poles of a horseshoe magnet, the magnetic field between its poles is considerably stronger than that existing around the poles of a bar magnet. It is this property of horseshoe magnets that makes them adaptable to so many uses in electrical machines, in headphones and certain magnetic types of loud-speaker units, and in electrical instruments.

Magnetic Lines of Force. The bar magnet and compass can also be used to demonstrate what is meant by *magnetic lines of force.*

If the compass is held at one end of the magnet and then moved in the direction toward which the needle points, Fig. 13, a pencil that follows the compass needle will inscribe an elliptical figure. This curved line represents a *magnetic line of force,* which may be defined as a line drawn through a magnetic field in such a manner that all

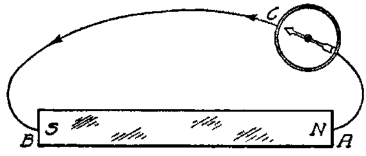


Fig. 13. Diagram Showing Method of Plotting Lines of Force in a Magnetic Field

points on the line are in the direction of the field. Actually, the line represents the path that the north pole of the magnet would follow if it were free to move.

When the first line has been completed, start from another point on the end of the magnet and inscribe another such line. If the starting point is nearer to the center of the end of the magnet, the line will be farther removed from the bar than the first one; if the second starting point is toward one edge of the end, the second line will be closer to the bar. In either case, the line will be elliptical in shape.

The lines of force, taken as a unit, are also known as *magnetic flux,* which is dependent in quantity upon the intensity of the magnetic field or the field strength.

Terrestrial Magnetism. That a magnetic field surrounds the entire earth, is demonstrated by the fact that a compass will always point in a north-and-south direction, unless disturbed by some other type of magnetic field stronger than that which envelops the earth.

Although it is commonly thought that the compass needle points due north, it does not actually do so; instead, it points to the magnetic pole which does not coincide with the earth's geographical north pole. Magnetic meridians do not follow geographical meridians, and in some localities the compass needle *may* point to the astronomical north; in other places it declines to the east, or to the west, of north.*

*Through a confusion of terms that dates back to the early discoverers of electricity, we are accustomed to label as "north" everything lying above the equator, while everything lying below it is labeled "south." As a matter of fact, the north pole of a magnet or compass needle is attracted by the south magnetic pole of the earth, which is located somewhere near Hudson Bay; while the south pole of the magnet or compass is attracted by the earth's north magnetic pole, which is located near the earth's geographical south pole. Full explanation will be found in any standard work on magnetism.

It is terrestrial magnetism, which surrounds and permeates the earth, that provides a source of electrical energy and makes possible the generation of electric power for the thousands of uses to which man has applied it. Electricity, as it is known to us, is terrestrial magnetism that has been collected and controlled to meet the needs of mankind.

ELECTRICITY AND ITS PROPERTIES

Electricity is a power—beyond that, even the scientists know little about it except theoretically. However, experience and research have given man the knowledge of how to produce and direct electrical energy so as to serve his purposes.

Discovery and Development. The first recorded discovery of any of the electrical phenomena appears to have occurred about 600 B.C., when Thales, a Greek, found that a piece of amber rubbed with fur had the property of attracting and holding light objects. The Greek name for amber was "elektron," from which is derived the term "electricity."

It was not until about 1600 A.D. that Gilbert discovered that glass and certain other materials could be *electrified,* and so given the ability to pick up bits of paper, cork, and similar light objects. He concluded, however, that metals could not be electrified. In 1730, Gray demonstrated that metals had not been electrified because they allowed the electricity to escape by *conduction,* and concluded that substances which thus permit the electricity to escape must necessarily be used in conjunction with substances which do not permit the escape of electricity. Here was the first differentiation between *conductors,* media that carry or conduct electricity, and non-conductors, or *insulators,* substances that do not conduct electricity, such as glass, silk, and rubber.

About twenty years after Gray's discovery, when Benjamin Franklin "drew" electricity from the clouds with his historic kite with a metal key attached to its string, the discharge from the key knocked him to the ground. A Russian scientist, who attempted to repeat the experiment a short time later, was killed by the charge. Franklin was extremely fortunate, but it is doubtful if he was aware of the risk he took.

The development of electricity began to make real progress with the beginning of the nineteenth century, when Alessandro Volta combined copper and zinc in cells containing an acid solution to make the first electric battery (1800). Other applications rapidly appeared: telegraph, electric generator, electric motor, arc lights, telephone, incandescent lamps, electric railway, railway signals, wireless telegraph, household appliances, medical treatments, and radio.

Kinds of Electricity. Electricity is produced in two forms: first, as *electrostatic* energy; and, second as *electrodynamic* energy.

Electrostatic energy is electricity at rest. It is a charge of electrical energy that is produced when a piece of amber, glass, or hard rubber is rubbed with a piece of silk, fur, or flannel. The electrical charges collect upon the surface of the substance rubbed, as well as upon the material with which the rubbing is done. Electrostatic charges are polarized; that is, the charge is either positive or negative, according to the substances with which it has been produced. For instance, a piece of glass rod, rubbed with a piece of silk, will carry a positive charge. On the other hand, the charge on the glass will be negative if the rod is rubbed with flannel or fur.

A glass rod that has been rubbed with a piece of silk will attract another glass rod that has been rubbed with a piece of fur. Contrariwise, a glass rod that has been rubbed with a piece of silk will repel another glass rod that has also been rubbed with silk. Similarly, a glass rod that has been rubbed with a piece of fur will repel another rod that has also been rubbed with fur. Here, then, we have the electrical law: "Like charges repel—unlike charges attract."

Electrodynamic energy is electricity in motion. It is electricity that is collected—produced—either by some chemical action or by some means of mechanical generation. Electrostatic energy has little or no value except for its use in experiments and for providing a basis of proof of theories or phenomena. Electrodynamic energy is that form of electricity that serves the needs of man in furnishing power, light, heat, entertainment, and in many other ways.

The Electron Theory. The *molecular theory* and the *atomic theory* are closely associated with the latest and now accepted scientific explanation of electrical phenomena, the *electron theory*. That all matter consists of small particles called *molecules* has been accepted in scientific circles for several years. Scientists have also agreed that the molecules consist of still smaller subdivisions called *atoms*; but until recent years it was held that the atom was the smallest part into which a substance could be divided.

The invention of the radio, with the resulting intensive research, brought forth the theory that an atom consists of electrical charges, one of which is positive in nature, while other parts are negative. The positive charge—the nucleus, as it were—is known as the *proton*, and is a fixed particle. The negative charges, which attach themselves to the positively charged proton, are called *electrons*, and their arrangement is believed to be similar to the solar system, with the sun corresponding to the proton, and the planets represented by the electrons.

Thus all matter is believed to consist of varying combinations of electrical charges, and the substance is considered to be charged negatively if an oversupply of electrons is present; or charged positively, if the number of electrons is less than enough to balance exactly the intensity of the positive charge on the proton.

Scientists differ, however, as to the physical properties of the electron. Some say that the electron has no mass. They base their conclusions upon the inability to detect any change in the weight of a substance even after it has been subjected to treatment that causes either an emission or an attraction of electrons. Others, however, substantiate their belief that electrons do have mass, by asserting that the mass of the atom is almost entirely centered in the proton, and that an electron does have weight, though to an inconceivably small degree.

Electrons are free to move about within the substance of which they are a part. In fact, anything that is done to disturb the molecular or atomic structure of the substance—such as heating, for example—causes a greater movement of the electrons, so that they finally leave the parent proton. If the heating continues until the temperature of the substance becomes sufficiently high, the electrons will leave the surface of the substance and fly off into space; but either they or other electrons will attach themselves to the protons as the temperature once more returns to normal. Heating the substance another time will again cause a similar movement of electrons.

According to the electron theory, then, any passage of electricity is really a movement of electrons within the conducting medium. Electrons are subject to the fundamental law of electrical charges, "Like charges repel—unlike charges attract." Thus it is that the negative particles, or electrons, are attracted to the proton which has a positive charge, and move about only when disturbed, or when it is necessary to effect a balance between the positive and negative charges.

A magnet, then, is a metal bar that has been subjected to an electrical treatment which has caused the negative charges to leave one end of the bar and collect at the other end. In the case of the permanent magnet, the treatment is such as to prevent the movement of the electrons back to their normal positions; and if, after a period of years, the magnet loses its power to attract metals—iron and steel—it is because the electrons themselves have overcome the inertia and have made their way back through the metal and attached themselves to other protons.

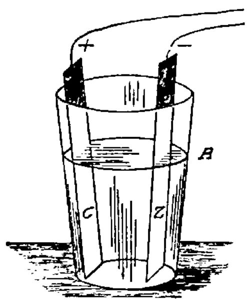


Fig. 14. A Simple Voltaic Cell

The current of electricity passing through the coil of an electromagnet causes the electrons to move through the core of the magnet toward one end, which will then attract the positively charged surface of a metal that responds to magnetic fields. If the current is reversed, the electrons will fly back through the metal to the other end.

Sources of Electrical Energy. Electrostatic energy is created by friction. Electrodynamic energy is produced either by chemical action or by mechanical generation. Electricity that is produced by chemical action is constant in its potential; that produced mechanically is vibratory. The electrochemical method of producing an electric current was invented by Alessandro Volta, an Italian physicist, in 1800. His invention, now known as the voltaic cell, consisted of two plates of different metals—copper and zinc, for instance—immersed in a suitable solution or electrolyte, such as sulphuric acid, as shown in Fig. 14.

When zinc is immersed in a solution of sulphuric acid, the acid attacks the zinc, which may be said to provide fuel for the cell. The chemical symbol for zinc is *Zn*; for the sulphuric acid, H_2SO_4, which means that a molecule of sulphuric acid contains two atoms of hydrogen (which is positive), one atom of sulphur (which is negative), and four atoms of oxygen (which is negative). The negative charges embodied in the sulphur and the oxygen balance the positive charge of the hydrogen, because every normal molecule contains a positive electrical charge equal to its negative charge.

When the sulphuric acid attacks the zinc plate in the voltaic cell, the hydrogen in the sulphuric acid is liberated, and may be seen to collect on the copper plate, rise to the surface, and disappear. The zinc then associates with the solution to form zinc sulphate, $ZnSO_4$. Thus it is that through the disassociation of the metal and the solution, the removal of the positively charged zinc particles from the zinc plate leaves that electric terminal, or *electrode,* with an excess of electrons, which are negative charges of electricity. The positively charged hydrogen atoms on the copper plate tend to increase the intensity of the positive charge on that electrode, so that a difference of potential is established between the copper and the zinc electrodes, with the result that current will flow between them when they are connected by a conductor.

The passage of the current through the conductor is a transmission or movement of negative charges—electrons—which pass from the zinc plate through the wire to the copper plate. This explanation is different from the theory in vogue until recent years, which considered the current as flowing from the positive to the negative terminals of a cell through an external circuit; but the electron theory has now been adopted and is in universal use. In other words, the flow of electricity is now regarded as electron flow, which is exactly opposite to what was formerly considered as current conduction or current flow. In order to correlate the old and the new theories and prevent confusion, some scientists assert that the electrons moving in a conductor actually create a path over which the current may flow.

Primary Cells. A cell is an individual unit. When cells are combined for any purpose, the combination is called a battery. The *dry cell* in common use today is an adaption of the voltaic cell. The outer shell, Fig. 15, which constitutes the form for the cell, is

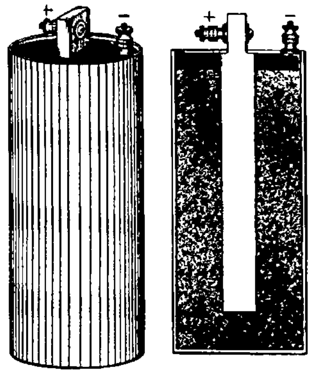


Fig. 15. Cross Section of a Dry Cell

the negative electrode and is made of zinc. It is filled with various combinations of porous materials over which an electrolyte is poured, and in the center of which is embedded a carbon rod that becomes the positive electrode. The electrolyte reacts upon the zinc shell as previously explained, setting up a difference of electrical pressure between the positive and the negative electrodes, so that current will flow when the electrodes are connected.

Storage Batteries. A storage battery is not a primary cell such as that just described, yet, at the time that it is providing electrical energy, its method of operation is that of the primary cell. The storage battery consists of two plates, or several pairs of plates assembled in dovetailed fashion, with thin wooden separators to prevent the adjacent plates from touching one another. The entire assembly is immersed in a solution of sulphuric acid that has a specific gravity of 1.280. The plates are of two distinct types: one type forms the positive electrode, the other type forms the negative electrode. The plates are constructed by preparing a "skeleton" or grid upon which is laid a compound that will react chemically to the acid solution. Although the materials used may vary, one commercial type of storage battery uses a lead plate for the negative electrode, and for the positive electrode a plate with a coating of lead sulphate, $PbSO_4$, which, by charging and discharging the battery several times, is changed to a reddish-brown lead peroxide, PbO_2. If the battery uses the grid type of plate for the negative electrode, the pores in the grid are filled with sponge lead.

During discharge, the sulphuric acid attacks the lead of the negative electrode, causing a disassociation of the compounds and forming lead sulphate, $PbSO_4$, which coats both the positive and negative plates. When both plates have become coated with an equal quantity of the same material, the battery is said to be discharged and will not produce current. However, connecting the battery to a source of outside energy, and passing a direct current through the battery in the direction opposite to that in which the battery delivers during discharge, will remove the lead sulphate from the plates, leaving them as they were originally—lead for the negative electrode, lead peroxide for the positive electrode. The battery will then produce an electric current.

During the process of charging and discharging, the solution in the battery escapes as gas—necessitating occasional replenishing, since it is essential that the solution should cover the electrodes, to prevent warping or breaking the plates. Water only is required for refilling the battery; and it is quite important that the water be pure and free from harmful substances, such as metals in suspension, or chemicals that would react on the battery plates or neutralize the acid. For this reason, distilled water is usually used.

Mechanical Generation. If a wire were passed through the magnetic field, as shown in Fig. 12, and discussed under the heading "Magnetic Field," a current of electricity would be produced because of the movement of the wire and its cutting of the lines of force. Herein lies the principle involved in the *mechanical generation* of electricity, in which several wires formed into a coil are rotated through magnetic fields, thereby setting up an electric current that may be used in a number of ways. This text discusses electrical phenomena only as they may apply to radio. Further information regarding the details of generators and the generation of electrical energy by mechanical means can be obtained from any electrical engineering text.

Mechanically produced electric current differs from the steady-flowing current produced by chemical action, and is fluctuating in nature. There are two kinds of mechanically produced current, known as *direct current* and *alternating current,* both of which have extensive commercial applications. Direct current flows through a circuit in the same direction at all times. Alternating current, on the other hand, flows first in one direction and then in the other, at regular intervals.

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MODERN RADIO ESSENTIALS

CHAPTER IV

GENERAL DEFINITIONS

Electric Circuits. An *electric circuit* is a path through which an electric current flows. A circuit is said to be *shorted*—or a *short circuit* is said to exist—when conductors touch one another to divert the current flow and prevent passage of the current through all parts of the circuit. A circuit is said to be *open*—or an *open circuit* is said to exist—when the continuity of the circuit is broken so that the electric current does not have free flow to all parts of the circuit.

Conductors. A *conductor* is a substance, usually metal, that offers little resistance to the free flow of an electric current. It is a substance whose molecular construction is such that the electrons can readily free themselves from the positive protons to which they have attached themselves. A conductor is said to be "good" or "bad," according to the facility with which it conducts electric current. However, some metals that are exceedingly good electric conductors are impractical for general use, because of their high commercial value. Copper, because it is abundant and easily shaped into wire and other forms, is the metal most widely used as a conducting medium.

Insulators. An *insulator* is a substance which sets up an exceedingly high resistance to the flow of electric current and which, for all practical purposes, actually prevents the flow of current. Glass, rubber, mica, and fabricated phenol compounds (Bakelite) are commercial types of insulating material.

Resistance. Anything that tends to oppose the free flow of electric current is said to possess resistance. Carbon, graphite, nichrome, and other forms of steel constitute the principal commercial resistance materials. Opposition to the flow of alternating current through a circuit caused by inductance (coils) and capacity (condensers) is called *reactance*. In alternating-current circuits, where resistance and reactance both exist, the combination of the two opposing forces is called *impedance.* Resistance, reactance, and impedance are measured in *ohms.*

Conductance. Conductance is the measure of the amount of electrical energy that a conductor will permit to pass through the circuit. It is inversely proportional to the resistance of the conductor. The unit of measure is the *mho.* Thus, a resistor that has a resistance of two ohms is said to have a conductance of one-half mho. Similarly, a resistor that has a resistance of three ohms will have a conductance of one-third mho.

It will be seen, therefore, that a conductor having three times as much resistance as another conductor, will conduct only one-third as much electric current. It is also true that the conductance of a conductor is always determined by dividing *one* by the resistance of the conductor.

Electrical Units. A *volt* is the unit of electrical pressure or electromotive force. It is defined as the pressure required to force a current of one ampere (measure of current flow) through a resistance of one ohm.

An *ampere* is a unit of electrical current flow. It may be defined as the current which will flow through a resistance of one ohm with a pressure of one volt. A *milliampere* is one one-thousandth (.001) of an ampere. A *microampere* is one-millionth (.000001) of an ampere, or one one-thousandth (.001) of a milliampere.

A *watt* is a unit of consumption of electric power, represented by a current of one ampere at a pressure of one volt. The number of watts is found by multiplying the current in amperes by the pressure in volts. Thus, an incandescent lamp that draws one ampere of current on a 110-volt line is known as a 110-watt lamp. Similarly, an electric iron that draws five amperes of current on a 110-volt line will consume 550 watts of energy.

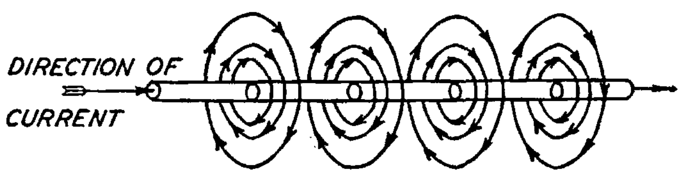


Fig. 16. Diagram Showing Lines of Force Around a Wire

Lines of Force—Electromagnetic Field. When an electric current is flowing through a conductor, an *electromagnetic field* is created in the form of *lines of force* that whirl around the conductor, as indicated by the arrows in Fig. 16. The lines of force move in a definite direction with respect to the direction of flow of the current through the conductor.

The directions in which the lines of force travel around the conductor is determined by the use of Fleming's Right-Hand Rule, which is illustrated in Fig. 17. When the conductor is grasped in

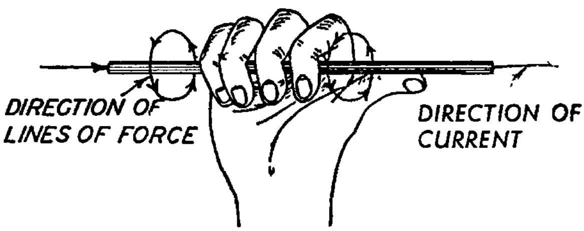


Fig. 17. Application of the Right-Hand Rule

the right hand, with the thumb pointing in the direction in which the current is flowing, lines of force are circling around the conductor in the direction indicated by the fingers.

If a circuit such as that shown in Fig. 18 were set up, so long as the key—or switch—remained open there would be no current flow, nor would lines of force surround the conductor AA'. However,

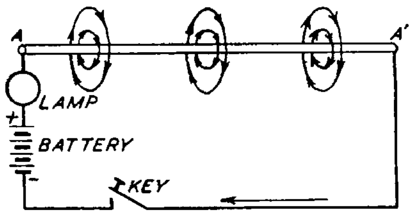


Fig. 18. An Electric Circuit

closing the key would cause the current to begin to flow; and during the period required for the energy to attain its maximum values in current and pressure, the lines of force would whirl, and at the same time expand outward, as shown by the arrows of different size. To demonstrate the expansion of the magnetic field, grasp the conductor with the right hand and then loosen the grip so that the fingers move outward. The outward movement of the fingers corresponds to the expansion of the magnetic field during the period required for current and voltage to reach their maximum values.

The phenomenon just explained can be further emphasized by means of a hydraulic experiment. In Fig. 19, the conductor shown in Fig. 18 has been replaced by a rubber tubing connected to a pump; this pump represents the battery, to the extent of supplying

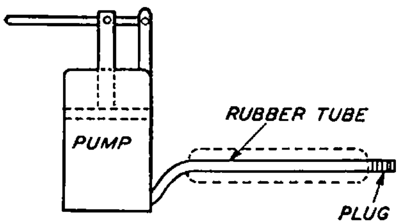


Fig. 19. Diagram Illustrating Effect of Applying Pressure to a Soft Rubber Tube

the water (current) and the pressure (voltage). When the pump is not operating, the rubber tube is at rest and in its normal state. If the pump is started, the pressure rises until the rubber tube expands, as indicated by the dotted lines. The extent to which the hose expands will depend upon the amount of water forced into it, and the amount of pressure at the pump.

Similarly, the lines of force surrounding an electrical conductor carrying a continuous current, such as that delivered by a battery or a direct-current generator, will expand outward in accordance with the amount of current and voltage that is sent into the circuit. Also, just as the rubber hose expanded gradually during the period in which the pressure attained the maximum, so in the electrical circuit, as the current and voltage are built up, the lines of force expand outward to the maximum.

Stopping the pump would relieve the pressure and allow the rubber hose to resume its normal state. Similarly, in the electrical circuit, raising the key would open the circuit and cause the current to stop flowing, so that the lines of force would collapse just as the rubber hose did when the pump stopped operating.

Magnetic Induction. If, as shown in Fig. 20, one end of a bar magnet is passed over the conductor *BC*, to which a galvanometer is connected, the needle of the instrument will move. As the magnet swings back in the opposite direction, the needle will swing toward the other side of the zero point. This experiment shows that an electric current is being induced in the conductor—a phenomenon that occurs when lines of force are cut by a conductor.

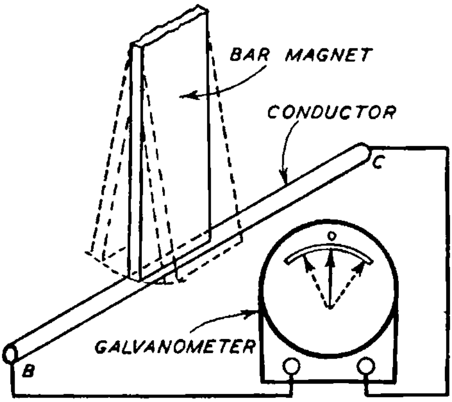


Fig. 20. Electric Circuit Produced by a Moving Magnetic Field

The same result would be obtained by passing the conductor up and down through the magnetic field surrounding the end of the magnet.

Electromagnetic Induction. It has been shown that a current will be caused to flow in a conductor when it is passed through the lines of force surrounding the poles of a magnet. It was also shown

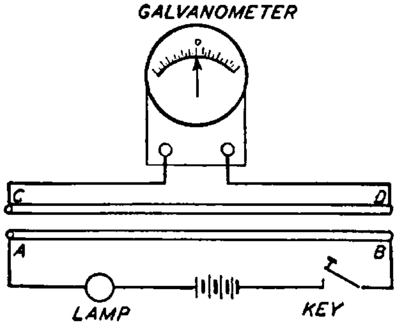


Fig. 21. Electromagnetic Induction Experiment

that a magnetic field is produced around a conductor when a current is flowing in a circuit. Therefore, if conductor *CD*, Fig. 21, is laid alongside conductor *AB*, which is connected to a battery, and if the ends of conductor *CD* are connected to a galvanometer as shown, the needle of the galvanometer will move from the zero point when the key is closed. However, the needle will return almost instantaneously to its normal position when the voltage and the current flowing through conductor *CD* attain their maximum values. Releasing the key will open the circuit and again cause the needle on the galvanometer to move, but this time in the direction opposite from the normal position to which it moved when the key was closed. Again the needle of the instrument will come to normal when voltage and current attain their maximum values.

The foregoing experiment shows graphically that a current is caused to flow in a conductor when that conductor is cut by lines of force. The fact that the needle on the indicating instrument moved at the time when the key was closed and then returned to normal, shows that the magnetic field surrounding the conductor was being built up and that the lines of force were expanding outward. That there was no movement after voltage and current had attained the maximum, indicates that the electromagnetic field surrounding the conductor was stationary—that is, it was not moving inward and outward. Again, when the key was opened, the lines of force that had been whirling around the conductor as a center, collapsed—that is, they moved inward, and the lines of force cutting the conductor caused the current to flow instantaneously in conductor *CD*.

Similarly, if a vibrating current of electricity is flowing through a conductor, the lines of force surrounding the conductor are constantly moving inward and outward, so that if another conductor were placed alongside the one carrying the vibrating current, an electrical current would be induced in the second conductor. This can be determined by connecting a galvanometer in circuit with it, as shown in Fig. 21.

Inductance Coils. *Coil* is the term applied to the form into which a conductor is wound to concentrate the electromagnetic field produced by current flow. If the conductor *AB* in Fig. 21 is wound around a stick—a pencil, for example—and suspended so that it remains fairly taut, and if the terminals are connected to a battery as shown in Fig. 22, it can be used for some very interesting experiments.

First, place one end of a needle on the first turn of the coil, and hold the other end with a finger. Then push the key and the needle will fly into the coil. If the needle used is heavy, it will gain enough momentum to throw it through the coil to the other side. If it is light, it will stop in the coil and remain there until the circuit is opened by releasing the key.

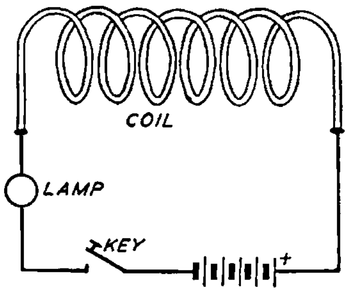


Fig. 22. An Electromagnet

Second, run a steel rod through the coil, holding it firmly at both ends, then push the key to close the circuit. The windings of the coil will be seen to pull together.

Third, place one end of the steel rod within the coil, and hold the other end in the hand. Then push the key and note the pull that is exerted on the rod.

Fourth, place the steel rod within the coil; then hold a needle in the palm of the hand and close to the rod. Push the key to close the circuit, and the needle will jump to the end of the rod and adhere to it. This shows that the rod has become magnetized as a result of the lines of force caused by the flow of electric current through the coil.

These, and many similar experiments, can be conducted with this simple set-up. All of them are direct applications of the creation of an electromagnetic field around the conductor, as already described.

In this creation of the electromagnetic field about the turns of a coil, the latter should be regarded as though it were a straight conductor. Fig. 23 shows part of a conductor wound into a coil. It can be seen that the lines of force whirl about each turn of the coil and add to one another, thus setting up a highly intensified field within the coil.

Magnetic Field Around a Coil. The form taken by the magnetic field about a bar magnet has already been discussed. A similar phenomenon is found in the electromagnetic field surrounding a coil, as illustrated in Fig. 23. Note that one end of the coil corresponds

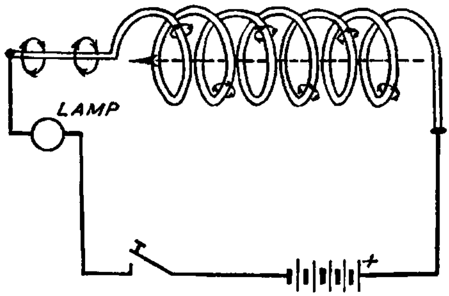


Fig. 23. Magnetic Fields Around a Conductor and Coil

to the north pole of a magnet, and the other end corresponds to the south pole; also, that the north pole is designated as the positive (+) end of the coil, and the south pole is designated as the negative (−) end. This latter fact is important because, in later analyses, and especially when analyzing circuits, it must be kept in mind that the opposite ends of a coil have opposite polarity; or, in other words, when one end of a coil is positive, the other end is negative. Thus, at any given time, the polarity is dependent upon the direction of flow of the electric current through the windings of the coil.

Likewise, the magnetic lines of force pass from the positive end of the coil toward the negative end; and, as just stated, which end is positive and which is negative, depends upon the direction of current flow.

Inductance. Inductance is the ability of a circuit to generate an electromotive force in the same circuit or in another circuit, because of the rise or fall of the electromagnetic field created by the flow of electric current. The unit of inductance is the *henry.*

Capacitance. Capacitance is the term which indicates the ability of any substance to receive and retain a charge of electrical energy.

Condensers. The *condenser* is a well-known form of capacitance unit, consisting of two sets of metal plates separated by an insulating material (in the larger condensers, air may provide the insulation) known as the *dielectric*. (See Fig. 24.) The unit of capacity of a condenser is the *farad*. A *microfarad* is one-millionth of a farad. A *micro-micro-farad* is one-millionth of a microfarad.

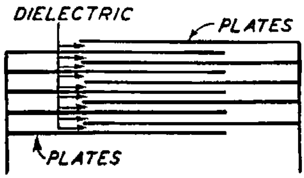


Fig. 24. A Condenser

Ohm's Law. Ohm's law, one of the most useful and most widely used rules in electrical engineering, concerns the relation existing between volts, amperes, and resistance. If any two of the three properties of a circuit are known, the third can be readily determined by applying Ohm's law.

By Ohm's law, we find that the electromotive force—the pressure or voltage—is equal to the current in amperes multiplied by the resistance in ohms. Expressed in symbol form, this is

$$E = IR$$

This means

$$E = I \times R$$

Here E designates the electromotive force (voltage), I designates the current (amperes), and R designates the resistance, measured in ohms.

To illustrate the application of this formula, let us assume that the resistance of a circuit is 10 ohms, and that 5 amperes of current, as measured with an ammeter, are flowing through the circuit. We wish to know the voltage across the circuit. According to the formula, the voltage is equal to the current multiplied by the resistance. Therefore, multiplying 10 by 5, we find the electrical pressure is 50 volts.

Ohm's law may also be expressed

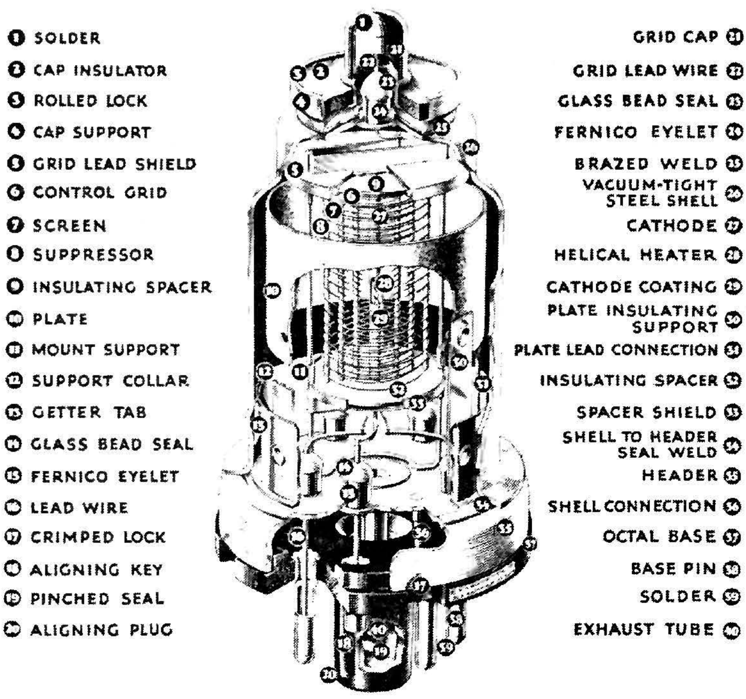
$$I = \frac{E}{R}$$

or

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

This is determined by making algebraic calculations. Any one of the three formulas may be used, as preferred.

Numerous applications of Ohm's law to radio work, will be found in this volume. This rule is so very important that it should be firmly fixed in the mind of every one engaged or interested in radio as a profession.



INTERIOR VIEW OF A METAL TUBE
Courtesy of RCA Manufacturing Company, Inc.

MODERN RADIO ESSENTIALS

CHAPTER V

RESISTANCE, CAPACITANCE, AND INDUCTANCE

All electrical circuits—including radio circuits—consist of combinations of resistance, inductance, and capacity, which may be termed "foundation functions." The relationship of the functions determines the effect created by passing a current of electricity through circuits of which they are a part. The general physical construction of the three electrical foundation units, together with their action individually or in combination, will explain the cause of certain phenomena, and help discover the reason for the failure of any part of a circuit to perform its function.

ELECTRICAL CONNECTIONS

Series and Parallel Connections. Electrical devices are said to be connected in *series* when they are joined end to end so that current passing through any part of the circuit must also pass through all other parts. Electrical devices are said to be connected in *parallel* when they are connected so as to provide more than one path over which the current may flow through the circuit, thus dividing it among the various branches during its flow.

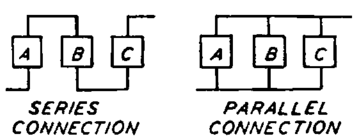


Fig. 25. Diagram Showing Difference between Series and Parallel Circuits

Fig. 25 shows the difference between series connections and parallel connections. Here the units *A*, *B*, and *C*, represent three resistances, three condensers, or three inductance units—a resistance, a condenser, and an inductance—or any combination that may be desired. It is evident, however, as explained above, that current flowing through the series circuit must flow through *A*, *B*, and *C*;

but that in the parallel circuit the current is divided among *A*, *B*, and *C*, so that either one or two of the units could be disconnected and still leave a complete path for the current to flow.

The effects produced by connecting the various electrical functions in series differ greatly from those produced by connecting them in parallel.

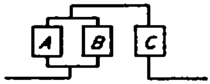


Fig. 26. A Series-Parallel Circuit

Series-Parallel Connections. Fig. 26 shows the arrangement of electrical devices in a *series-parallel* circuit. Units *A* and *B* are connected in parallel, while the network is connected in series with unit *C*.

RESISTANCE

General Resistance. Resistance has been defined as that which tends to retard the flow of electric current. Its applications are many and varied.

Since metal resistance materials have a relatively high current-carrying capacity, before the introduction of radio practically all resistance elements were required to carry heavy currents, and therefore were of the wire-wound type. In resistors of this type, the resistance wire is wound on a porcelain tube provided with a hole pierced through the center longitudinally, to permit the dissipation of heat. In some cases, the entire assembly (wire on porcelain) is

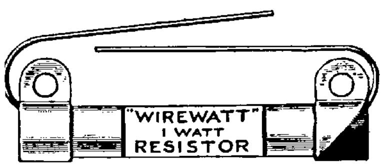


Fig. 27. A Wire-Wound Resistor

coated with a vitreous substance and subjected to a heat treatment to bake the covering, in order to prevent losses and changes due to moisture and temperature. Vitreous resistors, Fig. 27, are used in many radio circuits, particularly in power units for larger installations.

Carbon, another resistance material, is used extensively in radio circuits where the current is measured in thousandths of an ampere. It has an important part in the construction of ordinary forms of radio receiving apparatus.

The resistance of a substance varies in direct proportion to its length. For example, a piece of resistance wire two feet long has twice the resistance of a piece of the same wire only one foot long. The resistance also varies inversely with the cross section of the conductor—a conductor with a cross-sectional area of one square inch has only one-half the resistance of a conductor of the same material with a cross-sectional area of one-half square inch. Thus a wire .010 of an inch in diameter has four times the resistance of a wire of the same material with a diameter of .020 of an inch, because the wire with a diameter of .020 in. has a cross-sectional area four times that of the wire which is .010 in. in diameter.

Rheostats. A resistor whose resistance value may be varied—in other words, a variable resistor—is called a *potentiometer* or a *rheostat.* A potentiometer is a device in which both extremities of the resistance element may be connected into the circuit, while a sweeper arm that makes contact over the range of the resistance may vary the amount of resistance in another related circuit. The rheostat has only two terminals—one at the end of the resistance element, the other connected to a sweeper arm so that the resistance

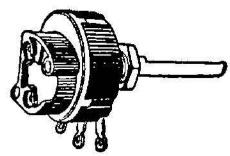


Fig. 28. Wire-Wound Rheostat and Potentiometer Used in Radio

introduced into the circuit may be varied. Fig. 28 shows a wire-wound rheostat and potentiometer, together with the symbols used in radio.

A wire-wound rheostat usually consists of a circular-shaped resistance element which is made by winding the resistance wire on an insulating material—fiber, for example. The resistance element is mounted on a form in such manner that the edge of the resistance element protrudes slightly above any physical part of the mounting. The sweeper arm, which is pivoted in the center, establishes contact by bearing lightly but firmly against the bare resistance wire. Since the wire used to form the rheostat has a definite resistance for each turn of the spirally wound unit, it is evident that each successive turn causes the resistance to vary in accordance with the resistance per turn.

Another method of constructing a rheostat or potentiometer—a design that makes the unit appear to be a wire-wound resistor—is to wind a wire that will hold its form around a piece of insulating material that has been treated with a carbon compound. After winding the wire on the form, a cutter severs each turn of the wire, so that each individual turn is making direct contact with the carbon, which acts as the resistance material. The wire protects the carbonized paper, preventing the sweeper arm from wearing off the carbon, and so making more positive connection with the resistance element.

There is another form of rheostat and potentiometer in which the sweeper arm rolls along a piece of thin metal that springs away from the resistance material—a carbonized sheet—so that contact is made only at the point where the arm holds the thin spring metal closely upon the carbon-treated plate. The spring-metal sheet actually rolls down upon the carbon-treated surface and does not in any way rub it.

In still another type of variable resistor, the carbon, combined with graphite and other substances to give it pliability, is placed in a container provided with a piston that compresses the resistance compound. When the carbon particles are packed closely together, the value of the resistance is lower than when they are less compressed.

Variable resistors of the carbon type used in radio circuits are not designed to carry high electric currents. They serve to vary the resistance gradually, instead of by steps, as is the case with resistors of the wire-wound type.

Wattage Rating. Heat is developed whenever an electric current flows through a resistance, and unless the heat is dissipated into the surrounding air, the resistance may become extremely hot. A resistance should operate at a constant temperature in order to be efficient. The heat developed by the flow of an electric current is determined by the formula:

$$W = I^2R$$

Or, the wattage rating (W) is equal to the square of the current (I) times the resistance (R).

The *wattage rating* (a resistor is a 25-watt unit, for example) of a resistor is the maximum number of watts of energy required to produce a temperature rise of 482 degrees Fahrenheit, when the unit is provided with one foot of free air which has a temperature not to exceed 104 degrees Fahrenheit. Most resistors used in radio circuits are rated according to their ability to dissipate heat (wattage), as well as to their ohmic resistance.

To apply the foregoing formula, let us assume that two-tenths of an ampere of current (200 milliamperes) are flowing through a 1000-ohm resistor. To find the wattage (200 milliamperes = .2 ampere):

$$W = .2 \times .2 \times 1{,}000 = .04 \times 1{,}000 = 40.00 \text{ or } 40$$

Therefore, 40 watts of energy are being dissipated if the resistor operates at the allowable steady temperature.

Also, if the wattage input and the resistance are known, the current that is flowing may be determined by using the same formula. Assume, for example, that the input is known to be 7.5 watts and that the resistance is 3,000 ohms. To find the current:

$$7.5 = I^2 \times 3{,}000$$

From this we find that

$$I^2 = \frac{7.5}{3000}$$
$$= .0025$$
$$I = .05$$

or 50 milliamperes of current.

The same calculation will show how much current a resistor of a given rating will carry. For instance, to find how much current a 25-watt resistor of 2,500 ohms will carry:

$$25 = I^2 \times 2{,}500$$

or

$$I^2 = \frac{25}{2500} = .01$$
$$I = .1$$

or 100 milliamperes of current.

Resistances in Series. When resistances are connected in series, the total value of the resistance is the sum of all the individual units. For example, if three resistors—$A=65$ ohms, $B=100$ ohms, and $C=85$ ohms—are connected in series as shown in Fig. 29, the

Fig. 29. Diagram Showing Resistances in Series

total resistance is 250 ohms. *A* and *B* combined would be 165 ohms, *A* and *C* combined would be 150 ohms, and *B* and *C* combined would be 185 ohms.

Resistances in Parallel. The action of resistances in parallel can best be shown by analogy. Fig. 30 shows a roadway 28 feet in width, just wide enough for a platoon of infantry (16 men) to march

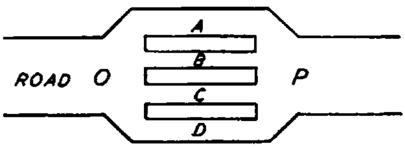


Fig. 30. An Illustration of Parallel Roads

abreast. The road branches at *O* to form a parkway, and for a short distance consists of 4 roads, *A*, *B*, *C*, and *D*, each of which is wide enough for 4 men. When the column, moving in the direction of the arrow, arrives at *O*, it divides: the 4 men at the right march through road *D*, the next 4 through road *C*, the next 4 through road *B*, and the 4 on the left through road *A*. They reassemble at *P*.

Assume, now, that the roadway narrowed at point *O*, and that each of the roads permitted only one man to pass. It is evident that the rate of travel will be impeded—that the number of troops that can pass point *P* within a given length of time will be less. In other words, the current flow will be decreased, because there will be a resistance to the flow of marchers. Only 4 men can pass point *P* in the same length of time that 16 men could pass if each of the roads were wide enough for 4 men to march abreast. If road *A* were wide enough for 2 men to march abreast, then 5 men would pass point *P* in the same length of time required for 4 to pass, under the former conditions. Similarly, if road *D* were wide enough for 3 men, a total of 7 men could pass *P*. Therefore, the number of men who will pass point *P* at the same time will depend upon the width of the paths. It is also evident that even if 3 of the roadways were closed, there would still be a path for the passage of men between *O* and *P*.

Now suppose we assume that each man corresponds to an ampere of electric current. Since 16 men can march abreast on the main artery, there is available passage for 16 amperes. But the narrowness of the roadways prevents passage of the full 16 amperes; and since the 4 paths will accommodate only one man each, only 4 amperes can flow. The remaining 12 must be dissipated. In the case of men, they would create a block in traffic. Electric current, however, would generate heat, and so pass off into the surrounding air.

Applying this analogy to electric circuits, as in Fig. 31, a circuit which includes conductor *X* divides into 4 branches, represented by resistance elements, *A*, *B*, *C*, and *D*, diverging at point *O*, and converging again at point *P*. Following the analogy of the troops

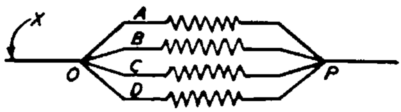


Fig. 31. Circuit Showing Parallel Resistances

on the road, where one of the paths permitted the passage of 2 men, it is evident that the narrower roads offered greater resistance to the passage of men. It can be said, therefore, that the narrow roads correspond to resistance to the flow of electric current and that, as the resistance increases, the current flow will decrease.

Since, again following the analogy, doubling the width of the roadway lowered the resistance to the passage of men and permitted twice as many as before to pass through, we can say that the conductance of current is inversely proportional to the resistance value. In other words, since twice as many men passed through road *A*, its resistance to the passage of men must have been one-half that of the other roads, which permitted only one man to pass. Therefore, the conductance is inversely proportional to resistance, designated by the reciprocal of the resistance, $\frac{1}{R}$.

Thus, in order to determine the resistance that exists between the points O and P, we find first the *conductance* of the network. This, as has been stated, is a measure of conductivity, and therefore the reciprocal of the resistance. The formula for determining the conductance, and from which the *equivalent resistance** is obtained, is:

$$\frac{1}{R}=\frac{1}{r_A}+\frac{1}{r_B}+\frac{1}{r_C}+\frac{1}{r_D}+\text{etc.}$$

in which R is the equivalent resistance, r_A is the resistance of A, r_B is the resistance of B, and so on.

If the resistance of each of the resistors is 20 ohms, we can substitute the numerical value, 20, for the symbols in the formula and then have:

$$\frac{1}{R}=\frac{1}{20}+\frac{1}{20}+\frac{1}{20}+\frac{1}{20}$$
$$=\frac{4}{20}=\frac{1}{5}\text{ mhos}$$

From this we find that the resistance R is 5 ohms, or one-fourth of the resistance of each of the individual elements.

Thus it is evident that, *if all the resistors of a parallel network are of equal value, the equivalent resistance may be determined by dividing the ohmic value of one of the resistors by the number of resistance units in the network.*

If the values of the resistances are not identical, the equivalent resistance of the network may be determined by using the formula given. For instance, assuming that the resistance value of A is 10 ohms, of B is 20 ohms, of C is 30 ohms, and of D is 40 ohms, then:

$$\frac{1}{R}=\frac{1}{10}+\frac{1}{20}+\frac{1}{30}+\frac{1}{40}$$

The lowest common multiple of 10, 20, 30, and 40, is 120. Therefore, the equation becomes:

$$\frac{1}{R}=\frac{12}{120}+\frac{6}{120}+\frac{4}{120}+\frac{3}{120}$$
$$=\frac{25}{120}=\frac{5}{24}\text{ mhos}$$

*By *equivalent resistance* is meant the actual resistance that results from connecting resistances in parallel.

Stated in the form of a proportion, the equation is:

$$1 : R = 5 : 24$$

Calculating:

$$5R = 24$$
$$R = 4.8 \text{ ohms}$$

Thus we find that the equivalent resistance of a network of four parallel resistors having values of 10, 20, 30 and 40 ohms respectively, is 4.8 ohms which is *less than* the value of the lowest resistance in the circuit. Since the values were taken at random, it has been proved that: *The equivalent resistance of parallel resistances is less than the ohmic value of any element of the network.*

Resistances in Series-Parallel Circuit. When resistances are connected in series-parallel, as shown in Fig. 32, the equivalent value

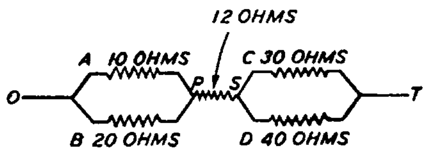


Fig. 32. Resistance Connected in Series-Parallel Circuit

of each parallel network is calculated first and the results obtained are added together to obtain the total resistance, as from O to P. Substituting the values given in the diagram for those of the given formula, we find that the resistance of the section OP would be 6.67 ohms; that of the section PS would be 12 ohms; that of ST would be 17.14 ohms. Adding the three values, the total resistance of O to T would be 35.81 ohms.

Current Flow through a Circuit Having Resistance. In order to calculate the amount of current flowing through a circuit, it is necessary to know the electromotive force—that is, the voltage—and the resistance. These values, substituted for the symbols of Ohm's law, $I = \frac{E}{R}$, will give the value of the current in amperes. Let us first consider a circuit which has a single resistance.

If the value of the resistance (R) is 1,000 ohms, and there is an impressed electromotive force of 50 volts, the equation becomes:

$$I = \frac{50}{1000} = .05 \text{ amperes}$$

Thus, in a simple circuit in which there is a resistance of 1,000 ohms and in which the voltage is 50 volts, .05 amperes (50 milliamperes) of current will flow.

In Fig. 29, three resistances of 65 ohms, 100 ohms, and 85 ohms respectively, are connected in series, making the total resistance 250 ohms. If, now, we assume a circuit in which the electromotive force is 50 volts, and substitute in the equation the known values for E and R, we have:

$$I=\frac{50}{250}=.2 \text{ amperes}$$

That is, two-tenths of an ampere (200 milliamperes) is flowing in the circuit.

Similarly, a network of parallel resistances is shown in Fig. 31. Four resistance elements, A, B, C, and D, having values of 10, 20, 30, and 40 ohms respectively, are connected in parallel, giving an equivalent resistance of 4.8 ohms. Here again, assuming an electromotive force of 50 volts, the equation becomes:

$$I=\frac{50}{4.8}=10.42 \text{ amperes}$$

This shows that 10.42 amperes are flowing in the circuit.

It may be desired, however, to know the current flowing in any part of the parallel circuit—for example, that part which has 20 ohms resistance. Each element of the parallel network can be considered individually, and the current flow can be determined by applying Ohm's law as shown, thus:

$$I=\frac{50}{20}=2.5 \text{ amperes}$$

Therefore, 2.5 amperes are flowing through the leg of the network which has a resistance of 20 ohms.

If similar calculations were made for each element of the network, the current flow would be found to be:

For A (resistance 10 ohms), 5 amperes
For B (resistance 20 ohms), 2.5 amperes
For C (resistance 30 ohms), 1.67 amperes
For D (resistance 40 ohms), 1.25 amperes

Adding the separate values of current flow, we obtain a total of 10.42 amperes, the same result that was obtained by using the equivalent resistance (4.8 ohms) as the value for R.

It has been shown that the value of the current flow can be determined by using the equivalent resistance in parallel circuits; the current flow in a circuit having series resistances is determined by using the total resistance value which is the sum of the resistances. It is evident, then, that the current flow in a series-parallel circuit can be found by first obtaining the equivalent resistance of those circuits, or devices, that are in parallel with each other. Then the total resistance of the circuit is obtained by adding the equivalent resistance (or resistances) and the resistance (or resistances) of the series parts of the circuit. As an example, in Fig. 32 the equivalent resistance of A and B is 6.67 ohms. The equivalent resistance of C and D is 17.14. The total resistance in this series-parallel circuit is the sum of the equivalent resistances AB and CD plus resistance PS, which is $6.67+17.14+12=35.81$ ohms. The current will be $50 \div 35.81$ or 1.4 amperes.

Voltage Drop. Resistance may be employed to regulate voltage, and in this capacity it performs the function known as "dropping the voltage." For instance, early types of radio receiving sets employed the voltage drop method of reducing the voltage delivered by a storage battery (6 volts) to the value required for the filament of tubes of the "199" type (3.3 volts).

In making a calculation of this kind, it is necessary to know both the current consumption, and the required drop in voltage. The "199" type tube draws six one-hundredths (.06) of an ampere, and the required drop in voltage is $6-3.3$, or 2.7 volts. Therefore, applying Ohm's law:

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

$$=\frac{2.7}{.06}=45 \text{ ohms}$$

So, if a single tube of the "199" type were used in a circuit fed by a 6-volt storage battery, a fixed resistor of 45 ohms would drop the voltage to 3.3 volts, which is the maximum voltage that the filament element is capable of withstanding.

If two tubes of the "199" type were used, the current consumption would be twice that of a single tube, or .12 amperes. Therefore, to calculate the resistance required to drop the voltage from 6 volts to 3.3 when two tubes were to be used, .12 would be the value of *I* in the foregoing illustration. Similarly, .18 would be the value of *I*, if three tubes were used; .24, if four tubes were used, and so on.

The general practice is to connect a rheostat in series with a fixed resistance, such as we have been discussing. The purpose of this is to control the volume output of the set by further reducing the voltage applied to the filaments of the tubes.

CAPACITANCE

Capacity. Capacity is the property of two electrical conductors, separated by an insulating material called a *dielectric*, to receive and retain electrical charges—that is, electricity. A device called a *condenser*, consisting of two metal plates separated by a dielectric material, will receive a charge of electricity and retain it until it is released.

The dielectric material used in condensers may be any sort of electrical insulator, but usually it is paper, mica, glass, air, or oil; or, in the case of electrolytic condensers, a film of gas. The dielectric must have the ability to insulate the plates from each other, and to withstand the potential difference that exists between them.

Leyden Jar. A convenient form of condenser for experimental purposes can be constructed with a fruit jar and enough foil—tin, lead, or aluminum—to cover half or more of the inner and outer surfaces of the glass. Such a device is known as a *Leyden jar*, Fig. 33. The pieces of foil constitute the *plates* of the condenser; the glass serves as the insulator. A strip of conducting material—it may be a piece of the foil—should be joined to the plate on the inside of the jar and brought out at the top as a terminal.

If the terminals of the Leyden jar are connected to a source of electric energy such as a battery, the inside of the jar connected to the positive terminal of the battery, and the outer foil to the negative battery terminal, the inner foil will become charged positively, and the outer foil will be charged negatively. However, if a current indicating meter—an ammeter—is placed in the circuit, it will be found that the current will flow for only an instant and that the needle will then come to rest at zero, showing there is no current flow. Since there is no connection between the two pieces of foil, there is not a continuous path over which the current can pass, so that the ammeter will indicate a flow of current only during the time required to charge the plates. Having thus charged the plates of the Leyden jar, the connections to the battery may be removed. If a conductor is now touched to the outer foil of the jar, and then brought up slowly toward the conductor that is connected to the inner foil, a spark will "jump" across the gap, when the terminal to the inner plate is touched, showing that the charge has been dissipated. Thus,

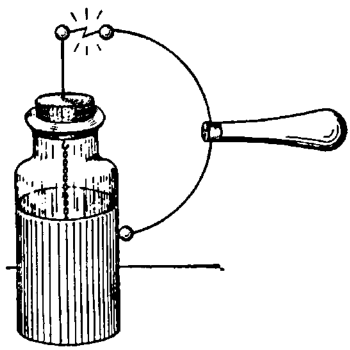


Fig. 33. Discharging Leyden Jar

charging the plates of the jar created a potential difference, which was neutralized when the conductor connected the two pieces of foil, and provided a path for the charge to follow.

The charging of the plates of the Leyden jar results from a flow of electrons: the negative electrons leave one plate, which then becomes charged positively, and settle on the other plate, which becomes negatively charged because of the excessive number of electrons on it.

The Leyden jar is an experimental device which lends itself to numerous interesting investigations of the phenomena of this electrical function.

Industrial Condensers. Condensers for industrial use—including radio—are designed according to the purpose they are to serve. The selection of the dielectric material depends upon many factors, such as the difference in potential that will exist between the plates, space limitations, etc.

Of all the dielectric materials available, paper, mica, air, and the gas film are most widely used in radio work. Mica is used in condensers where relatively high capacities are needed in circuits in which the voltage is high and space is an important factor. Mica is usually equivalent to glass as an insulator and dielectric—some forms are even more efficient than glass. It is pliable and may be used in its natural state. Paper is used as the dielectric material in condensers of the ordinary type, such as those used in filter circuits. Air is the dielectric for condensers of the variable type, such as those used in the tuning circuits of radio receiving apparatus, and in the fixed or variable condensers in transmitters where precautions must be taken to prevent arcing between the plates. The gas film is employed in condensers of the electrolytic type, such as are found in radio receiving circuits.

Since a condenser is, in fact, an open circuit, it is imperative that every precaution be taken to prevent the plates from being "shorted," or connected, through the dielectric. Mica is particularly free from metallic particles, and it rarely happens, even during process of manufacture, that it gives any trouble of this kind. Air and the gas film are naturally free from metallic substances that would cause a short circuit. Paper, however, is different in this respect, and the development of a special paper for use in condensers with paper dielectric, required the closest cooperation between the condenser manufacturers and the paper makers.

Regardless of all that is done at the paper mill to prevent minute particles of metal from imbedding themselves in the paper, they will get in. They may be readily detected by immersing a piece of paper in a solution of copper sulphate, which turns the iron and steel particles a reddish brown. If two or three layers of paper are used as the dielectric material in a condenser, the possibility of metallic particles causing contact between the plates is minimized. By using this method, contacts which would effectively short circuit the condenser plates are rarely made. However, in order to reduce the number of metallic particles to the minimum—not more than eleven to the square foot—the liquified paper pulp is passed over several electromagnets during its flow from the vats, and in this way the particles of iron, steel, and other metals that respond to magnetic fields are withdrawn from the paper fibers. Also, the material from which condenser tissue is fabricated is carefully selected new fabric —mill scraps, that contain very little metal of any sort.

The capacity of a condenser is determined by the size of the plates and the distance between them, together with a factor known as the dielectric constant (explained in detail later). If it were necessary to stretch the plates out flat, an exceedingly wide area would be required for a unit of relatively low capacity. So, in making paper condensers, the sheets of foil, which are separated by the dielectric, are made in the form of a roll, and the spacing between the sheets of foil is determined by the number of layers of paper which are used.

A specially designed type of machine is used to wind the foil and paper together, placing one, two, three or more sheets of paper between the foil. After the foil and paper have been wound together, the roll is flattened and connecting terminals are attached, one for each sheet of foil or set of sheets. In some cases, however, this operation is performed during the winding process.

The rolls are then placed on trays in a drying oven to drive out the greater part of any moisture that may be present; after that they are placed in vacuum tanks, into which a molten wax compound is injected under pressure. Because of the vacuum created in the tank, the wax makes its way into the folds of the condenser, sealing it against moisture. The wax also acts as a dielectric.

The condensers are finally sealed into cans, and otherwise protected with sealing compounds that prevent moisture from collecting on the plates and destroying their efficiency. Moisture is very detrimental to the action of a condenser and will cause considerable changes in its capacity.

Electrolytic Condensers. Generally speaking, an *electrolytic condenser*, Fig. 34, consists of two electrodes—usually lead and aluminum —immersed in an electrolyte. The electrolyte constitutes one plate of the condenser, the aluminum electrode the other; while the lead element provides the means to make a connection with the electrolyte. The dielectric in an electrolytic condenser is a film of gas that surrounds the aluminum electrode.

In another type of electrolytic condenser, both plates are aluminum, and their surfaces become covered with a thin layer of oxide when the plates are immersed in the electrolyte. A thin layer of gas, which has an exceedingly high resistance, forms on the layer of oxide, and serves as the dielectric.

The capacity of an electrolytic condenser depends upon the area of the plates, the thickness of the gas layer, and the materials composing the plates. The thickness of the gas layer is determined by the value of the voltage that is impressed across the condenser during the process of "forming."

The condenser electrodes are thoroughly cleaned with chemical baths during the process of manufacture and are subjected to a forming process which causes the formation of the gas film. The

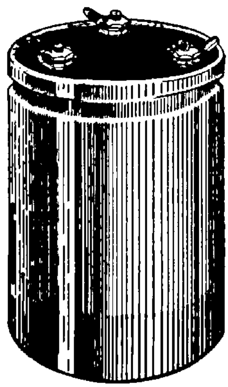


Fig. 34. Typical Electrolytic Condenser Having Multiple Electrodes

forming process requires about eight to ten hours or more. Higher voltages applied to the plates will create a thicker gas film, and a consequent higher resistance to the flow of electric current. The working voltage of the condenser must always be less than the voltage used to form the plates.

Electrolytic condensers have the property of permitting the flow of electric current from the electrolyte to the electrode, but present an exceedingly high resistance to the flow of current in the opposite direction. In this respect, the action of the electrolytic condenser is identical with that of the electrolytic type of rectifier used in some of the early models of power supply devices for radio apparatus.

The commercial forms of condensers already explained are not, however, the only form of capacity units. Any two conductors across which there is a difference of electrical potential will form a condenser, and capacity will exist between them. While this particular form of capacity is of little or no consequence in ordinary electrical work, it is an important factor in the design of radio apparatus, as will be explained later.

Fixed Condensers and Variable Condensers. A *fixed condenser* is one in which neither the plates nor the dielectric are movable—hence, it is one in which the capacity is not changed. A *variable condenser* is one in which one or both plates—or sets of plates—can be moved to vary the existing capacity. The condensers used in the tuning stages of radio receiving sets are examples of variable condensers. The capacity of the condenser increases as the plates are enmeshed and decreases as they are pulled apart. Even at the full open position, however, capacity exists between the plates when there is a difference of potential between them.

A *semivariable condenser* is one in which one or both of the plates may be moved for purposes of making adjustments, although the plates can be locked in position. Most condensers of this type consist of two brass plates, one solid, the other in the form of a spring, separated by a mica dielectric. The adjustment is made by means of a screw which brings the plates closer together or permits them to spring apart.

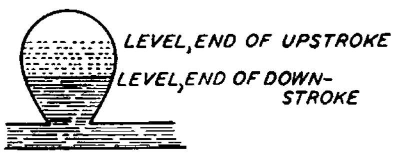


Fig. 35. Pump Forcing Water through Pipe System Illustrating How Energy Is Stored and Then Released

Action of Condenser. In a sense, a condenser is a form of equalizer. It is placed in circuits where it is necessary to equalize the voltage or current fluctuations. Fig. 35 shows an analogy of a pump forcing a stream of water through a hydraulic system. With each upward stroke of the piston, the force is so great that all the water cannot rush through the pipe. Therefore, the tank above the pipe line first acts as a reservoir to receive the excess water, and then empties it into the pipe as the piston of the pump makes its downward stroke.

A condenser acts in the same manner. As the electric current surges through the circuit, the plates of the condenser absorb or store a part of the force that is not needed, and allow it to feed off into the circuit when the pressure is lowered; thus equalizing the flow and stabilizing the circuit. Fig. 36 shows a circuit containing two

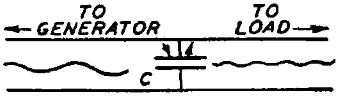


Fig. 36. Diagram Showing How a Condenser Smooths Out Pulsating Currents

conductors carrying a direct current that pulsates as indicated by the wavy line at the left. As it passes the condenser, *C*, the high voltages are absorbed or stored on the plates of the condenser during the time that the peak voltages are passing. Then, when the pressure is lower, as indicated by the valley between the crests, the condenser discharges the energy that it is holding; as a result, the flow of the current is made more uniform, as indicated by the shallow waves at the right. These indications in the flow of the current are only relative, and serve merely to illustrate the change that takes place through the action of the condenser. They do not represent current values.

Condensers and Current Flow. Since the dielectric of a condenser is an insulator, it is evident that a condenser is an open circuit and that current cannot flow *through* it. This is actually the case with direct current, where the flow of current is continuous and in the same direction at all times. Alternating current, however, flowing through the circuit, as it does, first in one direction and then in the other, reacts differently, and at least appears to pass through the condenser. When a condenser is connected into a circuit through which alternating current is flowing, the plates of the condenser are alternately charged negatively or positively, according to the changes in direction of the current flow; this gives rise to the question as to the ability of alternating current to flow through the condenser.

In order to demonstrate the action of a condenser in an alternating current line, connect a condenser (2 mfd., say) in series with an incandescent lamp and plug into the alternating-current lighting circuit. The lamp will glow, provided its resistance does not prevent.

Then connect another condenser in parallel with the first one, and the glow will become brighter. Adding more condensers—and thereby increasing the capacity—will increase the brilliancy of the illumination produced by the lamp. Thus, while the condenser appears to be passing the alternating current, it is really acting as a resistance to the flow of the current. Actually, however, the current is flowing through the lamp, storing on the plate of the condenser, being discharged from that plate, passing through the lamp, storing on the other plate of the condenser, being discharged therefrom, and so on. Thus, the effect of alternating current flows through a condenser, even though the current itself does not do so.

On the other hand, if a condenser were connected in series with a lamp in a direct current line, there would be an instantaneous flash from the lamp as the plates of the condenser were charged, and then there would be no further illumination or evidence of current passing through the circuit, no matter how long the connection to the lighting system was sustained. However, if the connection to the lighting system were severed, and the terminals were shorted with a conductor, there would likely be another flash as the plates of the condenser gave up their charge, at which time current would flow through the circuit.

Dielectric Constant. It was stated that the amount of charge that a condenser can receive and retain depends upon the area of the plates, the distance between the plates, and the *dielectric constant.* The area of the plates and their separation require no explanation—they are fixed values. The dielectric constant, however, is a variable factor, actually a ratio.

In calculations to determine the ability of a condenser to store electrical energy, air is assumed to be the standard or basic dielectric. But it has been found that when other materials are used—such as mica, paper, wax, oil, and the gas film—if the area of the plates and the separation of the plates are equal, the capacity will be greater. It has also been found that, relatively speaking, the ratio will remain reasonably constant for the same substance. Consequently, the *dielectric constant* is the ratio that exists between the capacity of a condenser in which some dielectric other than air is used, to the capacity of the same condenser if air were the dielectric. For instance, a condenser that has a capacity of one microfarad with air as the dielectric, may be found to have a capacity of five microfarads with X material as the dielectric; in that case, substance X would be said to have a dielectric constant of 5.0.

Therefore, the capacity of a condenser with air dielectric is to the capacity of a condenser having a dielectric of some other substance, as one (1) is to the unknown factor, K, the dielectric constant of the substance. The ratio may be expressed

$$C_a : C_x = 1 : K$$

In this equation, C_a is the capacity of the condenser having air as its dielectric, C_x is the capacity of the condenser having another substance as its dielectric, 1 is *unity,* and K is the dielectric constant of the substance used in the condenser which has the capacity C_x. The dielectric constant is usually designated by the letter K, and is also known as specific inductive capacity.

Dielectric Constant Values. The value of K as an unvariable quantity cannot be given for the reason that the substance itself may vary somewhat insofar as its density, temperature coefficient, purity, etc., are concerned. Even air, the standard dielectric which nominally has a value of 1, will vary if the atmospheric pressure is greater or less than normal. The dielectric constant of a vacuum is 0.999; of air with a pressure of 20 atmospheres, it is 1.022.

The value of the dielectric constant will also vary in accordance with the kind of electromotive force applied to the plates of the condenser. When direct current of constant voltage is supplied, the dielectric constant will vary according to the length of time the voltage is applied. If the charging is done with alternating current, the frequency of the alternations will determine the value of the dielectric constant. Therefore, it is necessary that the conditions under which the substance is measured should be known in order to interpret the values properly. The values given in the accompanying table are for radio frequencies.

It is evident, therefore, that a condenser which has a given value when used in one circuit, will have a different value when it is adapted to a circuit with a different type of current.

The values for K have been calculated within given limits, and Table III shows the dielectric constant for the more common substances used in radio receiver construction.

TABLE III
Dielectric Constants

Substance	Dielectric Constant
Air	1.000—Pressure, 1 atmosphere Temperature, 32° F.
Vacuum	.999
Carbon Dioxide	1.001—Pressure, 1 atmosphere Temperature, 32° F.
Petroleum	4.67
Transformer Oil	2.5
Vaseline	2.17
Fiber	5.0 —8.0
Flint Glass	6.6 —9.9
Lead Glass	5.4 —8.0
Paper	1.5 —3.0
Paraffin	2.1 —2.3
Shellac	3.0 —3.7
Wood, Dry	3.0 —6.0

Capacity of a Condenser. The capacity of a condenser is measured in *farads*, a farad being the charge produced by one *coulomb** of electricity by a potential difference of one volt. A *micro-farad* is one-millionth (.000001) of a farad. A *micro-micro-farad* is one-millionth (.000001) of a micro-farad. An *electrostatic unit*, another term applied to the charge on the plates of a condenser, is 1.1124 micro-micro-farads.

For many years, it was common practice to refer to the capacity of a condenser in terms of micro-farads. For instance, a condenser rated at .00025 micro-farads was called a "triple-0-two-five" condenser. Later, however, terms expressed in micro-micro-farads became more common, so that a .00025 micro-farad condenser is known as a condenser having 250 micro-micro-farads capacity, .00025 micro-farads being 250 millionths of a micro-farad. The symbol for micro-farad is *mfd*, *mf*, or *μfd*; that for micro-micro-farads is *mmfd*, *mmf*, or *μμf*.

It has been stated that the capacity of a condenser depends upon the area of the plates, the distance between the plates, and the dielectric constant. This is shown in the formula for determining condenser capacity:

$$C = \frac{.0885 \times S \times K}{t} \text{ or } \frac{.0885\ SK}{t}$$

*A coulomb is a measure of the amount of electricity transferred by a current of one ampere in one second with an electrical pressure of one volt.

in which S is the area of the smaller plate in square centimeters, K is the dielectric constant of the insulating material, t is the thickness of the dielectric (distance between plates), in centimeters, and C is the capacity in micro-micro-farads.

Attention is called to the "smaller plate" for the reason that one plate of a condenser may be exceedingly large and the other very small, yet the effective capacity will be that produced because of the smaller area, and capacity effect beyond that area will be negligible.

To cite an application of the formula, a condenser is formed of two sheets of foil, five centimeters wide and 80 and 90 centimeters long respectively, separated by .02 centimeters of paper which has a dielectric constant of 2. (In winding a condenser of this type, one sheet may be given another wrap or two, but it does not increase the capacity; as stated, the shortest one is used in the calculation.) Therefore, substituting in the formula, we have:

$$C=\frac{.0885\times400\times2}{.02}$$

$$=\frac{70.80}{.02}=\underline{3540.00\text{ mmf.}}$$

Or, a condenser having the physical specifications as stated, would have a capacity of 3,540 micro-micro-farads (.00354 micro-farads).

The numerical term ".0885" is a constant. The original formula for determination of condenser capacity was based upon spherical bodies, which gave the value in electrostatic units instead of micro-micro-farads. Inasmuch as the spherical body was considered, the calculation necessarily took into account the spherical surfaces, and was stated:

$$C=\frac{KS}{4\pi t}$$

in which C is the capacity in electrostatic units, K is the dielectric constant for the dielectric substance, S is the area of the plate in square centimeters, t is the separation of the plates in centimeters, and π is 3.1416.

From the foregoing it will be seen that the latter part of the equation includes the fraction, $\frac{1}{4\times3.1416}$, which, calculated, will give the value, .07958. If we used this calculation at this point the formula would become:

$$C=\frac{.07958\ K\ S}{t}$$

but the result would still be the value in electrostatic units. In order that the result may be in micro-micro-farads, it is necessary to divide C by 1.1124 (one electrostatic unit equals 1.1124 micro-micro-farads) so that the equation resolves into:

$$\frac{C}{1.1124}=\frac{.07958\ K\ S}{t}$$

Simplifying:

$$C=\frac{.0885\ K\ S}{t}$$

as already stated.

In the event that the condenser is multi-plate, such as, for example, a variable condenser for tuning radio circuits, the value for S is determined by multiplying the area of one plate by the number of plates, less one. The formula, then, is stated:

$$C=\frac{.0885\ K\ S\ (N-1)}{t}$$

in which C is the capacity in micro-micro-farads, K is the dielectric constant (usually 1, inasmuch as air is the common dielectric), S is the surface area of one plate, in square centimeters, the quantity "(N-1)" is the number of plates less one, and t is the separation of the plates in centimeters. Thus, in a condenser having 11 plates, the enmeshed portion of which has an area of 22.6 square centimeters, the plates separated .08 of a centimeter, will be found by substituting in the given formula:

$$C=\frac{.0885\times1\times22.6\times(11\text{-}1)}{.08}$$

$$=\frac{.0885\times1\times22.6\times10}{.08}$$

$$=\frac{20}{.08}$$

$$=250 \text{ micro-micro-farads,}$$

in other words, a .00025 mfd. variable condenser.

Increasing the number of plates, increasing the area of the plates, or decreasing the distance between the plates, will create an increase in the capacity of a condenser—an increase in the amount of electrical energy the condenser will receive and retain. The capacity will be increased also if a dielectric substance having a higher dielectric constant is used.

Condensers in Series. Connecting condensers in series decreases the amount of capacity in the circuit. In fact, the equivalent capacity in a circuit containing condensers in series will always be less than that of the condenser having the least capacity in the series circuit.

The formula to determine the equivalent capacity of condensers connected in series is the counterpart of that for resistances connected in parallel, thus:

$$\frac{1}{C}=\frac{1}{C_a}+\frac{1}{C_b}+\frac{1}{C_c}+\frac{1}{C_d}+\frac{1}{C_e}+\frac{1}{C_f}+\text{ etc.}$$

For example, if four condensers, having capacities of 200, 400, 600, and 800 micro-micro-farads, are connected in series, we may find the equivalent capacity by substituting in the foregoing formula as follows:

$$\frac{1}{C}=\frac{1}{200}+\frac{1}{400}+\frac{1}{600}+\frac{1}{800}$$

The lowest common multiple is 2400

$$\frac{1}{C}=\frac{12}{2400}+\frac{6}{2400}+\frac{4}{2400}+\frac{3}{2400}$$

$$\frac{1}{C}=\frac{25}{2400}=.010417$$

$$C=96\text{ micro-micro-farads}$$

or expressed in micro-farads, .000096 mfd.

If more than one condenser having the same capacity are connected in series, the equivalent capacity will equal the capacity of one condenser divided by the number of condensers in the circuit. Thus, for a circuit containing four condensers, each of which has a capacity of 200 micro-micro-farads,

$$\frac{1}{C}=\frac{1}{200}+\frac{1}{200}+\frac{1}{200}+\frac{1}{200}$$

$$=\frac{4}{200}=.02$$

$$C=50\text{ micro-micro-farads,}$$

one-fourth the capacity of *any* of the condensers. If two condensers, each of which has 200 micro-micro-farads capacity are connected in series, the equivalent capacity would be 100 micro-micro-farads. If five were connected in series, the equivalent capacity would be 40 micro-micro-farads, and so on.

Condensers in Parallel. Connecting condensers in parallel produces the same effect as increasing the number of plates. Therefore, the equivalent capacity is the sum of the capacities, as for example, if the same group of condensers mentioned in the foregoing example were connected in parallel, the equivalent capacity would be 200+400+600+800=2,000 micro-micro-farads, or .002 (.002000) mfd.

Condensers in Series-Parallel. When condensers are connected in series-parallel, the capacities of the parallel combinations are determined first, and then the equivalent values are calculated in accordance with the formula given for series connections.

INDUCTANCE

Inductance—General. Inductance has been defined as the ability of a circuit to cause the generation of an electromotive force in that circuit or in a nearby circuit, by an increase or decrease in the flow of electric current (and the attending rise or fall of the electromagnetic field) flowing through the circuit.

It has been shown that a magnetic field is produced around a conductor through which an electric current is flowing, and that if the current varies, the magnetic field varies (rises or falls) correspondingly. The varying magnetic field acts to create an induced electromotive force or voltage which always opposes the change which produced it.

It has also been shown that if a conductor is turned back upon itself, the electromagnetic field surrounding the conductor is confined within a small area, and that the lines of force surrounding the conductor, moving in and out from the conductor, cut the conductor as they rise and again as they fall. Thus when current of a fluctuating nature is flowing through the conductor which has been turned back upon itself, a secondary electromotive force or voltage is generated in the circuit, which phenomenon is known as *self-inductance*. The voltage thus induced by the current flowing through the conductor is called *counter electromotive force,* or counter e.m.f., because it tends to oppose the flow of the current that produces the magnetic field.

When a conductor is turned back upon itself a number of times, it is formed into what is known as a *coil,* otherwise referred to as an *inductance* or an *inductor.* Coils, in general, consist of a number of turns of insulated wire wound upon a suitable supporting structure. If the wires are placed, as shown in Fig. 37, the turns form a spiral, and the coil is known as a *solenoid.* A coil may also be made by placing the wire haphazardly upon a spool, much as the thread is wound upon the shuttle of a sewing machine. If space is an important factor, the *honeycomb* type of coil is provided. There is also the *basket-weave* coil (Fig. 38) where the permissible length of the coil

Fig. 37. A Solenoid

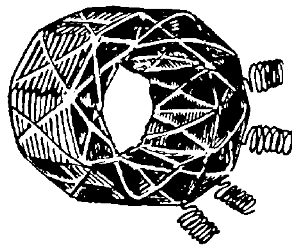


Fig. 38. A Basket-Weave Coil

is limited; and the *spider-web* form of winding, which is a helix, wound spirally outward from the center. Regardless of the form into which a coil is wound, the principle of its function is identical—the conductor, turned back upon itself, provides a means to generate an electromotive force in the circuit of which it is a part, or in a nearby circuit.

The induced electromotive force generated by an electric current flowing through the turns of a coil, prevents the primary current from performing certain functions. For instance, the induced voltage may prevent the primary current from increasing, even though it may have a tendency to do so. On the other hand, the induced voltage may prevent a decrease in the primary current flowing through the circuit.

A very interesting experiment to illustrate the presence of counter electromotive force in a coil is shown in Fig. 39. If the switch, S, is closed, current supplied by the battery will flow through the coil, and also through the voltmeter, which will indicate the voltage across the terminals of the coil, A and B. However, when the switch is opened, the needle on the voltmeter will be deflected in the direction opposite that which indicated the voltage across the terminals of the coil when the switch was closed. This will demonstrate that when the current flowed through the turns of the coil, it set up an electromagnetic field, which, owing to the fact that the current flowed in the same direction (it did not flow in first one direction and then the other, or fluctuate), remained constant until the

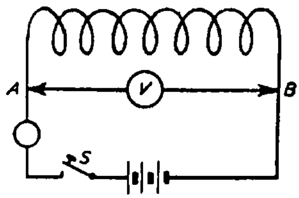


Fig. 39. Experiment Illustrating Counter Electromotive Force of a Coil

switch was opened, when the lines of force, in collapsing, created a secondary voltage opposite to that of the primary current. The current thus generated in a circuit such as used in the experiment, is momentary, and the needle will again come to rest at its zero position.

The unit of inductance is the *henry,* which represents the inductance produced by the generation of an electromotive force of one volt in a circuit when the current is changing its flow at the rate of one ampere per second. The henry is a comparatively large value, however, and is found in those parts of radio circuits which have to do with providing power for the operation of the receiver. The *millihenry* is one one-thousandth of a henry. A *microhenry* is one one-thousandth of a millihenry.

Calculation of Inductance. It is impossible to make accurate calculations of inductance, and formulas developed to determine it are only approximate. Furthermore, it would not be feasible to attempt to discuss herein the calculation of inductance of all forms of coils, inasmuch as to do so would involve the introduction of lengthy mathematical formulas that are to be found in treatises on radio engineering.

The inductance of a solenoid coil may be calculated, with fair accuracy, however, by the use of the following formula:

$$L = \frac{.03948\ a^2 n^2}{b} \times K$$

The number of turns in the winding is indicated by n, a is the radius of the coil in centimeters (measured from the axis of the coil to the center of the wire), b is the length of the coil in centimeters, and K is a constant, the value of which is to be found in Table IV as a function of $\frac{2a}{b}$. (1 inch = 2.54 centimeters.)

Applying the formula, let us assume a coil of 50 turns on a form that is 5 centimeters in diameter and that the length of the coil is 10 centimeters. To find the inductance:

$$L = \frac{.03948 \times (2.5 \times 2.5) \times (50 \times 50)}{10} \times K$$

Since the coil is 5 centimeters in diameter, and the formula specifies the radius, we divide the diameter by 2 to obtain the value for a in the formula. To determine the value for K it is necessary to calculate the fraction $\frac{2a}{b}$, which, in the example given, is $\frac{2 \times 2.5}{10} = \frac{5}{10} = .50$. Now referring to Table IV which gives the values for K, we find in the column under K and directly opposite .50, the value .8181, which is the numerical value to be substituted for the letter K in the formula. Hence, we have:

$$L = \frac{.03948 \times (2.5 \times 2.5)(50 \times 50)}{10} \times .8181$$

$$= \frac{.03948 \times 6.25 \times 2500}{10} \times .8181$$

$$= \frac{616.875}{10} \times .8181$$

$$= 61.6875 \times .8181$$

$$\times 50.47 \text{ microhenries}$$

If in the calculation of the shape ratio—diameter to length, $\frac{2a}{b}$—the value is between those given in Table IV, it will be necessary to approximate the values. For example, assume that the value is

.52, for which there is no value listed for K. Reference to Table IV shows that for .50 the value is .8181 and for .55 it is .8031. The difference in these values of K is .0150. It is necessary to divide the value .0150 by 5 in order to find the difference between .50 and .51, .51 and .52, etc. Thus $.0150 \div 5 = .0030$ the value of K will be lowered in steps of .0030, and since we are to consider the ratio of .52, the value for K will be .8181 minus $2 \times .0030$ or .8121. This value is only approximate, but, as previously stated, all calculations of inductance are approximations, and the slight discrepancy is negligible.

The foregoing calculation is for an air-core solenoid, that is, one which is wound upon a supporting structure that does not affect the magnetic field. The self-inductance of a coil will be increased greatly if metal is introduced in the windings of the coil to form what is called an iron-core inductance. Such a device is treated separately.

Inductance in Circuit. Inductances may be connected in series, in parallel, or in series-parallel, in exactly the same manner as condensers and resistors. The value of the inductance of a circuit is determined for the entire circuit of which it is a part—a circuit is said to have a certain amount of inductance, or there are X henries (millihenries or microhenries) of inductance in the circuit.

Inductances in Series. Inasmuch as inductance constitutes a means to oppose the flow of electric current, it is evident that in many respects it may be treated in the same manner as a resistance. Hence, when inductances are connected in series, the total inductance in the circuit is obtained by adding the inductance values of each of

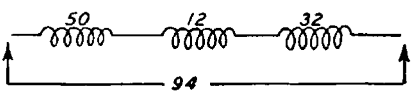


Fig. 40. Inductance Coils Connected in Series

the units so connected. Thus, in Fig. 40, the three inductances having values of 50 millihenries, 12 millihenries, and 32 millihenries will give an equivalent inductance of 94 millihenries in the circuit.

Inductances in Parallel. Inductances connected in parallel constitute as many paths for the flow of electric current, but since they serve to retard the flow of the current in exactly the same manner as though resistors were used, the equivalent inductance in a circuit

TABLE IV

Values for Calculating the Inductance of a Single-Layer Coil or Solenoid

Diameter / Length $\frac{2a}{b}$	K	Diameter / Length $\frac{2a}{b}$	K	Diameter / Length $\frac{2a}{b}$	K
0.00	1.0000	2.00	0.5255	7.00	0.2584
.05	.9791	2.10	.5137	7.20	.2537
.10	.9588	2.20	.5025	7.40	.2491
.15	.9391	2.30	.4918	7.60	.2448
.20	.9201	2.40	.4816	7.80	.2406
0.25	0.9016	2.50	0.4719	8.00	0.2366
.30	.8838	2.60	.4626	8.50	.2272
.35	.8665	2.70	.4537	9.00	.2185
.40	.8499	2.80	.4452	9.50	.2106
.45	.8337	2.90	.4370	10.00	.2033
0.50	0.8181	3.00	0.4292	10.0	0.2033
.55	.8031	3.10	.4217	11.0	.1903
.60	.7885	3.20	.4145	12.0	.1790
.65	.7745	3.30	.4075	13.0	.1692
.70	.7609	3.40	.4008	14.0	.1605
0.75	0.7478	3.50	0.3944	15.0	0.1527
.80	.7351	3.60	.3882	16.0	.1457
.85	.7228	3.70	.3822	17.0	.1394
.90	.7110	3.80	.3764	18.0	.1336
.95	.6995	3.90	.3708	19.0	.1284
1.00	0.6884	4.00	0.3654	20.0	0.1236
1.05	.6777	4.10	.3602	22.0	.1151
1.10	.6673	4.20	.3551	24.0	.1078
1.15	.6573	4.30	.3502	26.0	.1015
1.20	.6475	4.40	.3455	28.0	.0959
1.25	0.6381	4.50	0.3409	20.0	0.0910
1.30	.6290	4.60	.3364	35.0	.0808
1.35	.6201	4.70	.3321	40.0	.0728
1.40	.6115	4.80	.3279	45.0	.0664
1.45	.6031	4.90	.3238	50.0	.0611
1.50	0.5950	5.00	0.3198	60.0	0.0528
1.55	.5871	5.20	.3122	70.0	.0467
1.60	.5795	5.40	.3050	80.0	.0419
1.65	.5721	5.60	.2981	90.0	.0381
1.70	.5649	5.80	.2916	100.0	.0350
1.75	0.5579	6.00	0.2854	.....	.....
1.80	.5511	6.20	.2795	.....	.....
1.85	.5444	6.40	.2739	.....	.....
1.90	.5379	6.60	.2685	.....	.....
1.95	.5316	6.80	.2633	.....	.....

containing inductances in parallel is based upon conductance, which has been discussed. The following formula is used to determine the equivalent inductance of a network of inductances in parallel:

$$\frac{1}{L}=\frac{1}{L_a}+\frac{1}{L_b}+\frac{1}{L_c}+\frac{1}{L_d}+\frac{1}{L_e}+\text{, etc.}$$

The equivalent inductance is L, and L_a, L_b, L_c, L_d, and L_e represent the inductance of each of the inductances connected in parallel. Thus, if in Fig. 41 which shows inductances in parallel, L_a is 10 micro-

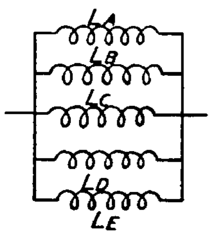


Fig. 41. Inductance Coils Connected in Parallel

henries, and L_b is 20 microhenries, L_c is 25 microhenries, L_d is 50 microhenries, and L_e is 5 microhenries,

$$\frac{1}{L}=\frac{1}{10}+\frac{1}{20}+\frac{1}{25}+\frac{1}{50}+\frac{1}{5}$$

The least common multiple is 100

$$=\frac{10}{100}+\frac{5}{100}+\frac{4}{100}+\frac{2}{100}+\frac{20}{100}$$

$$=\frac{41}{100}=.41$$

Hence, $.41L=1$

$L=2.44$ microhenries, the equivalent inductance.

It was shown in the article "Resistances in Parallel" that if the resistances are all of equal value, the equivalent resistance is found by dividing the value of the resistance by the number of resistance units connected in parallel. Similarly, if all the inductances connected in parallel are of equal value, the equivalent inductance is obtained by dividing the value of one unit by the number of inductances in the parallel network. The equivalent inductance of a parallel network is always less than the inductance of any individual inductance in the parallel circuit.

Inductances in Series-Parallel. When inductances are connected in series-parallel as shown in Fig. 42, the equivalent inductance

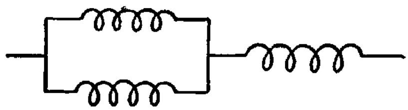


Fig. 42. Inductance Coils Connected in Series-Parallel

is obtained by finding first the equivalent inductance of each parallel network, and then adding the values together as for a series circuit.

Iron Core Inductances. The discussion of the subject of inductance considered inductance units known as the *air-core* type, that is, the wire was turned back upon itself on a supporting structure consisting of an insulating material, or, as in the honey-comb and basket-weave types of coils, the coils were constructed so as to be self-supporting. Such coils have a definite use in radio design and operation, but there is also the coil that is wound upon a core of iron or steel, called the *iron-core* inductance.

Iron Core. The iron core used in the iron-core inductances varies considerably in shape and design. First of all, there is the straight iron bar, as in *A* Fig. 43, or, the bar may be bent in the shape of the letter *C*, as in *B* Fig. 43. Again, the core may be closed entirely as in *C* Fig. 43. The iron core may be a solid bar of iron or

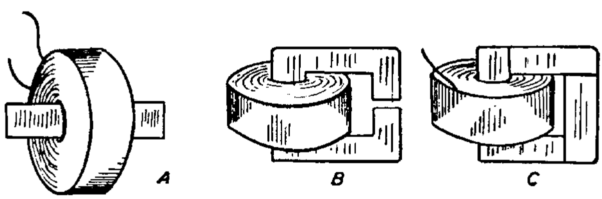


Fig. 43. Construction of Iron-Core Inductance or Choke Coil

steel, but it is usually constructed of a number of thin pieces of iron or steel, each of which is called a *lamination.* A core constructed of thin sheets of metal is known as a *laminated core.*

Generally speaking, there are two types of iron-core inductances, the *open-core* type, and the *closed-core* type. An open-core inductance is one in which the ends of the core are not joined together to form a complete path for the flow of magnetic flux. A closed-core inductance is one in which the ends are joined so that continuous path is provided for the flow of magnetic flux. The space between the ends of the open type core is called the *air gap,* across which the magnetic flux will flow, but not so readily as through the metal that forms the major portion of the core. The purpose of the air gap is to create stability in the action of the iron-core inductance, and to insure greater uniformity of characteristics, regardless of variations in voltage, current, and frequency, as is shown in another chapter of this book.

Laminations and Eddy Currents. Most iron-core inductance units employ cores that consist of several thin sheets of steel or iron. The reason for constructing the core as described is to minimize losses due to *eddy currents.*

If an iron bar is placed inside the windings of a solenoid through which an electric current having fluctuating characteristics is flowing, the magnetic lines of force pass through it longitudinally. Their flow creates a current that travels at right angles to the flow of flux —cross-sectionally—which current is called an eddy current. The cross-sectional current has the property of opposing the flow of the magnetic flux, and thereby causing lower efficiency—eddy current losses.

By building an iron core of several pieces of thin steel, each of which is coated with an insulating compound—an oxide, shellac, or insulating varnish—the path for eddy currents is greatly reduced, and the losses are minimized. It can be seen readily that if there are two iron cores, one of solid steel, the other fabricated of several thin sheets, their length and width being equal, the longitudinal path for the flow of magnetic flux would be the same, but the path for the flow of eddy currents (currents perpendicular to the flow of the magnetic flux) would be reduced materially in the fabricated core, so much so as to render them practically negligible. Eddy currents produce heat, and since a solid steel core provides a greater path for the flow of eddy currents, an inductance having a solid core will become much hotter than one of the same size made up of laminations, both inductances being operated under identical voltage and current conditions.

Iron Core Inductance Calculations. The self-inductance of a coil having an iron core depends upon what is known as the *permeability* of the core—the measure of the ability of the metal to carry the magnetic lines of force—the number of turns of wire, the area of the core, and the size of the air gap. Permeability, as applied in inductance calculations, is a ratio of the number of lines of force conducted by the material, to the number of lines of force that will pass through air under identical circuit conditions as to current flowing and voltage impressed. The permeability of air is 1. If, in the experimental set-up shown in Fig. 39, a small nail were inserted into the coil, the deflection of the voltmeter needle when the switch is opened and closed, would be found to be much greater than if the nail were not present. Similarly, if a larger piece of soft iron were inserted, the deflection would be found to be still greater. This result is due to the ability of the iron to conduct the lines of force with greater facility than the air conducts them. Silicon steel is a commonly used core material, and has a flux density of about 20,000 lines of force per inch. Since silicon steel is used so widely, the calculations herein shall be based upon its characteristics.

Generally speaking, the inductance of an iron core may be determined by the following formula:

$$L = \frac{\text{Core Area} \times (\text{Number of Turns})^2}{\text{Air Gap} \times 40{,}000{,}000}$$

The air gap may be measured in a fabricated inductance, but if it is desired to ascertain what the air gap should be when designing an iron-core unit, the following formula will give an approximate value.

$$\text{Air Gap} = \frac{\text{Number of Turns} \times \text{Current in Amperes} \times 2.2}{\text{Flux Density in Lines per Inch}}$$

Thus, an inductance unit having 5,000 turns on a silicon steel core that measures 1 inch × 1¼ inches (1¼ square inches), through which a current of one-tenth of an ampere is to pass, should have an air gap of .055″, thus

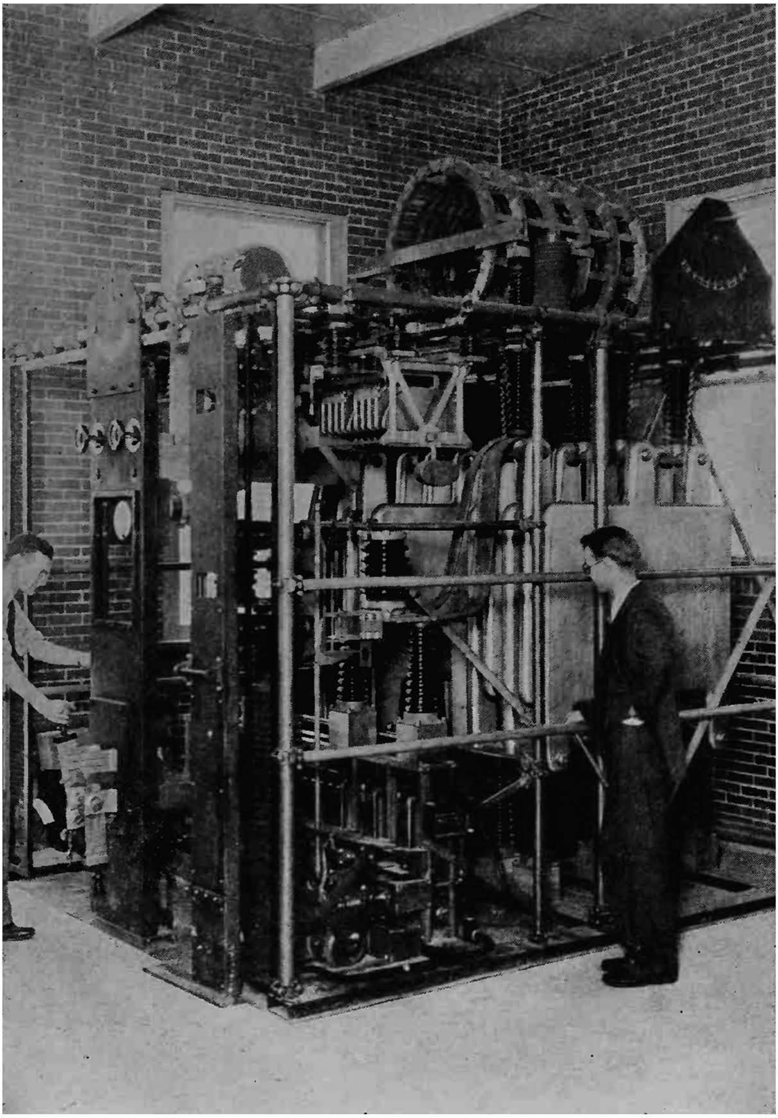
$$\text{Air Gap} = \frac{5{,}000 \times .1 \times 2.2}{20{,}000}$$

$$= .055''$$

Substituting the measurement of the air gap in the formula, to determine the amount of inductance,

$$L=\frac{1.25\times 25{,}000{,}000}{.055\times 40{,}000{,}000}$$
$$=\frac{31{,}250{,}000}{2{,}200{,}000}$$
$$=14.2 \text{ henries}$$

It is evident from the foregoing that increasing the width of the air gap will decrease the amount of the inductance and, conversely, decreasing the width of the air gap will increase the amount of inductance. Increasing the number of turns will also increase the inductance. It is evident, too, that a larger core will cause a greater inductance, inasmuch as the core area is a function of the numerator in the equation as stated.



HIGH VOLTAGE INDUCTANCE OR TUNING COIL AND CONDENSER LOCATED IN ONE CORNER OF A RADIO BROADCASTING TRANSMITTER ROOM

Courtesy of Westinghouse Electric and Manufacturing Company

MODERN RADIO ESSENTIALS

CHAPTER VI

DIRECT AND ALTERNATING CURRENT

There are three types of dynamic electricity, that is, electricity which is in motion, known as direct current, pulsating direct current, and alternating current.

Direct Current. *Direct current* electricity is that kind of electrical energy that flows in the same direction through a circuit. It includes the energy that is supplied by batteries—chemical action—as well as that which is generated by mechanical means. Battery current does not vary in strength—voltage—so long as the battery is in good condition and the elements are not broken down chemically.

If a single loop of wire were rotated in a magnetic field the electricity generated would flow in one direction through the circuit but would not be constant in voltage or current. When the loop is at rest the voltage is zero. As it is turned through the magnetic field the voltage will rise to a maximum value and then decrease as the sides of the loop pass out of the magnetic field, again reaching zero. It will be seen, therefore, that the current, while not reversing its direction of flow is gradually forced onward with greater and then with lesser pressure throughout the revolution of the loop or coil.

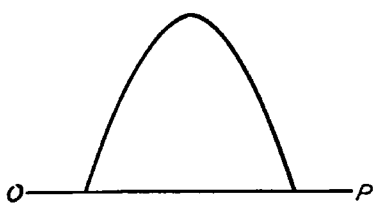


Fig. 44. One Pulsation Caused by Passing a Coil through a Magnetie Field

The rise and fall of the potential of direct current produced by a single coil of a generator is shown diagrammatically in Fig. 44. The vertical distance from the line OP representing voltage, movement horizontally representing the time required to rotate the coil through the magnetic field.

The result obtained by rotating a single loop of wire within a magnetic field is augmented by other similar loops or coils, so that by increasing the number of such coils and arranging them properly, the current is made to flow continuous, or so nearly so that it is practically steady in voltage.

Pulsating Direct Current. *Pulsating direct current* is that kind of electrical energy that flows in the same direction through a circuit, but does not maintain a constant voltage value. It may vary only in slight amounts, and, again, it may vary greatly. The diagram in Fig. 44 indicates the fluctuations of pulsating direct current.

Alternating Current. *Alternating current* is a form of electrical energy that reverses its direction of flow through a circuit at regular periods. It is said to flow in cycles, and the reversals in direction are called alternations. Alternating current is rated in accordance with its *frequency*, that is, the number of times the current reverses its direction of flow in a second, a sixtieth part of a minute. For instance, 60-cycle alternating current reverses its direction of flow through the circuit 60 times in a second, 120-cycle alternating current reverses its direction of flow 120 times per second. Reversing the direction of flow means, also, that one side of an alternating-current circuit is at positive and negative polarity alternately.

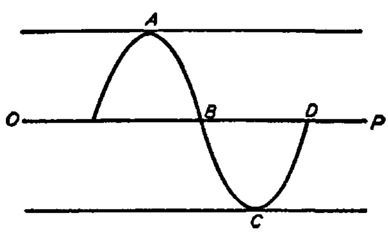


Fig. 45. Diagram Showing One Cycle of Alternating Current

Alternating current is symbolized in Fig. 45, which indicates the relative value of the voltage and the polarity of the current at any given position of the coils of the generator with the magnetic field. Fundamentally, the action of alternating current is identical with that previously explained for the single-loop coil rotating between magnetic fields. Starting from zero potential—no voltage—the strength increases gradually in a positive direction until it reaches a maximum, *A*, after which it decreases gradually until it comes again to zero at *B*. At this point, the current reverses its direction of flow, and follows the same procedure as has just been explained, except that the current is flowing in the opposite direction, as shown by *BCD*. At *C* it has reached its maximum negative potential.

Referring to Fig. 45, the distance along the horizontal line, *OP*, represents time, the distance above and below the line, *OP*, represents the strength of the energy, the amplitude. That part of the curve included in *OAB* is one alternation, and that included in *BCD* is another alternation. The two combined constitute a cycle, indicating that the current has flowed through the circuit in one direction and then the other. It will be noted also that there are twice as many alternations as there are cycles, there being two alternations to each cycle.

Effective Voltage. Effective voltage is a measure of the heating effect of the current, or, in other words, the rate at which the electrical energy is converted into heat, regardless of the direction of the flow of the current, compared to the same heating effect produced by direct current.

In view of the fact that the voltage of alternating current rises from zero to maximum positive, back to zero potential, thence to maximum negative and again back to zero potential, the amount of energy for the same maximum voltage and current values is less than is obtained when direct or continuous current is used. Calculations will show that the effective voltage of alternating current is .707 of the maximum voltage, or, in other words, an alternating current at 100 volts will actually have an effective voltage of 70.7 volts. Similarly, if the current is 10 amperes, the effective-current flow is 7.07 amperes. These values will be those that are shown by a measuring device, such as a meter.

An alternating-current voltmeter connected across an alternating-current circuit will indicate, for example, 70.7 volts. The peak voltage across the circuit will be 100 volts, inasmuch as the measuring instrument indicates the average or effective value.

An Alternating-Current Circuit Containing Resistance. Alternating current will flow through a resistance, and the relationship of the current to the voltage will be identical with that found to exist in direct current at any given instant. The relationship may be found by applying Ohm's law, $E = IR$, to the instantaneous voltage and current (not the average or effective voltage or current). Thus, to apply Ohm's law to the action of resistance in an alternating-current circuit, it is necessary to determine the instantaneous voltage and current, found by calculating on the basis that the measured current and voltage are .707 of the maximum values.

The terminals of a resistance are always at opposite polarity. That is, when one end of the resistance is of positive polarity, the opposite end is negative, and vice versa. The flow of alternating current through a circuit causes a fluctuating electromagnetic field around the conductor. This fluctuating field sets up another force known as counter electromotive force which tends to oppose the flow of the current that created it.

Counter Electromotive Force. Counter electromotive force, *c.e.m.f.*, the force that is equal to, but directly opposite to, the electromotive force impressed upon the circuit, is offered by resistance in an alternating-current circuit, in which case the impressed electromotive force and the resulting current, which are in phase with each other, are 180° out of phase with the counter electromotive force.

Inductance in an Alternating-Current Circuit. Inductance limits the flow of alternating current through a circuit because of the self-inductance set up in the coil. Inductance creates a strong counter electromotive force, a force which tends to retard the flow of the current. This counter electromotive force is not that of pure resistance, because in most cases the ohmic resistance of the inductance is negligible.

Inductive Reactance. Inductive reactance is the term applied to the retarding effect upon the flow of alternating current caused by inductance. Inductive reactance is indicated by the symbol X_L. It is measured in ohms, and its effect depends upon the frequency of the current—the number of cycles per second.

Capacity in an Alternating Circuit. Although a condenser comprises two plates or sets of plates separated by an insulator, therefore, constituting an open circuit, its action in an alternating-current circuit would lead one to assume that the alternating current is passing through the insulation. However, actually the electrons are being transmitted first to one plate and then to the other through the circuit in which the condenser is connected. If the condenser is connected into a 60-cycle alternating-current circuit, the electrons are passing through the circuit and back again 60 times per second.

Capacitive Reactance. Capacitive reactance is the term applied to the effect upon the flow of alternating current caused by the introduction of capacity into the circuit. As the capacity of the condenser increases, the number of electrons that flow from one plate or set of plates to the other increases, so that the current is greater. Hence, it is evident that the effect of capacity upon the flow of current—capacitive reactance—is exactly opposite to that of inductance—inductive reactance. The symbol for capacitive reactance is X_C, and expressed in ohms.

Phase. The position which an alternating current assumes in its path is known as the *phase,* and is measured in electrical degrees, 180° being an alternation, 360° being a complete cycle. Thus, the relationship of either current or voltage at any given instant may be measured as the number of electrical degrees from zero. When two waves start from zero at the same time and rise—or fall—simultaneously, so that they reach the maximum values—and all other corresponding positions—at the same time, they are said to be *in phase.* When one falls behind the other, it is said to *lag,* and the one that is leading is said to *lead.* Thus, if the current flow precedes the pressure in the circuit, it is said to *lead* the voltage; on the other hand, if the current flow is retarded so that it follows behind the pressure, it is said to *lag.*

Effect of Resistance on Phase Relationship. When resistance only exists in an alternating-current circuit, the current flow corresponds to the pressure and the circuit is in phase. This is, however, in the event that there is neither inductance nor capacity in the circuit.

Effect of Inductance on Phase Relationship. Inductance in an alternating-current circuit causes the current to lag behind the voltage, due to the counter electromotive force, which, as has been shown, retards the flow of current. The amount of lag is 90°, which means that when the voltage is at its maximum value the current flow is at zero, and when the pressure or voltage is at zero potential, the current flow is greatest.

Effect of Capacity on Phase Relationship. Capacity in an alternating-current circuit causes the current to lead the voltage by 90°, so that the current is at its maximum value when the pressure begins to rise, and is at its maximum value in the opposite direction when the pressure has returned to zero at the end of the first alternation. Fig. 46 shows diagrammatically the effect of either resistance, induc-

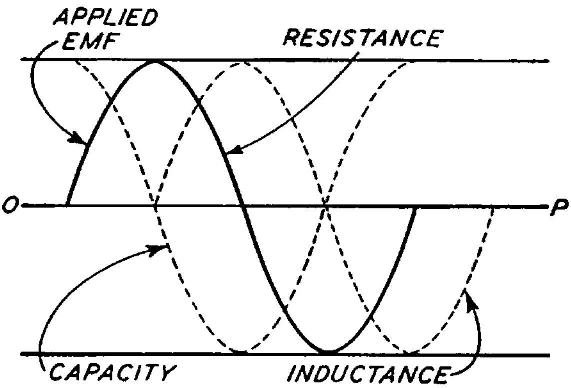


Fig. 46. Diagram Showing Effect of Capacity and Inductance on the Flow of Current

tance, or capacity upon the phase relationship in an alternating-current circuit.

Effect of Combinations of Resistance, Inductance, and Capacity on Phase Relationship. If the alternating-current circuit has resistance and capacity in series—but no inductance—the current will lead the voltage. However, the presence of the resistance will reduce the phase angle, which is the term applied to the number of electrical degrees between the current and the voltage. If the alternating-current circuit has resistance and inductance—but no capacity—the current lags behind the voltage, but, again, the resistance tends to reduce the phase angle.

If the alternating-current circuit contains capacity and inductance, the phase angle will be governed by the amount of capacitive or inductive reactance. Thus, if the capacitive reactance is greater than the inductive reactance, the current will lead the voltage. On the other hand, if the inductive reactance exceeds the capacitive reactance, the current will lag. If the inductive reactance and the capacitive reactance are equal, the current and voltage are in phase, and the circuit is said to be in *resonance*.

These conditions will hold also when the circuit contains resistance, inductance, and capacity, except that the resistance will tend to reduce the phase angle.

Calculation of Reactance. Reactance is measured in ohms, and is dependent upon the frequency of the current. Thus, the reactance of an inductance in a 60-cycle circuit will be half of what it would be in a 120-cycle circuit. The formula to determine capacitive reactance is:

$$X_C = \frac{1}{2\pi f C}$$

in which X_C is the capacitive reactance, f is the frequency of the current, C is the capacity of the condenser in farads, and π is the value, 3.1416.

The formula for inductive reactance is:

$$X_L = 2\pi f L$$

in which X_L is the inductive reactance, f is the frequency, L is the inductance and henrys, and π is the value, 3.1416.

Impedance. Impedance is the equivalent resistance set up to retard flow of alternating current through a circuit, due to the effect of resistance, capacity, and inductance or just inductance. Its calculation is simplified because the natural phase angles due to capacitive or inductive reactance, as stated previously, are 90° in both

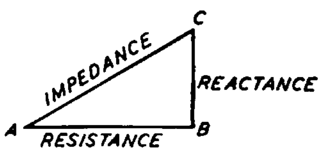


Fig. 47. Diagram Showing the Effect of Resistance and Reactance

instances. Thus, it is that the calculation of impedance is a geometrical function in which the resistance constitutes one leg of a right-angled triangle, and the reactance constitutes the other leg, while the impedance is represented by the hypotenuse, as shown in Fig. 47.

It has been shown that the current and voltage are in phase when there is resistance in the circuit; that the current leads the voltage when capacity exists; and that the current lags the voltage when inductance exists. Hence, if we lay out a straight line, and indicate thereon the ohmic resistance, and consider that inductive reactance is positive reactance, placed above the base line, while capacitive reactance is negative reactance, placed below the base line, then the calculations can be visualized more readily.

First, let us consider a case of a circuit in which resistance and inductive reactance are present. The resistance, we shall say, is 100 ohms. The inductive reactance is 50 ohms. If we consider that one inch on the base line is 100 ohms, then the length of the base of the right-angled triangle (line *AB*) is one inch, Fig. 47. On the same scale, the inductive reactance is represented by a one-half inch line (*BC*) perpendicular to the base line. The impedance is represented by the hypotenuse (*AC*). The phase angle, or the number of electrical degrees that the current lags the voltage is represented by the angle at *A*.

Since the square of the hypotenuse of a right-angled triangle is equal to the sum of the squares of the other two sides, we find the length of line *AC* by extracting the square root of 12,500 (100^2+50^2), or 111.8 ohms. Thus, the impedance in a circuit which has 100 ohms resistance and 50 ohms inductive reactance is 111.8 ohms and the current will lag the voltage by 27 degrees. On the other hand, if the circuit has 100 ohms resistance and 50 ohms capacitive reactance, there will be 111.8 ohms impedance, but the current will lead the voltage approximately 27 degrees.

If the circuit contains resistance, inductance, and capacity, it is necessary first to find the difference between the inductive reactance and the capacitive reactance. If the circuit had 100 ohms resistance, and 50 ohms each of inductive and capacitive reactance, the inductive and capacitive reactance would neutralize each other, so that the impedance would be 100 ohms, and the current and voltage would be in phase. However, if the resistance is 100 ohms, the inductive reactance 50 ohms, and the capacitive reactance 25 ohms, the triangle is as shown in Fig. 48, line *AB* representing the resistance, *BC* the inductive reactance, *BD* the capacitive reactance, *BE* is *X*, the difference between the inductive reactance and the capacitive reactance, and line AE is the impedance, which, when calculated, is found to be 103 ohms, and the angle of lag will be approximately 14 degrees because the inductive reactance is greater than capacitive reactance. If, on the contrary, the value of the capacitive

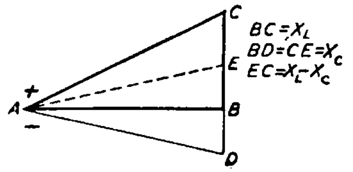


Fig. 48. Effect of Resistance, Reactance, and Capacity

reactance shown in the illustration had been 50 ohms, and the value of the inductive reactance had been 25 ohms, the phase angle would have been that as shown, but the current would lead the voltage by about 14 degrees.

In calculating the impedance of a certain unit connected into an alternating-current circuit, it is necessary to know the ohmic resistance it represents as well as the inductance or capacity. Thus, to calculate the impedance in a circuit containing a choke coil, it is necessary to find the resistance of the coil in ohms, measured on a bridge or with an ohmmeter, and to use this value together with any other value of resistance in the circuit.

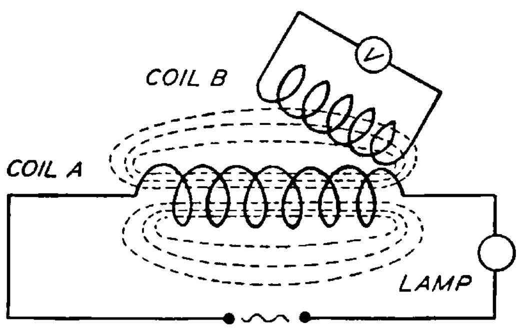


Fig. 49. Method of Exploring a Magnetic Field Around a Coil

Inductance in an Alternating-Current Circuit. If an alternating current is passed through a coil, a varying electromagnetic field is set up around the coil, as shown in Fig. 49. The electromagnetic field not only varies by expanding and contracting with relation to the axis of the coil, but the lines of force change their direction in accordance with each reversal of direction of current flow through the coil. If an experimental set-up is made, be sure that an incandescent lamp, or another current-consuming device is connected in series.

If another coil, *B*, is brought close to coil *A* and a measuring device is connected across its terminals, it will be found that a current is established in the circuit, of which coil *B* is a part, even though there is no physical connection with coil *A*. This secondary current —that flowing in coil *B*—is known as induced current, and the transference of the energy is called induction. The coil through which the current is flowing is always called the primary; that in which current is induced is called the secondary. Thus, in the illustration, coil *A* is the primary coil; coil *B* is the secondary coil. Similarly, the circuit of which coil *A* is a part is known as the primary circuit; that of which coil *B* is a part is known as the secondary circuit.

The phenomenon which has just been explained fundamentally is the basis of a very important electrical unit, so far as radio is concerned, the transformer. A transformer can be used in a circuit through which alternating current—or a varying current—is passing but cannot be adapted to a circuit through which continuous direct current is flowing.

The amount of energy that may be transferred from the primary to the secondary circuits depends upon the relationship that exists between the coils. If coil *B* is moved around coil *A* (which is allowed to remain fixed), the measuring device will show that the voltage is greater or less according to the relative position of the two coils. For instance, if coil *B* is placed parallel with coil *A*, the magnetic lines of force along one side of coil *A* cut the windings of coil *B* and set up a current in the circuit. But, if coil *B* is placed at right angles to coil *A*, that is, the open end of the coil is placed parallel with the side of coil *A*, the lines of force around coil *A* do not cut the windings of coil *B*, and the current flow in the secondary circuit is very small, or none at all. The combination of coil *A* and coil *B* is called a transformer, the purpose of which is to act as a means to transfer energy from one alternating-current circuit to another.

Radio Transformers. Transformers for use in a radio are of two types, known as air-core transformers, and iron-core transformers.

Air-core transformers are used in circuits through which high-frequency currents are flowing. Iron-core transformers are used in low-frequency circuits. An air-core transformer is, as the name implies, one in which the windings are formed with a means of support that is non-magnetic. An iron-core transformer is one in which the windings are formed on a core that will transfer the magnetic lines of force, and may be iron or steel.

The voltage induced in the secondary coil of an iron-core transformer is dependent largely upon the ratio that exists between the turns of the secondary coil and the primary coil. If there are ten times as many turns in the secondary coil as in the primary, the voltage induced in the secondary coil is ten times that impressed upon the primary windings (theoretically speaking), due to the fact that the lines of force set up around the turns of the primary coil cut ten times as many turns in the secondary winding. If, however, the voltage induced in the secondary coil is greater than that impressed on the primary circuit, the current flow is decreased, since the power—watts of energy—drawn from the secondary cannot exceed the power that is consumed by the primary circuit. Thus, a transformer, having a step-up ratio of 10 to 1, and consuming 50 watts of energy on the primary side (100 volts at one-half ampere), will deliver .05 of an ampere at 1,000 volts, which, again, is 50 watts—watts = volts × amperes.

The illustration given is for a hypothetical case in which conditions are ideal—one in which all of the lines of force set up around the primary windings cut all the turns of the secondary winding—one in which there are no losses of any kind. While such a condition meets the requirements for explanatory purposes, in practice it is found that correction must be made to compensate for losses sustained due to the fact that some of the lines of force cut only part of the windings in which voltage is being induced, some of them cut all of the windings, and some of them do not cut any windings. This type of loss is known as *flux leakage*. Also, in the case of transformers of the iron-core type there are losses caused by the generation of heat due to eddy currents in the laminations, and the inability of the core to respond to the rapid changes in magnetization.

There is no rule by which we may determine the extent of the losses, inasmuch as the physical characteristics of the materials and the design of the transformer are the principal factors. However, in general practice, transformers are designed with the secondary windings placed over the primary windings in order that the maximum number of lines of force—flux—set up by the current flowing through the primary windings will cut the maximum number of turns of the secondary coil.

The voltage may be increased or decreased—stepped up or stepped down—by providing the proper number of turns on the secondary coil with respect to the number of turns in the primary winding. Also, a transformer may be designed with several secondary windings in which current will be induced by the lines of force set up by current flowing through a single primary winding, but the total power available—that is, the sum of the number of watts of energy drawn from all secondary windings—cannot be more than the power consumed by the primary winding of the transformer.

Phase Relationship in Transformers. The current and voltage in the secondary of a transformer is 180° out of phase with that in the primary winding. In other words, when the current is at maximum positive polarity in the primary circuit, it is at maximum negative polarity in the secondary circuit, and when the current flow is at maximum in one direction in the primary it is at maximum in the opposite direction in the secondary winding. However, the primary current is in phase with the secondary voltage.

Pulsating Current. Pulsating direct current—or pulsating current—is one which flows in the same direction through a circuit but whose voltage rises and falls at intervals. In view of the fact that the electromagnetic field varies in accordance with the changes in voltage, pulsating direct current passing through the primary winding of a transformer will induce an alternating current in the secondary winding, which will have voltage characteristics that vary according to the fluctuations of voltage in the primary circuit.

Frequency of Induced Current. The frequency of the induced current is always the same as that of the current in the primary circuit. For example, if 60-cycle alternating current is passed through the primary winding, the induced current in the secondary winding will be 60-cycle alternating current also. Similarly, if the primary current is 600-cycle alternating current, that in the secondary circuit will be 600-cycle alternating current.

MODERN RADIO ESSENTIALS

CHAPTER VII

VACUUM TUBES

A vacuum tube, as defined by the Institute of Radio Engineers, is a device consisting of a number of electrodes contained within an evacuated inclosure. Its usefulness is made possible by certain natural phenomena, including applications of the electron theory and the fundamental laws governing electricity and magnetism.

In accordance with "The Electron Theory," all metals are said to consist of minute particles called molecules; the molecules, in turn, are subdivided into atoms; and atoms consist of combinations of positive and negative electric charges, called protons and electrons, respectively. Scientists have agreed that electrons are free to move within the metal, and if the molecular or atomic structure is disturbed, the electrons leave the protons to which they are attached and move about. It has also been stated that heat, among other things, will cause the electrons to move, and if sufficient heat is applied over a long enough period of time, the electrons will leave the metal and fly off into space. Herein lies a phenomenon that occurs in a vacuum tube in operation—electronic emission, caused by heat.

One of the fundamental laws of electricity which has been discussed under "Magnetism and Electricity," shows that "Like charges repel—unlike charges attract."

Generation of Heat to Cause Electronic Emission. If a piece of wire is connected across the terminals of a source of electric energy —a battery, for example—it will very quickly become heated, will glow, perhaps, and may burn in two. If the wire is made of metal that offers a high resistance to the flow of electrical energy, it will become hot, and the current it consumes will be disssipated in the form of heat. However, another phenomenon occurs through the process of heating. Electrons, or negative charges of electricity, disturbed by the heat leave the proton to which they are attached.

If the heat is sufficiently intense they will leave the surface of the metal and fly off into space. Eventually, these electrons will attach themselves to other protons, or they may return to the metal and associate again with the positive charges contained therein.

One of the electrodes of the vacuum tube is known as the filament. It is on the order of the filament that is a part of an incandescent lamp. When electric current is passed through the filament, it becomes heated and glows, giving off negative charges which fill the space within the glass inclosure, or envelope. Thus it is that the vacuum tube that is used in radio circuits is known as a thermionic tube, one in which the emission of electrons is caused by heat, as differentiated from phototube, one in which the emission of electrons is caused by the presence of light.

If the wire used as the filament in a vacuum tube were not inclosed within the vacuum, it would burn in two almost immediately, due to the presence of oxygen. The space within the glass envelope having been evacuated—the air and gases pumped out—no oxygen being present, the wire remains intact to act as a source of electrons set free by heat.

Diode Tubes. The simplest form of a vacuum tube is the *diode*, a tube which has two electrodes, known as the filament and the plate. There are three terminals for external connections, two for the filament and one for the plate element. If a battery of proper voltage is connected across the terminals of the filament, the wire becomes heated, setting electrons in motion. As the temperature of the filament element rises, the electrons moving about with the first application of heat, break through the surface of the filament wire and fly off into the space within the tube. Then if a connection is made from the plate terminal through a sensitive measuring device and to the positive terminal of the battery, a minute current will be found to flow through the circuit of which the plate is a part, even though there is no physical connection between the plate and the filament within the tube. If the plate circuit is opened and another battery is connected in series with the measuring device, so that the positive terminal of the battery is connected to the plate of the tube, as in Fig. 50, an appreciable current will flow in the plate circuit.

Here we have an example of the fundamental action of a vacuum tube. The filament, heated by the flow of electricity through it, emits electrons. The plate, given a positive charge because it is connected to the positive terminal of a battery, the negative terminal of which is connected to one side of the filament circuit, attracts the electrons given off by the filament and causes a flow of current

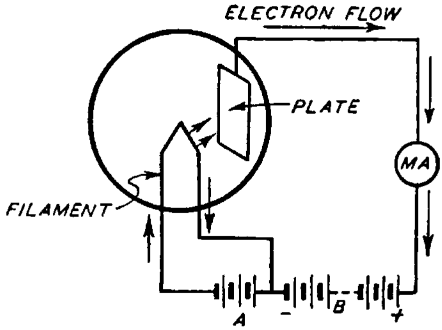


Fig. 50. Direction of Electron Flow in a Vacuum Tube Circuit

through the plate circuit. The electrons are moving from the filament to the plate and through the circuit to the battery, through the battery to the filament circuit, thence to the filament itself, shown diagrammatically in Fig. 50. The electrons serve to complete the circuit within the tube.

The discovery of this phenomenon, known as the Edison effect, is attributed to Thomas A. Edison, who, in 1883, could find no use to make of his discovery. It was not until twenty-one years later, in 1904, that J. A. Fleming of London found that the diode could be used for the detection of radio signals.

Triode Tubes. The introduction of the grid—a third element, or electrode—into a vacuum tube by Lee DeForest increased its utility tremendously by giving it the properties of amplifying and oscillating. The grid, so named because of its appearance, serves to control the flow of electrons between the filament and the plate elements. Fig. 51 shows the three elements placed in their respective relative positions—the filament on the left, the grid in the center, and the plate at the right. A battery is connected to the terminals of the filament. A second battery is connected into the plate circuit in exactly the same manner as shown in the paragraph describing the diode—the positive terminal connected to the plate terminal of the tube, and a measuring device, a milliammeter, connected in series. The negative terminal of the plate battery is connected to one of the terminals of the filament battery. The negative side of a third battery, the positive terminal of which is connected to the negative terminal of the filament battery, goes to the grid terminal on the tube. Note

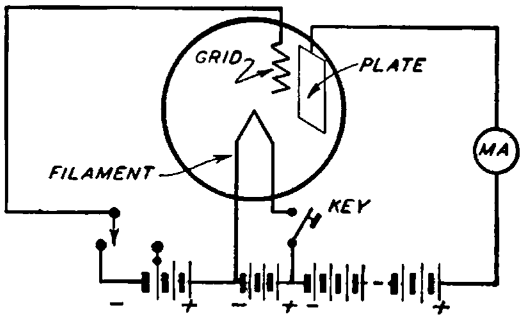


Fig. 51. A Radio Tube Circuit

that there is a third terminal on the battery by means of which we may vary the voltage delivered to the grid.

When the key in the filament circuit is closed, the current passes through the filament element, heating it, causing the electrons to flow. The positive charge upon the plate atrracts them, even as it did in the foregoing example. If the connection to the grid is removed, the current flowing through the plate circuit will be found to increase greatly. Reconnecting the grid battery into the circuit will cause the plate current to drop. Remove the connection from the negative terminal on the grid battery and place it on the center terminal—which is a lower-voltage output—then the current in the plate circuit will be found to increase over that which was passing when the entire battery was in circuit, but less than when the battery is out of circuit.

The explanation of the foregoing experiment is as follows: The electrons driven out of the filament are attracted to the plate because of the positive charge. The grid, however, carries a negative charge which repels the negatively charged electrons, and allows only a limited number of them to pass through to the plate. Hence, when the negative charge is increased, the number of electrons passing between the filament and the plate is decreased, with a consequent drop in current flow. Practically no current flows in the grid circuit as long as the grid is negative with respect to the filament and the plate. If, however, a positive charge is impressed on the grid, a milliammeter placed in the grid circuit would indicate the flow of grid current, due to the fact that the positive charge on the grid would attract electrons in exactly the same manner as the plate.

The grid is made of a fine wire wound in the form of a spiral, the turns held in position by supporting wires. It may be flat, round, or oval to meet requirements of design. The surface is relatively small compared to that of the plate. Hence, although it sets up a negative charge that repels part of the electrons and prevents them from passing on to the plate element, it cannot stop all of them—in fact, if it did so, the tube would not function.

Space Charge. Not all of the electrons which leave the filament would make their way to the plate, even though the grid element were at zero potential, owing to a phenomenon called the *space charge.* After the space between the filament and the plate has become saturated with the electrons—acting in accordance with the fundamental law, "Like Charges Repel"—they have a tendency to repel other electrons that are coming from the filament. This tendency is counteracted by the positive charge upon the plate, so that those electrons that get close enough to the plate are attracted to it, while those closer to the filament are pushed backward. Increasing the value of the positive charge upon the plate tends to overcome the space-charge effect.

Grid-Voltage, Plate-Current Relationship. There is a definite relationship between the value of the voltage on the grid element of the tube and the flow of current in the plate circuit. Any change whatsoever in the value of the voltage applied to the grid will cause a corresponding change in the plate current. Changing the value of the voltage applied to the plate element will likewise affect the amount of current flowing in the plate circuit—the greater the voltage, the greater the current, within certain limits. These two facts give rise to the determination of one of the characteristics of the tube, the amplification factor, which is a measure of its ability to amplify the signals that are impressed upon it through the grid circuit, and which may be further defined as the ratio of the effect of change in grid voltage to change in plate voltage on the flow of plate current. In order to determine the amplification factor of the tube, a set-up such as that shown in Fig. 52 may be supplied.

Citing as a hypothetical case, a tube of the 199 type which requires 3 volts on the filament: Having made the connections as shown, with a 200-ohm potentiometer at *P-1* and a 400-ohm (or higher resistance) at *P-2*, adjust the variable resistors until there are 4 volts on

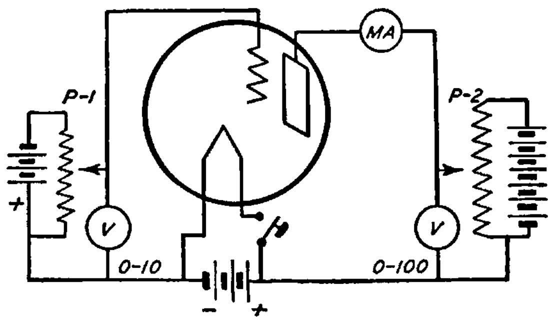


Fig. 52. A Radio Tube Test Circuit

the grid and 90 volts on the plate. Then adjust potentiometer *P-1* until there is a change of 1 milliampere in the plate current, noting the amount of change in the grid voltage that caused the change in current. Reset the potentiometer until there are again 4 volts on the grid and 90 volts on the plate, and adjust potentiometer *P-2* until the same change in plate current—1 milliampere—occurs. It will be found that a much greater change of plate voltage will be required to cause the variation in current than was the change in the grid voltage. Note the reading on the voltmeter in the plate circuit.

If the difference in plate voltage required to cause the change of 1 milliampere of current flow is divided by the change in grid voltage required to cause the same change in plate current, the ability of the tube to amplify is determined. For example, if it has been found that a change of 1.5 volts on the grid caused a drop of 1 milliampere in the plate current, and that a change of 9 volts on the plate caused a corresponding change, the amplification factor of the tube would be 9 divided by 1.5 which equals 6. In other words, a given signal impressed upon the grid of the tube would be amplified 6 times in passing through the tube, as would each change in the amplitude of the signal.

Effect of Varying Grid Voltage on Flow of Plate Current. It has been shown that the grid acts to control the flow of electrons to the plate, and that it thereby controls the flow of current in the plate circuit. The conditions, as set forth in the case cited, will not hold for all values, however, and in order to ascertain the action throughout a variation of voltages, we have set up a simple test circuit as shown in Fig. 53, from which we can determine what is going on in the circuit

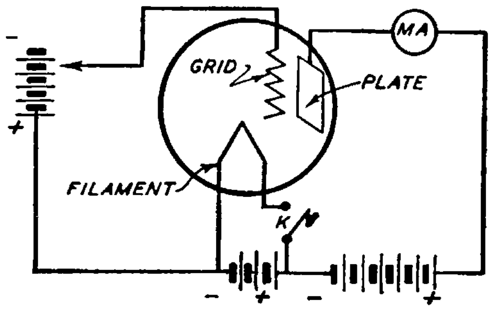


Fig. 53. Circuit Connections for Determining the Amplification Factor of Tube Circuit Connections Arranged for Varying the Grid Voltage

as the voltage is varied. The potential applied to the plate is 45 volts. The record of the results is shown in Fig. 54. When the

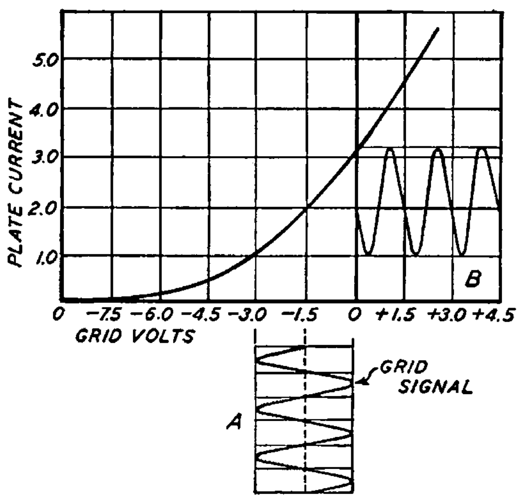


Fig. 54. Graph Showing Characteristic Curve of a Vacuum Tube
A—Wave Representing Alternating Voltage on Grid
B—Wave Representing Current in Plate Circuit

charge on the grid is 7.5 volts negative, the milliammeter in the plate circuit indicates a flow of .05 of a milliampere of current, practically zero. When a potential of 6.0 volts negative is applied to the grid, the plate current increases to .1 of a milliampere. With the grid at 4.5 volts negative, the plate current has increased to .5 of a milliampere; at 3.0 volts it is 1.0 milliampere; at 1.5 volts it is 2.0 milliamperes; at zero volts it is 3.2 milliamperes; and at 1.5 volts positive potential on the grid the plate current is 4.5 milliamperes.

Assume that there is a potential of 1.5 volts negative upon the grid, and that an alternating current of 3.0 volts is impressed upon the circuit. That would mean that the potential on the grid would vary between zero and 3.0 volts negative, neutralizing the negative charge at the time when the alternating current was at maximum positive potential, and adding to the charge on the grid when the cycle swung over to maximum negative. Referring to Fig. 54 it will be found that the plate current will vary from 3.2 milliamperes to 1.0 milliamperes. The alternating current, being pure, is represented by a *sine* wave, as shown at *A* in Fig. 54. The current in the plate circuit will vary in accordance with the values shown on the graph in Fig. 54, and may be represented as shown at *B* in Fig. 54. Note that the form of the curve representing the flow of current plotted against time follows that of the alternating current impressed upon the grid.

However, if we assume that the potential impressed upon the grid is 4.5 volts negative and that an alternating current of 3.0 volts is impressed upon the grid circuit, then the plate current will vary between .1 of a milliampere and 1.0 milliampere. In view of the fact that the change in plate current is much less between 4.5 volts and 6.0 volts on the grid than it is between 3.0 volts and 4.5 volts on the grid, the wave form is distorted as shown in Fig. 55. Hence, it is evident that in order to prevent distortion, it is essential that the tube be operated with a potential on the grid that will permit the use of that portion of the grid-voltage, plate-current characteristic curve that is straight, or approximately so, when the tube is used as an amplifier.

The variations in the plate current will follow the fluctuations in voltage at the grid regardless of whether the grid signal is sinusoidal or irregular. In the illustration given the voltage value of the impressed alternating-current signal is greater than those found normally in the circuit of a radio receiver, but was made sufficiently high for illustrative purposes.

Referring again to Fig. 54, it will be seen that the average plate current is 2.0 milliamperes, which is the same current that would be flowing with 1.5 volts negative bias—the normal operating bias of the tube according to the illustrative values given previously.

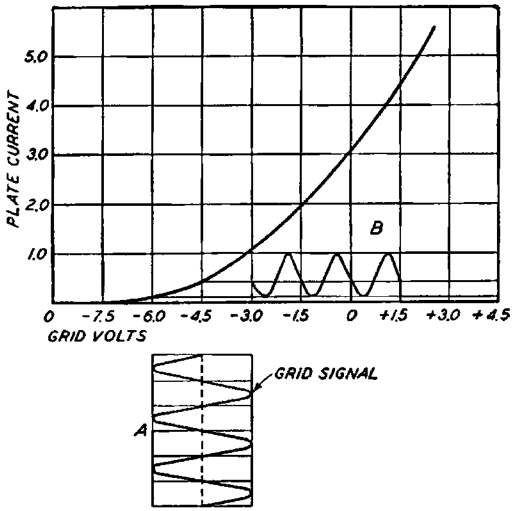


Fig. 55. Characteristic Curve of a Vacuum Tube Showing Result of Operating the Grid Signal Voltage on the Bend of the Curve

Therefore, it is shown that the plate current is divided into two components—one the alternating-current component, the other the direct-current component. The direct-current component is the one that would be shown by a measuring instrument, which measures the average value—in this case, 2.0 milliamperes. The alternating-current component has an amplitude of 2.2 milliamperes.

Effect of Gas in Tube upon Phase Relationship. The alternating component of the plate current will always be in phase with the alternating component of the grid voltage in a tube that is free from gas. But, in the event that gas is present, the ionization in the tube that occurs as a result thereof, causes the plate current to lag. Since, the current and voltage of an alternating current are in phase when resistance only is present, it is evident that the tube acts as a pure resistance—or conductance.

Plate Resistance—Plate Impedance. Plate resistance and plate impedance, though considered commonly to be more or less synonymous, are actually quite different, both as to value and as to effect.

Plate resistance is the measure of the resistance to the flow of direct current through the tube—in other words, the direct-current resistance. It is determined by applying Ohm's law, $E_p = I_p R_p$, E_p representing the plate voltage, I_p representing the plate current in amperes, and R_p representing the plate resistance. Thus, if it is found that with a plate voltage of 90 volts the plate current is five milliamperes, the plate resistance will be that shown by dividing 90 by .005 or 18,000 ohms. If, on reducing the charge applied to the plate to 45 volts, the current in the plate circuit is three milliamperes, .003 amperes, the resistance under such conditions would be 15,000 ohms. Hence, it is necessary to know the conditions under which the tube will function to determine its plate resistance.

Plate impedance is a measure of the resistance to the flow of varying currents in the plate circuit, thereby differentiated from plate resistance which is a measure of the resistance to direct current flow. It is determined by dividing the change made in the value of the plate voltage by the change produced in varying the pressure on the plate. Thus, if a change of 45 volts on the plate caused a change of two milliamperes in the current flow, the plate impedance would be 22,500 ohms, and if the reduction had been from 90 volts to 45 volts, the tube would be said to have a plate impedance of 22,500 ohms at 45 volts, and it would also be necessary to state the potential upon the grid. Plate impedance changes with each change in the value of either the voltage on the grid or upon the plate. Hence, it is necessary to know the conditions under which the tube is to function in order to determine the value of the plate impedance, as in the case of the plate resistance shown.

Mutual Conductance. In order for a vacuum tube to serve its purpose as an amplifier the most efficiently, it is necessary that it be capable of producing the maximum undistorted change in the flow of plate current with very small changes in grid potential. Such changes are a measure of the tube's ability to conduct electricity, and the effect is a ratio of the changes in grid potential with the changes in plate current. The ratio is known as the mutual conductance of the tube.

It has been shown that the amplification factor of a tube is the number of times the tube will amplify a given signal, determined by dividing the change in plate potential required to cause a certain change in plate current by the change in the grid potential required to create the same change in plate current. It has also been shown that the plate resistance is the ratio of the change in plate voltage to the change in plate current, found by dividing the change in potential applied to the plate to create whatever change in plate current it may cause. It is evident that the ratio of the plate current change to the plate potential voltage is a measure of the ability of the tube to conduct electricity. Therefore, the mutual conductance of a tube may be determined by dividing the amplification factor by the plate resistance.

Mutual conductance is measured in *mhos*, or, to be more specific *micromhos* (millionths of a mho). Thus, a tube that has an amplification factor of 6 and a plate resistance of 15,000 ohms will have a mutual conductance of .0004 mhos, or 400 micromhos. Inasmuch as the value of the plate resistance varies with changes in the value of the plate potential, it is evident that the mutual conductance of the tube will vary likewise, so that, again, it is necessary to know the constants of the circuit in which the tube is to function in order to specify its mutual conductance, otherwise known as the G_m.

Generally speaking, a tube that has a high mutual conductance will serve better as an amplifier than one which has a low mutual conductance. However, a tube that has a high mutual conductance will not serve so well as an output tube, as one with a low mutual conductance.

Power Output of a Tube. The power output of a tube is rated in the number of watts—or milliwatts (thousandths of a watt)—that the tube is capable of delivering. Power, it has been shown, is the product of the current flowing through a circuit multiplied by the pressure—watts equals volts times amperes, or $W = EI$. It would seem, then, that in order to obtain the power output of a tube, one would multiply the value of the plate voltage by the current to determine the number of watts. However, it must be remembered, that it is the *variations* in the voltage and current that cause the movement of the reproducing-device elements—the loud speaker or the headphones—and it is essential to take the plate circuit and other constants into consideration, as well.

Multi-Element Tubes. The discussion up to this point has concerned tubes of the types known as the diode and the triode, those having two and three elements, upon which the fundamental principles of tube operation is based. Engineering practice has brought about the development of tubes with a multiplicity of elements, each of which serves a definite purpose, and, as this treatise continues, the uses for the multi-element tubes will become evident.

Filament Element. It has been stated that the filament acts as a heater and as a source of electrons. That is true in tubes of the diode and triode types that have been discussed, but under the heading Cathode, another means to secure a flow of electrons is shown. In those tubes that rely upon the filament itself to supply the electronic stream, it is necessary that the metal be rich with the negative charges and that it be capable of delivering them with facility. Not all metals have the property of emitting electrons in quantities, however, and in fact there are only a few of them that are efficient in this respect. Tungsten is a resistance metal that has the property of withstanding high temperatures over extended periods.

In view of the fact that tungsten must be operated at an exceedingly high temperature to emit electrons in sufficient quantities, the pure metal is treated with thorium—thoriated—because thorium will give up its negative charges at a much lower temperature. The use of a thoriated tungsten filament reduces the power necessary to light the filament and increases the life of the tube considerably.

Alkaline-earth oxides are also used as a coating for tungsten wire filaments to permit free flow of liberated electrons at low filament temperatures. These oxides are seen as a whitish covering.

Cathodes. Electron emitting elements in vacuum tubes are known as the direct-heater type and the indirect-heater type. The direct-heater cathode is the one which is described under Filaments, and, as the name indicates, is an element that liberates electrons because of the heat which it produces due to the flow of electricity through it. The indirect-heater cathode is one in which the filament which acts merely as a heater element is inclosed in a sleeve upon which is a coating of oxide that supplies the electronic stream under sufficiently high temperatures. The indirect-heater cathode was developed shortly after the introduction of alternating-current tubes, as a means to better control the tube action and to eliminate the difficulties that arose due to direct connection with the low-frequency alternating-current circuits.

Grids and Plates. Nickel is used extensively in tube construction, due principally to the facility with which it can be formed and the ease with which it is freed of gases that penetrate its surface. While it is formed into different shapes readily, it is at the same time substantial, and is not particularly susceptible to damage.

Exhausting the Tube. It is very necessary that the space within the glass envelope be devoid of all traces of gas—air, it will be understood, is a gas, also. During the process of manufacture the air is pumped out of the inclosure, and the elements of the tube are heated by surrounding the tube with a coil through which a high-frequency current is flowing, thus driving the gases out of the metal and thence out of the tube. Even after all these precautions are taken, what traces of gas may remain are sealed tightly against the side of the glass by a device known as the "getter" which causes the silvery coating on the inside of the bulb. Magnesium is a commonly used "getter." A small tablet placed in a cup is discharged by heat generated by a high-frequency current flowing through a coil placed around the outside of the tube.

The connections to the elements are brought out through air-tight seals, using a specially developed wire for sealing through the glass. If ordinary wire were used, the contraction and expansion due to variations in temperature would crack the seal and allow air to be admitted to the inside of the tube. A great deal of research was required to develop a connecting wire that would serve the purpose.

Dissipation of Heat. In view of the fact that high temperatures are generated inside the tube, first by the heat of the filament, and second, by the electronic bombardment of the plate element, the other elements of the tube, particularly the plate, may become so hot as to liberate electrons, also. Consequently, it is necessary to provide a means to dissipate the heat and prevent a reverse flow of negative charges. Oxidation of the plate element—the black coating—is one means employed. Another method is to use a perforated element.

The Diode as a Rectifier. Direct current is required to supply constant potentials to the plate and grid elements of the vacuum tube in the circuits. Therefore, it becomes necessary to convert the alternating current into direct current, accomplished by means of the diode, serving as a rectifier. At the same time, it is desirable to have voltages higher than those available on the power lines.

It has been shown how higher voltages can be obtained by the use of transformers with alternating current. It has also been shown that direct current cannot be "stepped up" through a transformer, which means that in order to secure the higher-direct current voltages, it is necessary to provide a high-voltage alternating current and convert it into direct current.

There are two forms of rectification—known as full-wave rectification and half-wave rectification—according to whether the process converts both sides of the alternating-current wave or only one side. Half-wave rectification requires the use of a vacuum tube consisting of a filament and a single plate. Full-wave rectification requires a vacuum tube that has a filament and two separate plate elements.

Fig. 56 shows a diagram of a half-wave rectifier tube in circuit with a transformer. The transformer consists of a primary winding and two secondaries, one of which is to "step up" the voltage, the

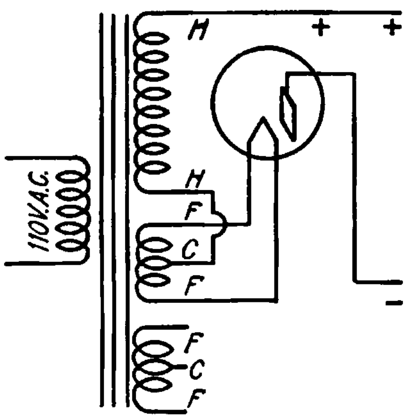


Fig. 56. Transformer Connections to Half-Wave Rectifier Tube

other to "step down" the voltage. The voltage delivered by the secondary winding marked *FCF* is that required on the filament of the rectifier tube according to the specifications of the tube manufacturer. The voltage delivered by the secondary winding marked *HH* will vary according to the requirements of the circuit—the value of the direct-current voltage needed to operate the device with which the rectifier is connected.

The terminal *C* on the low-voltage secondary is a center tap, and in view of the fact that the opposite ends of the coil are at opposite polarity, it is evident that *C* will be at the position of zero potential at all times, as will be seen by referring to a *sine* curve representing alternating current. Similarly, it will be seen that the terminals of the high-voltage secondary will be alternately positive and negative as the alternating current reverses its direction of flow, which means that the charge upon the plate—through the external circuit—will be positive and then negative with each alternation of the current.

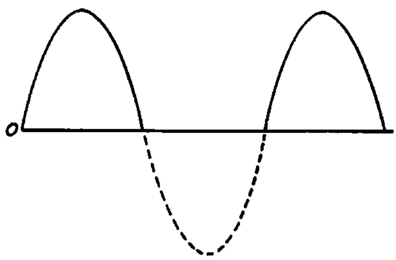


Fig. 57. Diagram Showing How a Pulsating Direct Current Is Obtained from Alternating Current

When current is passed through the filament of the tube, electrons are liberated into the space. In that part of the cycle when the current is positive there will be a positive charge upon the plate, at which time the plate will attract the negative charges given off by the filament and cause a flow of current. However, as the current reverses its direction of flow, the plate becomes charged negatively and repels the electrons, so that there is no current flow. Thus, a condition such as represented by Fig. 57 is created. Each of the alternations on one side of the zero potential line is retained while those on the other side of the line are eliminated, which means that the current flowing through the circuit, though pulsating, is flowing in the same direction and does not reverse its direction of flow. The pulsations are eliminated—or minimized—by the use of filter circuits.

The current flow from the rectifier circuit is shown by the symbols. The negative charges pass from the filament to the plate and out through the external circuit, returning through the high-voltage winding of the transformer to the center tap of the filament supply secondary, and thence to the filament. All this action takes place only during that part of the cycle when there is a positive charge upon the plate of the rectifier tube.

The principle of the full-wave rectifier is identical with that of the half-wave rectifier, the difference lying in the fact that both sides of the wave are converted, one of them being transposed to the opposite side of the zero potential line. A typical circuit for full-wave rectification is shown in Fig. 58. The high-voltage and the low-voltage secondaries are both center tapped.

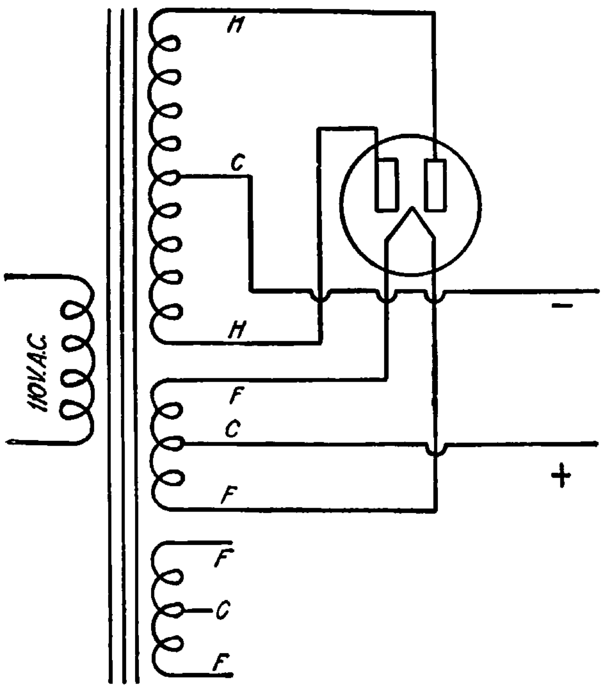


Fig. 58. Circuit of a Transformer for a Full-Wave Rectifier Tube

As the voltage is induced into the secondary of the transformer, the opposite ends of the high-voltage winding are at opposite polarity —when one terminal is positive the other is negative, and vice versa. Thus, it is evident that each of the plates of the rectifier tube will be charged positively and then negatively as the current flows through the cycle. It is also true that at the time one of the plates has a positive charge, the other plate will have a negative charge of equal value.

Electrons, that are emitted by the filament, are attracted toward the plate element on which there is a positive charge and are repelled by the plate on which there is a negative charge. As the current reverses, the electrons pass first to one plate and then to the other.

Terminal *C* of the secondary winding *HH*, Fig. 58, is at the electrical center of the winding and therefore at the position of zero potential. Similarly terminal *C* of the secondary winding *FF* is at the electrical center of the winding and at zero potential also. So far as the alternating-current characteristics go, then, the two center tap terminals are equal. But, as the electrons flow from the filament they pass to the plate charged positively—say, for example, the right-hand plate—they pass through the upper portion of the high-voltage secondary and out at *C*. The lower half of the winding at this time is negative, which repels the flow of the electrons, and they pass into the external circuit at the most convenient point. As the current reverses its direction of flow, the left-hand plate becomes charged positively and the electrons, again passing from the filament to the plate flow through the lower portion of the high-voltage winding, are repelled by the negative charge in the upper portion of the secondary coil and pass out into the external circuit at *C*. Returning to the filament circuit, it is only necessary that they find their way back to the filament—through first one and then the other portion of the filament winding. Hence, the polarities are as shown on the diagram, zero potential—negative—off the center tap of the high-voltage secondary, the positive terminal off the filament circuit.

The effect of the space charge is present in rectifier tubes as well as in those used for other purposes. The negative charges liberated by the filament tend to repel other electrons so liberated and force them backward away from the plate. Higher plate voltages will counteract the effect to some extent, but not entirely. In order to overcome the effect of space charge, a drop of mercury is placed in some rectifier tubes. The mercury gives off a vapor—minute particles or atoms moving freely inside the tube. When the filament is heated, the electrons moving at enormous velocity strike the mercury atoms and dislodge electrons by collision. The freeing of the negative charges from the mercury atoms causes the vapor to become ionized—carrying a positive charge—thereby neutralizing the space charge, allowing increased numbers of electrons emitted by the filament to pass to the plate unhampered.

Gaseous Rectifiers. All of the discussion on rectifiers has been confined to tubes of the thermionic type—that is, those which operate as a result of the liberation of negative charges due to the application of heat to a source of electrons. There is another form of rectifier known as the gaseous rectifier, which has a more limited use. The arrangement of the elements, consisting of a cathode and two anodes, is shown in Fig. 59. When the gaseous rectifier is connected in circuit, the terminals of the high-voltage secondary are connected to the anodes. The positive side of the circuit is connected to the cathode. The negative side of the rectified current is taken off at the center tap of the high-voltage winding.

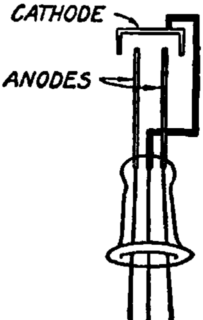


Fig. 59. Arrangement of Elements in a Gaseous Rectifier Tube

As the current reverses its direction of flow, the anodes are charged negatively and then positively, one being at positive potential at the time the other is negative. The particles of gas, set into motion by the changing electrical field, causes the gas to become ionized due to the collision of the particles with one another. The electrons move from the cathode to the anodes through the ionized space. The anodes of a gaseous rectifier are smaller than the cathode, which permits easy transfer of energy in one direction, but presents an exceedingly high resistance to its flow in the opposite direction.

Interelectrode Capacitance. Interelectrode capacitance or intertube capacity exists in all vacuum tubes. In some instances, the intertube capacitance is an aid in circuit design, whereas again it presents serious obstacles. Each electrode—element—of the tube constitutes one plate of a condenser of very low capacity, the value of which depends upon the size of the elements and the space between them. The interelectrode capacitance existing between the plate and the grid of the tube is probably of greatest importance, due to the fact that in high-gain high-frequency amplifier circuits, the capacity is likely to produce a coupling between circuits that will cause uncontrolled regeneration. Fig. 60 shows the capacitances as they exist in the triode.

Tetrode Tubes. The tetrode or four-element tube is commonly known as the shield-grid—or screen-grid—tube, Fig. 61. It was developed to provide a means to obtain high gain in a high-frequency amplifier circuit, especially in the radio-frequency stages. It has

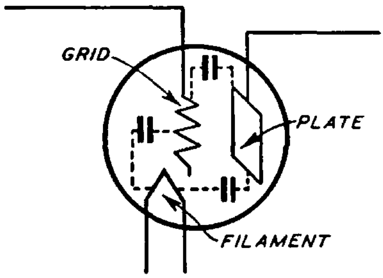


Fig. 60. Capacity Effect Between the Different Tube Elements

been shown how interelectrode capacitances exist, and how they are likely to cause uncontrolled regeneration in high-gain amplifier circuits. In order to overcome the effect of plate-to-grid capacity, another grid was inserted between the two elements, so that the capacitances then became plate-to-shield, shield-to-grid, and grid-to-filament, minimizing the objectionable grid-to-plate capacitance. The screen or shield operates at a positive potential lower than that applied to the plate.

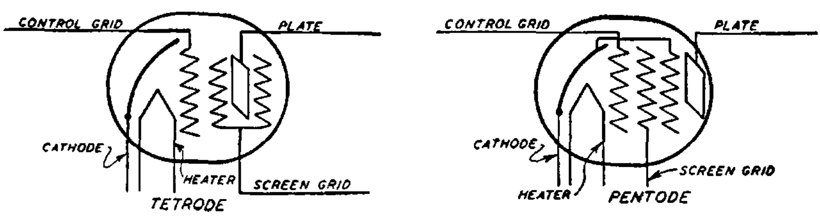


Fig. 61. Diagram Showing the Elements in a Tetrode and Pentode Tube

The use of the tetrode facilitates greatly the stabilization of high-gain amplifier circuits, particularly in high-frequency circuits. The amplification factor of the tetrode is many times higher than the triode.

Pentode Tubes. The pentode, so named because it contains five electrodes, was developed to provide a means to eliminate or minimize *secondary emission,* an emission of electrons caused by the bombardment of the plate with negative charges from the filament or cathode. The emission of electrons thus caused is called secondary emission to differentiate from the flow of charges coming from the cathode, which is the primary electronic flow. Naturally, secondary emission would have a tendency to retard the flow of electrons from the filament, thus jeopardizing the operation of the tube.

The presence of the screen or shield in the tetrode—carrying a positive charge, as well as the plate—increases the secondary emission because of the greater velocity attained by the electrons, thereby lowering the plate current, particularly at times when the plate voltage drops lower than the constant potential applied to the screen. Hence, a fifth electrode, a suppressor grid, placed between the screen and the plate, and usually connected to the cathode, reduces the velocity of the electrons because of the negative charge impressed upon it—the same as that of the cathode.

High amplification gain with relatively low potentials on the plate and screen are made possible by the use of the suppressor. Some of the pentodes are provided with separate terminal for the suppressor grid to permit variations in circuit design, by allowing varying potentials to be applied to the electrode for the purpose of producing certain effects.

Special-Purpose Tubes. During the course of the development of radio, the vacuum tubes used in radio circuits came to be known by such terms as "general-purpose tube," "detector," "high-mu," and so on. Although the "detector" and the "high-mu" tubes were of a special class, it was equally true that the "general-purpose tube" would serve in any stage, including the output until the introduction of the output power tubes.

Eventually, however, it became common practice to design tubes to meet specific requirements. Also, as a means to conserve space on the chassis, as well as reduce the cost of manufacture, it was found advisable to combine tubes—that is, provide a single tube with sufficient elements to serve more than one purpose. These tubes came to be known as the multi-electrode tubes or multi-purpose—multi-unit—tubes. Their purposes and the method of using them is specified in each case by the manufacturer.

CHAPTER VIII

OSCILLATORY CIRCUITS

An oscillatory circuit is a combination of inductance and capacity—and resistance—in which alternating current may surge back and forth at extremely high frequency. Such a circuit is shown in Fig. 62. The oscillatory circuit is the foundation of all radio circuits. Therefore, it is essential that the action be thoroughly understood.

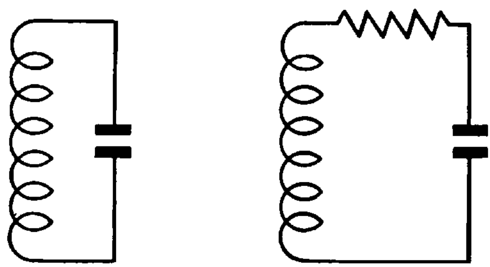


Fig. 62. Oscillatory Circuits

Producing Oscillations. Oscillation is the term applied to high-frequency alternating current. However, it may be caused or produced by continuous direct current supplied by a battery, as shown

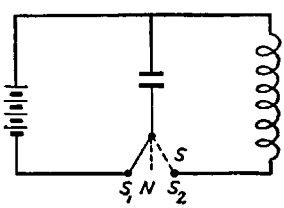


Fig. 63. Method of Charging and Discharging Condenser

in Fig. 63. Two separate circuits are included in Fig. 63. If the switch arm S is thrown to position S_1, current will flow from the battery to the condenser until the potential difference between the plates of the condenser equals that which exists between the terminals of the battery. If the switch arm S is thrown to position N, the battery circuit is open and the charge remains upon the condenser plate—there is no complete circuit. But, if the switch arm is thrown to position S_2, a circuit consisting of the condenser and an inductance is completed, and there is a path through which current may flow.

Suppose that the condenser had been charged with energy from the battery and that the switch arm is thrown to complete the circuit with the coil—to position S_2. With a path to follow, current flows from the condenser through the windings of the coil. It has been shown how the flow of current through a coil creates a magnetic field around the coil, and it has also been shown that the magnetic field will increase as the current flow increases.

With the switch arm at position N—an incomplete circuit—the current flow in either circuit is zero. Assume that the upper plate of the condenser has an abundance of negative charges, and that the lower plate is lacking negative charges—the upper plate then is negative, the lower plate is positive polarity. When the circuit with the coil is completed by placing the switch arm at S_2, the negative charges on the upper plate move through the circuit toward the positively charged plate. In the coil, however, they build up the magnetic field as previously stated, so that what had been a static charge is converted into a magnetic field. When the current flow has attained its maximum, the magnetic field is also at maximum.

At this point, the condenser giving up no more electrons, the magnetic field collapses and creates a flow of charges that move on through the circuit depositing on the lower plate of the condenser. If the switch could be opened at the exact instant that the charges have stored themselves upon the lower plate of the condenser, the condition would stand thus: Energy that *had* been stored on the upper plates of the condenser has passed through the circuit, and has been stored upon the lower plate of the condenser, which coincides with what occurs in an alternating-current circuit in which the current flows in one direction through the circuit from zero to maximum flow and back again to zero to complete one alternation.

With the switch arm again at position S_2, the negative charges on the lower plate of the condenser, attracted by the positive charge on the upper plate, move back through the circuit and again build up a magnetic field in the coil, which, upon attaining maximum coincidental with the maximum flow of current, collapses and forces the current onward through the circuit placing the negative charges again upon the upper plate of the condenser. If the switch arm could be thrown to position *N* instantaneously, the charges which had first been stored on the upper plate of the condenser, having passed through the coil and having been stored upon the lower plate of the condenser—one alternation—have now passed through the coil in the reverse direction and are again stored on the upper plate to complete a cycle. The process continues again and again until the energy is exhausted.

It would seem that the process—oscillation—could and would go on indefinitely. It would do so, were it not for the losses sustained by heat dissipation and the radiation of energy—lines of force around the coil that pass off into space instead of collapsing with the magnetic field. Heat dissipation is caused by the resistance of the circuit, which, although there may be no resistance element, will be present nevertheless—the wire used for connections and the windings of the coil offer resistance to the flow of current in any event.

A circuit that has little resistance will oscillate over a greater period of time than one which has more resistance. If it is desired that a circuit shall oscillate only a few times, a fairly high value of resistance can be introduced into the circuit in order that the energy may be dissipated quickly in the form of heat. In fact, a circuit that contains a high enough resistance will not oscillate, and all the energy stored upon the condenser plates will be absorbed or dissipated in the resistance itself.

The discharge of a condenser under any circumstances tends to be oscillatory. That which appears in the form of a spark when the terminals of a charged condenser are connected by a conductor is actually a large number of reversals of current flow between the plates.

COUPLED CIRCUITS

Two electric circuits are said to be *coupled* when a means is provided for the transfer of electrical energy from one circuit to the other. Circuits may be coupled by electromagnetic induction, using inductance; by electrostatic induction, using capacitance; or by resistance. Circuits may be coupled so that the coupling element is common to and in series with both circuits. Such circuits are said to be directly coupled—*direct coupling*. Or, circuits may be coupled so that the transfer of energy is accomplished by means of electromagnetic or electrostatic induction in which the coupling elements are not common to, or in series with, both circuits. Such circuits are said to be indirectly coupled—*indirect coupling*.

Electric current, in order to be transferred from one circuit to another, must have pulsating characteristics. It may be alternating current or it may be direct current which, though the direction of flow is always in the same direction, varies as to the voltage or amount of current flow. Continuous direct current is not applicable to the conditions under which the energy may be transferred from one circuit to another, except by means of direct connection through conductors.

Mutual Inductance. It has been shown how the flow of a varying current through the windings of an inductance induces a counter electromotive force which opposes the flow of the current which caused it, and that the generation of the counter electromotive force is called the *self-inductance* of the coil. It has also been shown that if two coils are brought close together, a varying current flowing through one of them induces the flow of current in the other, due to the linkage of flux—lines of force—cutting the windings of the coil in the secondary circuit. This linkage of flux creates a *mutual inductance* between the two circuits, the value of which depends upon the size and shape of the coils, and their position with respect to one another. If the coils are placed so that only a few of the lines of force, produced by the flow of current through the primary, cut the windings of the secondary coil, the mutual inductance is low. On the other hand, if the coils are arranged so that the lines of force cut all or nearly all of the windings of the secondary, the mutual inductance is high. Thus, the mutual inductance increases as the design of the coil permits greater flux linkage—less flux leakage.

The calculations to determine the value of mutual inductance are complicated and involved, principally because of so many variable factors—the size and shape of the coils, their relative position, and the permeability of the medium through which the flux flows. Consequently, the determination of the value of mutual inductance is of importance only to engineers, and engineering textbooks cover the subject thoroughly for them.

Coefficient of Coupling. The coefficient of coupling is a measure of the degree of coupling that exists between two circuits—a numerical expression of the ease with which electrical energy is transferred from one circuit to another. The relationship is expressed in terms of percentage, determined by the formula:

$$K = \frac{L_M}{\sqrt{L_1 L_2}}$$

in which K is the coefficient of coupling, L_1 is the inductance of the primary coil, and L_2 is the inductance of the secondary coil.

Tight Coupling—Loose Coupling. Circuits are said to be tightly coupled or loosely coupled according to the amount of energy that is transferred from one circuit to the other—or the ease with which the transfer is accomplished. Tight coupling is also referred to as *close coupling.*

Direct-Inductive Coupling. Circuits are said to be *inductively coupled* when the transfer of energy is accomplished by means of inductance. They are said to be *direct-inductively coupled* when the inductance, by means of which the transfer of energy is made, is common to both circuits, and is in series with the other elements that comprise the circuits. See Fig. 64.

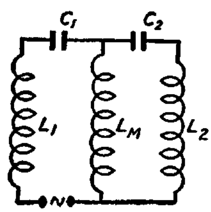


Fig. 64. A Direct-Inductively Coupled Circuit

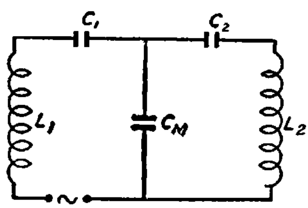


Fig. 65. A Direct-Capacity Coupled Circuit

A direct-inductively coupled circuit has a relatively high mutual inductance and a high coefficient of coupling, increasing with the efficiency of design of the inductance L_M, which is common to both circuits. Referring to Fig. 64 it will be seen that the primary circuit consists of inductances L_1 and L_M and capacitance C_1, and that the circuit is energized by a varying electrical source. The secondary circuit consists of L_2 and L_M with the capacitance C_2. As the varying current flows through the primary circuit, it produces a current through the common inductance L_M, which current is transferred to the secondary circuit. The self-inductance of the coil L_M is equal to the mutual inductance that exists between the two circuits.

Direct-Capacitive Coupling. Similar to direct-inductive coupling is the transfer of energy by capacitive coupling—that form of coupling that employs capacitances. Fig. 65 shows a circuit in which the capacitance C_M is common to the primary and the secondary circuits, thus forming a *direct-capacitively coupled* circuit. The transfer of energy in such a circuit is obtained by electrostatic means, and utilizes the effect of alternately charging and discharging the condenser C_M.

Resistance Coupling. Resistance coupling is another form of direct coupling, the resistance being common to both the primary and secondary circuits as shown in Fig. 66. The transfer of energy

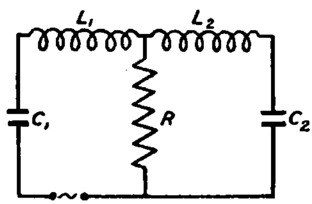


Fig. 66. A Direct Resistance Coupled Circuit

by means of resistance is accomplished by using the voltage drop across the resistance. The varying current flowing through the resistance is opposed according to the instantaneous value of the electromotive force and current, which opposition causes a difference of potential to exist between the opposite ends of the resistance. The difference of potential causes a current to flow in the secondary circuit, thereby effecting a transfer of energy from one circuit to the other.

In order that the transfer of energy may be accomplished by resistance alone, it is necessary that the resistance unit be non-inductive. If the resistance is inductive, the coupling will be that obtained by a combination of resistance and inductance, and the action will be considerably different from that obtained when pure resistance is the coupling element.

Indirect-Inductive Coupling. Indirect-inductive coupling is a means of transferring electrical energy from one circuit to another by utilizing the electromagnetic field that surrounds the inductance through which a varying current is flowing. The coupling device is commonly known as a transformer which consists of two windings, the primary and the secondary, which may be wound upon the same form or on separate forms, but which are placed in such relation as to permit linkage of the lines of force around the primary coil through the windings of the secondary coil. A transformer may be arranged so that the coupling is *tight* or *loose*, according to the arrangement of the coils. If the coils are close together so that little of the flux around the primary coil is lost, the coupling will be tight, but if the coils are separated or set at an angle, so that only a small part of the flux cuts the secondary windings, the coupling is loose. Tight coupling is employed where it is desired to conserve power; loose coupling is employed where certain frequencies of alternation are to be selected or rejected.

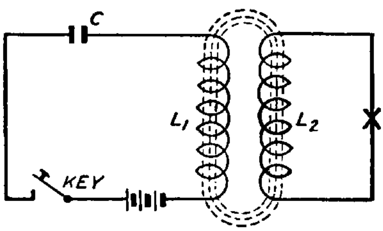


Fig. 67. An Indirect-Inductively Coupled Circuit

Fig. 67 shows an indirect-inductively coupled circuit in which the secondary circuit is closed—that is, the terminals of the secondary coil are shorted either directly or through a load. A battery is connected in the primary circuit, and a key is provided with which to close or open the circuit. Such a set-up can be made very readily. When the key is closed, the battery supplies energy to the coil in the primary circuit and while the current is flowing—until it has made the complete circuit from one terminal of the battery to the other—the lines of force build up around the coil. Since the current from the battery is continuous, there will be no change in the magnetic field after the voltage has built up in the circuit, but it will remain stationary. During the build-up period, the moving lines of force will induce an electromotive force in the secondary coil, but when the voltage has built up in the primary so that the field remains stationary, there will be no induction of electromotive force in the secondary coil. However, if the key is opened, the magnetic field around the primary coil collapses and again induces a current in the secondary coil. If the connection between the terminals of the secondary coil is severed and the ends held between the fingers while closing and opening the primary circuit, the effect can be felt distinctly.

The circuits as shown would be coupled indirectly regardless of whether the source of varying energy were impressed upon the circuit which has been referred to as the primary circuit, or that which is considered the secondary circuit. In either case, also, the mutual inductance existing between the circuits would be the same no matter which circuit is connected to the electrical source.

Indirect-Capacitive Coupling. Indirect-capacitive coupling does not differ greatly from direct-capacitive coupling. A circuit is shown in Fig. 68, and in many instances the capacitance C_2 is replaced

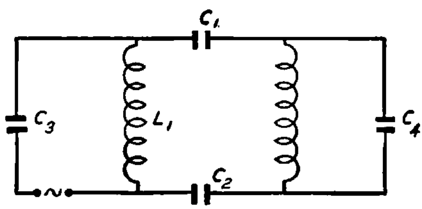


Fig. 68. An Indirect-Capacity Coupled Circuit

with a direct connection between the two inductances. It is to be understood that the inductances shown in the circuit are not inductively coupled, so that the transfer of energy between the circuits passes through the condenser C_1, or C_1 and C_2 if both condensers are used.

Resonance. It has been shown that the flow of alternating current through a circuit meets with opposition caused by three electrical functions, inductance, capacity, and resistance. It has also been shown that the opposition set up by inductance is called inductive reactance; that set up by capacity is called capacitive reactance; and that set up by resistance is resistance. Too, inductive reactance and capacitive reactance have been shown to have opposite characteristics—that whereas the inductive reactance is increased by increasing the inductance, the capacitive reactance is decreased when the capacity is increased. Inductive reactance has been referred to as positive reactance; capacitive reactance has been referred to as negative reactance. In other words, whereas they both act to oppose the flow of alternating current through the circuit there is a point where one neutralizes the other so that there is no opposition—or minimum opposition—to current flow.

Since inductive reactance and capacitive reactance tend to neutralize one another, even though each opposes the flow of alternating current, it is evident that if the inductive reactance and the capacitive reactance are equal, they will be entirely neutralized and will permit the greatest flow of current through the circuit. When such a condition exists, the circuit is said to be in *resonance.* However, since inductive and capacitive reactance both vary with the frequency of the alternating current:

$$X_L = 2\pi f L$$
$$X_C = \frac{1}{2\pi f C}$$

it is equally evident that *the circuit will be in a state of resonance at one particular frequency,* and that the flow of current at all other frequencies will be opposed by the inductive and capacitive reactances in the circuit. If provision is made to vary the value of either the inductance or the capacity, the circuit may be adjusted to resonance at any given frequency within the range of the reactance values.

Although theoretically, the circuit is in resonance at one given frequency, it will appear to be in resonance at other nearby frequencies. In fact, resonance can never be so sharply defined that the reactance is completely eliminated. But, the reactance is at its lowest value when the circuit is in resonance, and the flow of current is greater than for any other frequency. If the frequency is increased, it is necessary to decrease either the amount of inductance or the amount of capacity or both in the circuit to bring the circuit into resonance again. Contrariwise, if the frequency is lowered, it is necessary to increase either the inductance or the capacity or both to establish resonance.

Indication of Resonance. Resonance is indicated graphically as shown in Fig. 69, in which the frequency is represented by the horizontal line and the current flow through the circuit is represented vertically. Thus, at *A*, as the resonant frequency is approached, the

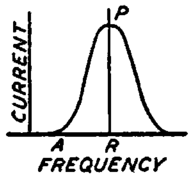


Fig. 69. Curve Showing Increase of Current as Resonant Frequency Is Increased

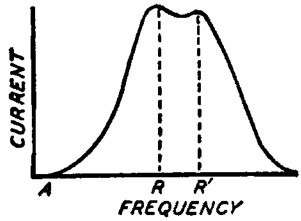


Fig. 70. Curve Showing How Mutual Inductance Effects the Resonance Frequency

equivalent reactance of the circuit—the difference between the inductive and the capacitive reactance—is approaching zero, there is less opposition to the flow of alternating current in the circuit, and as a result current begins to flow. As the adjustment of either the capacitance or the inductance—or both—brings the reactances closer to neutralization, the amount of current flowing increases, until at resonance, *R*,—where the inductive and capacitive reactances are equal—there is the maximum flow of current as indicated by the peak at *P*.

Resonance of Coupled Circuits. It is evident that while energy may be transferred from one circuit to another by employing one of the several forms of coupling previously discussed, the greatest amount of current will flow when the frequency of alternations is such that the circuit into which the energy is transferred is at resonance.

When two coupled circuits are tuned to resonance, the resonant peak takes a form different from that shown under the heading, Indication of Resonance. The mutual inductance, for instance, that exists between the two circuits, adding to and then subtracting from the value of the inductance in the individual circuits causes the circuit to be in resonance at two frequencies instead of one, as shown in Fig. 70. However, the double peak can be minimized, and even eliminated by loosening the coupling between the circuits to reduce the amount of energy transferred from one circuit to the other.

FILTERS

A filter, as applied to radio circuits, is a means to separate one or more types of current from other types of current in order that they may be directed according to the purpose they are to serve. This applies not only to a differentiation between direct and alternating current, but to alternating current of varying frequencies.

Several kinds of current may flow through a common conductor—the chassis of a radio receiver, for instance, serves to conduct practically every type of current flowing through the receiver circuit. Yet, through suitable filters and arrangements of circuits, the different currents and types of currents are directed to the proper places, where they serve to receive and amplify the radio signals to produce sound.

Resonant circuits and coupled circuits have already been explained. The circuits illustrated and explained were all of the *series* type, that is, the inductance and the capacity—as well as the resistance, if present—were in series with one another. The oscillatory circuit, for instance, consisting of a condenser and a coil, was a series circuit. The coupled circuits, taken individually, consisted of combinations of condensers, coils, and resistances, connected in series. In filter circuits, we deal with parallel circuits as well as series circuits, and as shall be shown, their action is very different.

Take first a filter to separate direct current from alternating current. In Fig. 71 is shown a network of three wires, the center

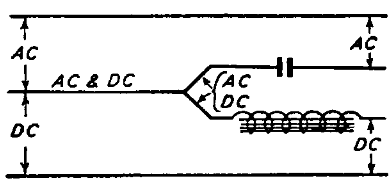


Fig. 71. A Simple Filter Circuit

one of which is common to an alternating-current source of supply and a direct-current source of supply. The upper wire is the other side of the alternating-current circuit, the lower wire is the other side of the direct-current circuit. Since the center wire is common to both circuits, it is evident that the direct current flowing through it is flowing constantly in one direction, while the alternating current is reversing its direction of flow periodically. At a certain point in the circuit it is assumed that either direct current or alternating current is desired, but not both. Hence, it is necessary to filter one from the other.

Direct current will not pass through a condenser due to the fact that the plates of the condenser are insulated from one another thereby creating an open circuit so far as the continuous flow of current is concerned. Alternating current, on the other hand, while not passing through the condenser, appears to do so, due to the alternate charging and discharging of the plates with each reversal in the flow of the current. Consequently, if a condenser is inserted in the alternating-current line, the alternating-current circuit is complete, but the flow of the direct current is effectively stopped. At the same time, in order to stop the flow of alternating current through the direct-current circuit, a choke coil is inserted in the branch of the filter that is to carry the direct current. Since the flow of direct current is continuous—and of unvarying amplitude—there is no self-inductance to set up a counter electromotive force to oppose the flow of direct current through it. The alternating current, on the other hand, passing into the windings of the coil, sets up a varying magnetic field which induces a counter electromotive force that opposes the flow of the current which produces it. Thus, in a filter as shown in Fig. 71, the direct current is separated from the alternating current and directed to serve its proper function.

Of equal importance in radio circuits, and used more extensively, is the filter network for the selection or rejection of certain frequencies of alternating current. It has been shown how capacitance opposes the flow of alternating current, and that the effect is termed capacitive reactance. It has also been shown that the reactance of a condenser is determined by its capacity and by the frequency of the current. From the formula to determine capacitive reactance:

$$X_C = \frac{1}{2\pi f C}$$

it will be seen that a condenser of low capacity will have a greater reactance to the flow of alternating current than a condenser of high capacity. Also a given condenser will have a greater reactance to currents at low frequency than for currents at high frequency. In other words, a condenser of, say, two microfarads will offer little opposition to the flow of alternating current at 100,000 cycles, but will oppose greatly the flow of alternating current at 1,000 cycles. And, a condenser of two microfarads will offer greater opposition to the flow of alternating current at 1,000 cycles than would a condenser of four microfarads.

Inductive reactance, X_L, depends likewise upon the frequency of the current and upon the value of the inductance, in accordance with the formula:

$$X_L = 2\pi f L$$

An increase in the value of the inductance will increase the inductive reactance—offer greater opposition to the flow of alternating current at a given frequency. Similarly, an increase in the frequency of the alternating current will increase the inductive reactance of a coil having a given inductance value. If we combine the two forms of reactances, as in Fig. 72, there is formed a series

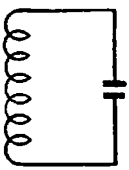


Fig. 72. A Series Resonant Circuit

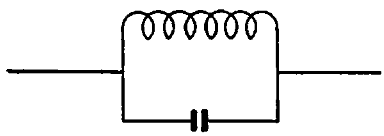


Fig. 73. A Parallel Resonant Circuit

circuit containing inductance and capacity, which will be resonant at whatever frequency the inductive and the capacitive reactances balance each other out, and they will offer little opposition to the flow of alternating current at that particular frequency.

On the other hand, if the condenser and the coil are connected in series as shown in Fig. 73 and the combination is connected into the circuit, they represent what is known as a parallel resonant circuit which offers a high resistance to the flow of alternating current at the resonant frequency, in accordance with the following explanation. It has been shown that inductance in an alternating-current circuit causes the current to lag the electromotive force by 90 degrees; that capacity in a circuit causes the current to lead the voltage by 90 degrees; and that the amount of current flowing in the circuit depends upon the inductive or the capacitive reactance found by using the formulas stated above. It is evident, therefore, that if the inductive reactance and the capacitive reactance present in a parallel circuit as shown in Fig. 73 are equal, the current will always be 180 degrees out of phase, and no current will flow through the parallel network into the external circuit. Thus, a parallel resonant circuit, such as that illustrated, opposes—and literally stops—the flow of alternating current at whatever frequency the circuit is resonant, but allows alternating current of all other frequencies to flow. The phase relationship of the current flowing through the circuit to the voltage will depend upon whether the frequency is higher or lower than that at which the circuit is resonant. If the frequency is higher, the capacitive reactance is lower than at resonance but the inductive reactance is greater. Therefore, the current would lag the voltage because of the preponderance of the inductive reactance over the capacitive reactance. Conversely, if the frequency were lower the inductive reactance would be lower than at resonance, and the current would lead the voltage.

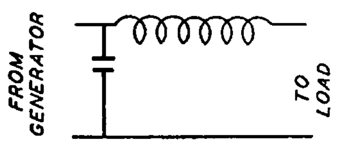


Fig. 74. A Filter Which Passes Low Frequencies

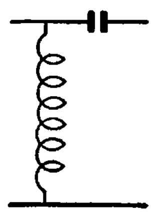


Fig. 75. A Filter Which Passes High Frequencies

There are numerous types of filters used in radio circuits. They are all combinations of the series-resonant or parallel-resonant circuits. Citing a few concrete examples: If it is desired to pass only the low frequencies through a circuit and cut off the high frequencies, a combination such as that shown in Fig. 74 would be used. The inductance offers little opposition to the flow of low-frequency alternating currents, but opposes the flow of high-frequency currents. The condenser, on the other hand, allows the high-frequency currents to pass, but opposes the flow of low-frequency impulses. If it were desired to retain the high frequencies and eliminate the low frequencies, the condenser would be placed in the line and the inductance would serve to by-pass the low frequencies, as in Fig. 75.

In order to reject a given frequency, a parallel-resonant circuit is placed in the line (see Fig. 76), and a series-resonant circuit serves

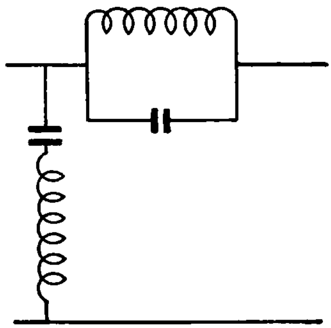
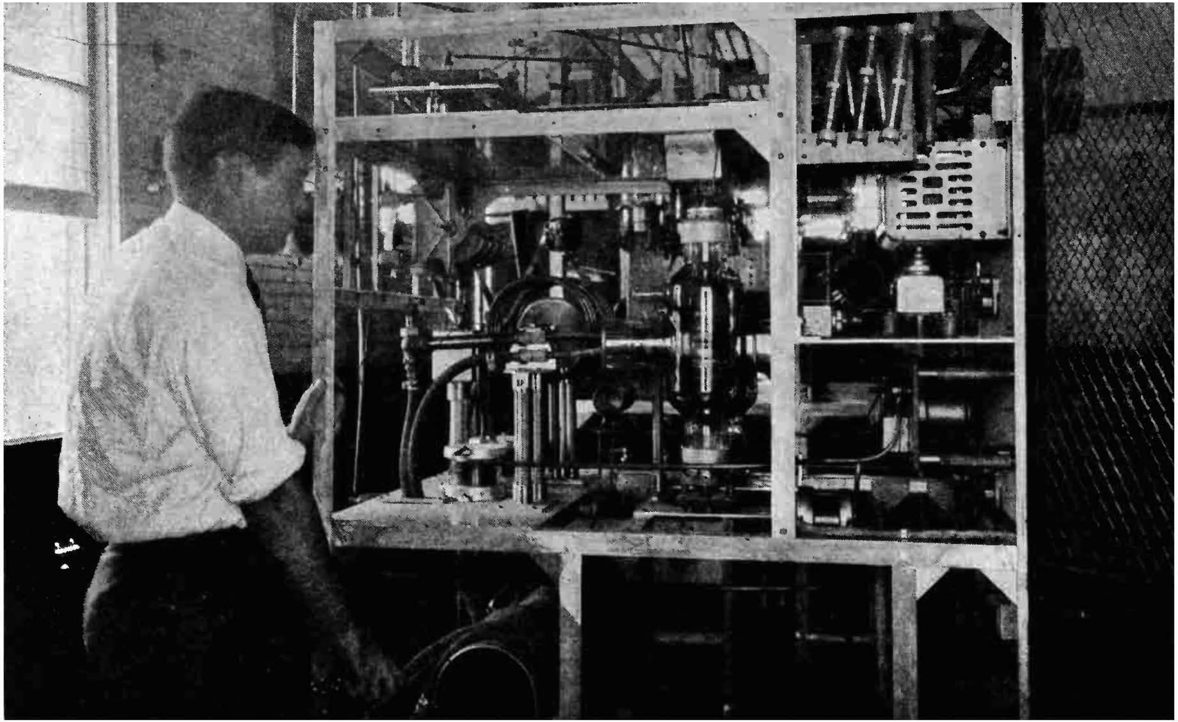


Fig. 76. A Filter Circuit Designed to Reject a Particular Frequency

to by-pass the current at that frequency. Conversely, if it is desired to select a particular frequency, the series-resonant circuit is in series with the line and a parallel-circuit resonant to that particular frequency serves to keep the current directed through the series circuit.



THE INTERMEDIATE LINEAR AMPLIFIER OF A SHORT-WAVE RADIO BROADCASTING STATION
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MODERN RADIO ESSENTIALS

CHAPTER IX

AMPLIFICATION

Amplification is the term applied to the result obtained by increasing the voltage or current—or both—through successive stages of oscillatory circuits, coupled circuits, filters, and vacuum tubes, which, combined, constitute a device called an *amplifier.*

Amplification. Amplification is accomplished by means of creating a gain of voltage or power. Voltage gain is obtained by means of *voltage amplifiers*; a gain in power is obtained by *power amplifiers.* Amplifiers are of two general classes, those for the amplification of radio frequencies—called *radio-frequency amplifiers*—and those for the amplification of voice frequencies—called *audio*

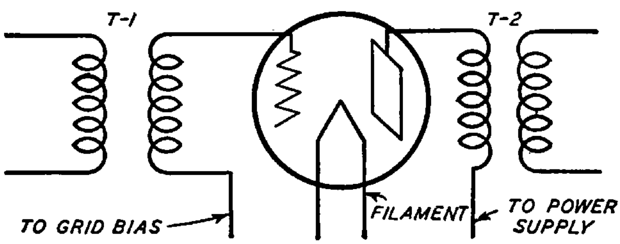


Fig. 77. An Amplifier Circuit

amplifiers. Voltage amplifiers or power amplifiers may be employed in either class of service, if desired, but since, in a radio-frequency amplifier, it is necessary to build up an extremely weak signal to one which has a high enough potential to cause an appreciable change in plate-current flow, the principle of voltage amplifiers is usually employed for the purpose. Voltage amplifiers are used to build up the grid potentials—and, as a consequence, create greater variations in the flow of plate current—in successive stages of an audio amplifier, using an increase in power to furnish the energy needed to actuate the sound creating devices.

Input Circuits—Output Circuits. A typical amplifier stage, shown in Fig. 77, consists of a transformer and a vacuum tube, and for purposes of illustration and more complete explanation the transformer for the succeeding stage is shown also. The *input circuit* is that which comprises the secondary winding of transformer *T-1*, feeding into the grid of the vacuum tube, and the necessary connections with the filament to complete the circuit. The *output circuit* of the stage is otherwise known as the plate circuit and consists of the primary windings of transformer *T-2*, connected from the plate of the vacuum tube to the source of energy—the power-supply unit—to complete the circuit.

The grid bias is a direct-current potential applied to the grid element of the tube. The *input signal* is the potential that is induced in the secondary winding of the transformer because of the variations in current flowing through the primary windings of transformer *T-1*.

The plate voltage is the direct-current potential supplied to the plate of the vacuum tube to attract the electrons emitted by the cathode. The plate current, also, has been described as the current which flows through the plate circuit under specific conditions of plate voltage and grid voltage. The *output signal* now is represented by the varying flow of plate current caused by the fluctuations of the voltage induced in the secondary of transformer *T-1*, and impressed upon the grid of the tube.

It is evident that as the alternating voltage applied to the grid of the tube is of greater amplitude, it will cause greater variations in the flow of plate current. Also, as the variation in the flow of plate current is increased a higher voltage will be induced in the secondary of the next transformer, which, in turn, will create still greater variations in the flow of current in the output circuit of the succeeding stage, and so on. Thus, by building up the amplitude of the input signal, the signal in the output circuit of each stage is amplified, and the amplitude of the input signal impressed upon the grid of the tube in each succeeding stage is increased proportionately.

Voltage Amplification. Voltage amplification is the ratio of the alternating-current voltage in the output circuit of an amplifier stage to the alternating current that is impressed upon the input circuit. Or, taking into account an amplifier, voltage amplification is the ratio between the alternating-current voltage at the output terminals of the amplifier to the alternating-current voltage that is impressed upon the input circuit of the amplifier.

Voltage Amplifiers. The ability of a vacuum tube to respond to minute changes in the value of the voltage applied to the grid element by causing corresponding and increased variations in the current flowing in the plate circuit has been explained. The measure of a tube's ability to amplify is the amplification factor; which is the ratio between the change in grid voltage to the change in plate potential required to cause a given variation in the flow of plate current.

In Fig. 77 there is a circuit containing (reading from left to right) a transformer, a vacuum tube, and another transformer. Assume that the primary of the first transformer, *T-1*, is connected to a source of direct current, suitably protected with resistance. There would be no action on the secondary side of the transformer, nor in either of the succeeding parts of the circuit. However, if an alternating or fluctuating current is impressed upon the circuit there is a rise and fall in the voltage—it must be understood that the average value, however, will remain constant—which changes create a magnetic field around the primary of transformer *T-1*, inducing a voltage in the secondary windings of the transformer.

If the transformer is of the iron-core type, such as used in audio circuits, there will be a voltage gain in the transformer itself, which gain will be in the order of the ratio existing between the number of turns in the primary and the number of turns in the secondary. If, on the other hand, the transformer is one used in radio-frequency circuits—the air-core type—there is little or no voltage gain in the transformer because of the losses due to flux leakage and loose coupling.

The voltage that is induced in the secondary winding of transformer *T-1*, changing in amplitude in accordance with the variations in the flow of current through the primary circuit, increases and decreases, alternately, the charge upon the grid of the vacuum tube. The rising and falling of the grid voltage cause a greater or less amount of current to flow through the output or plate circuit, amplified, however, according to the ability of the tube to cause changes in current flow with variations in the grid voltage. Hence, if the tube has an amplification factor of, say, six, the alternating component of the plate current will have an amplitude six times greater than that in the primary circuit of transformer *T-1*, theoretically speaking, but not practically.

What has happened in the amplifier stage illustrated and previously discussed will continue in the successive stages of the amplifier, building up the low alternating impulses until they are of sufficient amplitude to swing the grid enough to cause powerful changes in the flow of current in the plate circuit.

The voltage gain obtained in a radio-frequency transformer is negligible. However, a high-value inductance having a low ohmic resistance to the flow of direct current, used in place of the primary of transformer *T-2* in a radio-frequency amplifier, will have a high impedance to the flow of the varying current and will serve to cause a gain in the voltage through the coupling device. The inductance may be a choke coil—a universal, lateral wound, or honey-comb coil—having a large number of turns.

An inductance, while permitting the free flow of direct current —allowance being made for the ohmic resistance of the wire— effectively resists the flow of alternating, or fluctuating, current because of the counter electromotive force caused by the self-inductance of the coil. Hence, the coil having little, or negligible, effect upon the value of the positive charge upon the plate of the tube, acts as a resistance to the flow of the alternating component of the plate current, and establishes a potential difference across the terminals of the coil. This potential difference is induced into the secondary of the coupling device and may represent a substantial voltage gain.

The voltage amplification, or gain, obtained by means of a voltage amplifier is determined by the combined effect of the amplification factor of the tube, the plate resistance of the tube, and the load resistance of the output circuit. This condition is to be differentiated from that shown by taking into account only the static characteristics of the tube, from which the value of the amplification factor is obtained, and which would indicate that the input voltage in each succeeding stage of a voltage amplifier would be that of the previous stage multiplied by the amplification factor.

It has been shown that the plate impedance of the tube is a measure of the ratio of changes in plate voltage to the changes in the flow of plate current which cause the variations in potential. Due to the plate impedance, which is resistance to the flow of alternating current in the plate circuit, and which normally is of high ohmic value, the full advantage of the amplification factor cannot be taken.

The formula used for determining the voltage amplification is as follows:

$$E_{Amp}=\frac{Mu\times R_L}{R_L+R_p}$$

in which E_{Amp} is the voltage gain, Mu is the amplification factor of the tube, R_L is the plate-load resistance, and R_p is the alternating-current plate resistance—the opposition to the flow of alternating (or varying) current through the circuit. For example, in an amplifier stage using a tube that has an amplification factor of 10, an alternating-current plate resistance of 10,000 ohms, and in which the load resistance is 100,000 ohms, the voltage amplification obtained would be:

$$\frac{10\times 100{,}000}{100{,}000+10{,}000}=9.1$$

If the plate-load resistance is increased to 200,000 ohms, the voltage amplification would be:

$$\frac{10\times 200{,}000}{200{,}000+10{,}000}=9.5$$

showing that the gain increases, and approaches the amplification factor of the tube, as the resistance of the plate load is increased. The same condition would hold for impedance also. In fact, inductance is more popular than resistance in practice due to the fact that resistance, as resistance, reduces direct-current potential upon the plate in proportion to the value of the resistance, which necessitates the use of exceedingly high plate potentials. The inductance used in the plate circuit may be a choke coil, or it may be the primary of a transformer.

It is evident that the desirable objective in a voltage amplifier is to build up the voltage through successive stages without regard for power gain—power as measured in watts (volts times amperes). Actually, the resulting power as measured in the output circuit of a voltage amplifier stage may be less than that in the input circuit, due to low-current flow.

Power Amplifiers. When an increase in the strength of a signal is accomplished by an actual increase in the power as measured in watts (volts times amperes) such increase is said to be an amplification of power, as differentiated from the amplification of voltage. The purpose of power amplifiers is to develop sufficient dynamic energy to drive mechanical devices that create disturbances of the air to form sound waves.

Power amplifiers, unlike voltage amplifiers, usually require a high flow of plate current. The voltage gain, on the other hand, is low, and often negligible, in the power stage. The voltage amplifier has presumably served its purpose in building up the voltage so that the amplitude of the signal impressed upon the grid of the power tube is sufficient to cause an appreciable swing of the grid to create a corresponding variation in the plate current flow.

The amplification factor of vacuum tubes used to produce power is low, in the order of 3 to 3.5, as compared with 8 to 1,500 or more for tubes designed to be used in voltage amplifiers.

Distortion. Distortion is the term applied to any sort of variation between the original signal and the amplified signal. It may be caused in any one or more of several ways—in fact, it may be introduced into the circuit purposely—but in any event it represents a departure of the resultant flow of electrical energy, in the amplitude of either the voltage or the current at given frequencies, from that which is impressed upon the input circuits.

Distortion may exist in a circuit, yet may not be aurally perceptible. In fact, there are few—if any—amplifiers which transfer the energy through successive stages so faithfully that there is no measurable difference between the characteristics of the input signal and the output signal. However, the human ear is unable to detect such distortion until it becomes pronounced—a relatively high percentage of change in signal characteristics.

Tube Distortion. A great deal of amplifier distortion is due to the vacuum tubes—not because of improper design of the tubes, but because of the application of improper potentials to the various elements. It has been shown how the value of the current flowing in the plate circuit depends upon the potential applied to the grid, and how by introducing an alternating current to the input circuit of the tube, the potential on the grid changes during the cycle, adding to the negative bias during the period that the alternating current is flowing through the negative alternation, and subtracting from the value of the grid bias during the positive alternation.

Fig. 78 shows a typical example of the phenomenon, in which, from all practical standpoints, there is no distortion. The curved heavy line represents the grid-voltage plate-current characteristic curve, showing little flow of current when the charge on the grid is highly negative, rising as the charge on the grid approaches zero. The vertical line *O* indicates zero grid potential, negative to the left, and positive to the right. Note that the curve rising very gradually and slowly at first makes an abrupt rise when the grid is at about 4.5 volts negative, and has become practically straight at 4.0 volts. If now a negative potential of 3.0 volts is applied to the grid and an alternating current having a constant amplitude at 1.0 volt is introduced into the input circuit, the charge on the grid will swing from

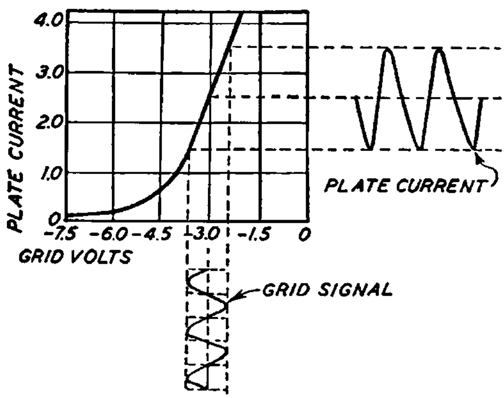


Fig. 78. Showing Type of Signal Produced When Tube Is Operated on Straight Portion of Characteristic Curve

3.5 volts negative to 2.5 volts negative. The *sine* curve between the vertical lines at the bottom of the illustration indicates the swing of the alternating current. Since a bias of 3.5 volts on the grid causes a certain amount of plate current to flow—1.5 milliamperes—and a bias of 2.5 volts on the grid causes a greater amount of plate current to flow—3.5 milliamperes—it is evident that the variations in the potential on the grid will cause a fluctuation in the flow of current in the plate circuit as shown by the *sine* curve at the right.

Suppose now that the grid is at 4.0 volts negative, and that an alternating current having a constant amplitude at 1.0 volt is introduced into the input circuit, see Fig. 79. The grid swings from 4.5 volts negative to 3.5 volts negative, as shown by the curve below the horizontal line. But the plate-current changes caused by varying the grid voltage from 4.5 to 3.5 volts are greatly different from those caused by changing the grid potential from 3.5 to 2.5 volts negative as in the previous example. Here, the alternating component will not correspond to the input voltages, but will follow the path as shown at the right, the alternations below the line being very much lower in amplitude than those above the line. This variation will cause a distorted signal, and demonstrate that in order to deliver an undistorted signal it is necessary that the tube be operated on the

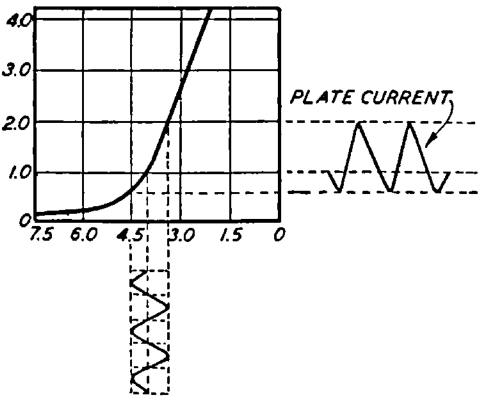


Fig. 79. Curves Showing Result of Charging the Grid Bias

straight portion of the grid-voltage plate-current curve, except as shown in the next and in later paragraphs.

Assume again that a negative bias of 1.0 volt is applied to the grid and that an alternating current of constant amplitude at 2.5 volts is impressed upon the input circuit. This means that when the impressed alternating current is positive, the grid will be at one-fourth volt positive, (−1.0 less one-half of 2.5), in which case, it, too, will attract the electrons emitted by the cathode, causing current to flow in the grid circuit as well as in the plate circuit. Hence, the relationship existing between the grid voltages and the plate currents will be as represented in Fig. 80, and the current flowing in the plate circuit will not be a reproduction of the input signal, but a representation of the static characteristics of the tube under the conditions described.

We have considered only those alternating potentials on the grid which are of constant amplitude. If they were of varying amplitude—as caused by the variations in speech and music—the effect would be very pronounced in that some of the sounds would be over-exaggerated and others would be under-emphasized, while a few, within a given range would not be changed.

Overloading. A tube is said to be overloaded when the applied alternating voltages drive the grid bias so far negative that the tube

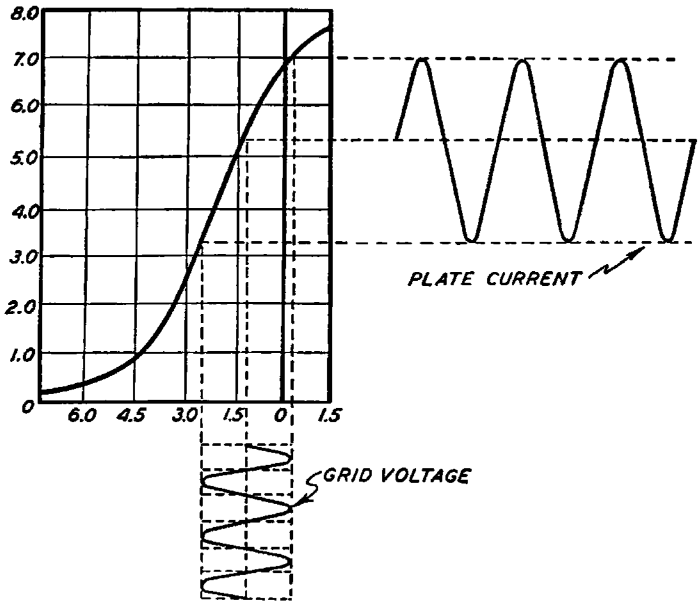


Fig. 80. Result of Operating a Tube Without Enough Negative Grid Bias

is forced to operate on the curved portion of the grid-voltage plate-current curve, or when the grid is driven positive. Unless the amount of energy supplied to the grid is too great, lowering of the normal grid bias—making it less negative—will place the alternating component swing on the straight portion of the curve and correct the difficulty, if the tube is forced to operate on the curved portion of the grid-voltage plate-current curve. Similarly, if the alternating current drives the grid positive, increasing the grid bias will rectify the abnormal condition. Naturally, however, if the energy that is applied to the grid drives the grid potential too highly negative, and at the same time drives the grid positive with the next alternation, the only alternative is to reduce the amplitude of the alternating current applied to the grid or to increase the plate potential.

Types of Amplification. Engineers recognize three distinct types of amplifiers, known as and referred to universally as *Class A*, *Class B*, and *Class C*. The differentiation lies principally in the relationship between input voltages and plate-current flow, and the resulting wave form. The selection of the type of amplifier to be used depends on the results which the engineer wishes to attain.

Class A Amplifier. When the grid of an amplifier tube is biased so that the alternating voltage impressed upon the input circuit will swing the grid voltage within such limits as will neither force the tube to operate on the curved portion of the grid-voltage plate-current characteristic curve nor cause it to become positive, the plate-current wave form is substantially identical with the input-voltage wave form, as shown in Fig. 78. Such an amplifier—known as a *Class A Amplifier*—is characterized as having low efficiency and output with a high ratio of power amplification. Reference to Fig. 78 will show that plate current flows in the output circuit at all times.

Class B Amplifier. A *Class B Amplifier* is one in which the grid is biased so that with no excitation upon the grid there is practically no flow of plate current. When the alternating current is applied to the grid of the tube, plate current will flow during the positive half of the cycle. Then during the alternation when the excitation current is negative, there is practically no current flow in the plate circuit. An ideal Class B amplifier would be one in which there is *no* current flow during the negative alternation—complete cut-off—or current flow during 180 electrical degrees of the cycle. Class B amplifiers are characterized as having medium efficiency and output with a relatively low ratio of power amplification.

Class C Amplifier. A *Class C Amplifier* is one in which the grid is biased considerably beyond the cut-off so that plate current flows through less than 180 electrical degrees of the cycle. The use of a Class C amplifier permits the use of exceedingly high alternating-current potentials on the grid, thus passing plate current of high amplitude during a portion of the positive alternation of the grid-excitation voltage. Class C amplifiers are characterized as having high plate-circuit efficiency and output with relatively low ratio of power amplification.

Class A Prime Amplifiers. A *Class A Prime Amplifier,* otherwise known as a *Class AB Amplifier,* is one in which plate current flows through substantially more than 180 electrical degrees of the cycle, but less than 360 electrical degrees as in the *Class A Amplifier.* Hence, it will be seen that the tube in a Class A prime amplifier will be biased so that a portion of the negative half of the cycle will swing the grid past cut-off and that during that part of the cycle no plate current will flow. A Class A prime amplifier has characteristics midway between a Class A amplifier and a Class B amplifier.

Class BC Amplifier. A *Class BC Amplifier* is one in which the grid is biased so that plate current flows during less than 180 electrical degress of the alternating-current cycle, but over a greater portion of the cycle than in a Class C amplifier. The characteristics are intermediate to a Class B amplifier and a Class C amplifier.

There is no distinct line of demarcation between the classes of amplification. In fact, it can be seen very readily that a Class A amplifier may be changed slightly and become a Class AB amplifier, or even a Class B amplifier. The vacuum tube may be the key to the type of amplification employed, and an amplifier may operate as a Class A amplifier with one type of tube, but by substituting another tube, especially designed to shift the operating characteristics, the amplifier may fall into Class AB or Class B classifications.

Therefore, if it is remembered that plate current flows in the output circuit in amplifiers, as follows:

Class A —through 360 electrical degrees of the cycle
Class AB—through more than 180 electrical degrees, but less than 360 electrical degrees of the cycle
Class B —(theoretically) through 180 electrical degrees of the cycle
Class BC—through little less than 180 electrical degrees of the cycle
Class C —through appreciably less than 180 electrical degrees of the cycle

the distinguishing characteristics may be kept well in mind, and the classification of any amplifier may be determined by analyzing the grid-voltage plate-current characteristics of the tube used in the circuit, together with the operating potentials on the grid and on the plate.

A Class A amplifier may be used either as a voltage amplifier or as a power amplifier, the differentiation being determined by the tube used and the constants of the circuit. If the tube is one having a high-amplification factor feeding into a high-resistance load, it will serve to amplify the alternating voltage impressed on the input circuit of the succeeding stage. On the other hand, if the tube has a low-amplification factor—such as power tubes have—and feeds into a relatively low-load resistance—as required in output circuits—it will develop appreciable power to drive the mechanical sound creating devices. The tubes which operate in voltage amplifiers draw little plate current from the power-supply device, and the output power of a voltage-amplifier stage may even be less than the input power—measured in watts.

A Class A amplifier may also be used as a voltage amplifier to drive an output-power stage using Class B amplification. In view of the fact that low distortion is one of the characteristics of Class A amplifiers, it is evident that the wave form of the alternating voltage impressed upon the grid or grids of the tube or tubes in the output or power stage will be substantially identical with the wave form of the originating signal, and, therefore, the distortion at the output terminals will be low. Such a combination provides a means to develop higher power in the output, because of the increased power efficiency of Class B amplifiers. The power-output circuit may be designed so that the distortion occurring in the output stage will not exceed the permissible 5 per cent.

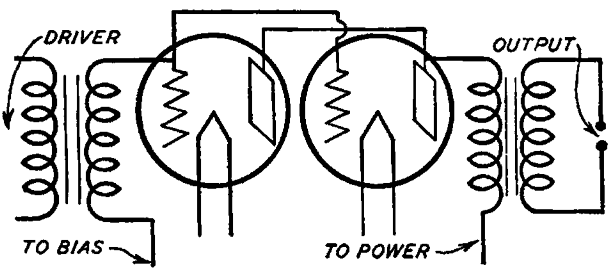


Fig. 81. A Plate Circuit Using Two Power Tubes in Parallel

A Class A amplifier is the only classification of amplifiers that permits the use of a single tube in the power stage without perceptible distortion. However, the power available may be increased considerably by using tubes connected in parallel or in push-pull.

Fig. 81 shows two triodes connected in parallel in a power stage. Twice the output may be obtained from such a parallel connection with no increase in the input voltage over that required for a single tube. The plate current will be that of two tubes. A push-pull stage shown in Fig. 82 will likewise develop twice the power of a

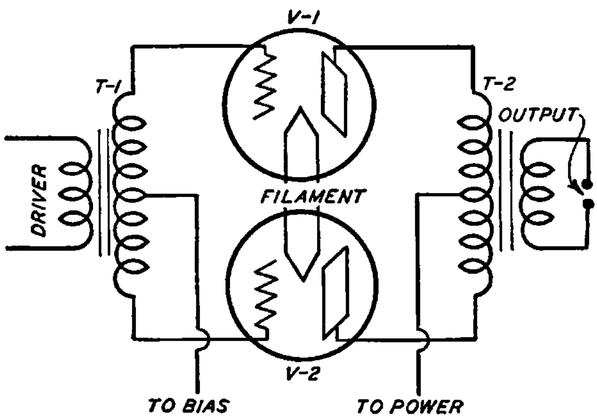


Fig. 82. A Push-Pull Amplifier Stage

single tube, but requires twice the signal input voltage of one tube. The push-pull circuit has advantages over either single-tube or parallel-tube operation particularly in the elimination of distortion due to even-order harmonics, and the cancellation of hum due to plate-voltage-supply fluctuations.

A Class B amplifier is used where large power output is required. In view of the fact that a relatively low plate current flows with no excitation on the grid, a signal of sufficient magnitude will cause an output wave which is very small during the negative half of the cycle and high during the positive half of the cycle. Thus, it is advisable—and in fact essential—to use a push-pull output stage to minimize distortion, and it is essential, too, that the push-pull stage be well-balanced.

The transformer connecting the driver stage and the Class B output-power stage is usually of the step-down type, ranging between a ratio of 1.5 to 1 and 5.5 to 1. The design of the transformer and the step-down ratio are dependent upon the type of the tube in the driving stage, the type of tube used in the power stage, the load on the power tube, the permissible distortion, and the efficiency of the transformer.

It is very evident that so far as circuit design is concerned, the principles are identical in all classes of amplification. The difference lies in the constants of the circuits and in the type of tubes used. All classes of amplification may be adapted to resistance-coupled amplifiers, impedance-coupled amplifiers, transformer-coupled amplifiers, or any circuit that may be selected. The fundamental idea is that first the alternating voltage must be built up to cause a substantial swing of the grid bias in order to create maximum fluctuations in plate-current flow. The load resistance through the voltage-amplifier circuits must be high in order to provide a high-voltage drop—and a consequent high difference of potential across the load—for transference to the succeeding stage. Tubes having a high-amplification factor are desirable in order to obtain the maximum variation of plate current with relatively small changes in the grid potential. The power is developed in the final stage which feeds the sound producing devices, using additional current obtained from an external source of electrical energy.

Power-Output Calculations. Power is measured in watts, and is a function of voltage and current—watts equals volts times amperes ($W = EI$). Calculations of the power output of amplifiers, while not accurate, give results that are not seriously in error and serve to give a basis for practical computations.

The manufacturers of tubes usually furnish charts showing all characteristics of their products, among which is one which shows the relationship that exists between plate current and plate voltage with different grid bias—called the plate family of curves.

Let us assume that an output tube feeds into a load resistance of 4,000 ohms; that it is drawing 40 milliamperes of current with 250 volts on the plate and a negative grid bias of 45 volts. In Fig. 83 there is shown a plate family of curves—hypothetical for purposes of illustration. The lower horizontal line is the zero-current axis. The vertical line on the left is the zero-voltage axis. The plate voltages are indicated along the zero-current axis and the plate current is indicated along the zero-voltage axis. We shall say that the tube cuts off at 10 milliamperes—the minimum current at which it will develop measurable power.

From the point on the zero-current axis indicating the plate voltage at which the tube is operating, 250 volts, a line is drawn to a point on the zero-voltage axis, determined by dividing the plate voltage by the value of the load resistance, in this case $250 \div 4{,}000 = .0625$, or 62.5 milliamperes. This line BB', serves as the base.

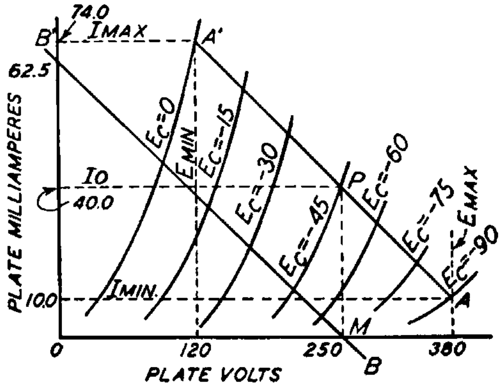


Fig. 83. A Group of Plate-Voltage Plate-Current Curves Obtained with Different Grid-Bias Voltages

The tube, it has been stated is drawing 40 milliamperes at 250 volts on the plate. Therefore, at the intersection of the dotted lines indicating the two values (40 milliamperes and 250 volts) is point P. The grid-voltage curve for a negative bias of 45 volts intersects at the same point. If now a line is drawn parallel with BB' through point P, the necessary factors to make the calculation may be determined. The formula to determine the power output for triodes is:

$$\text{Power Output} = \frac{(I\ \text{max} - I\ \text{min}) \times (E\ \text{max} - E\ \text{min})}{8}$$

The maximum current flow at any point along the line AA' will be at the intersection of the line with the curve indicating zero grid bias—in this case 74 milliamperes at 120 volts. The minimum current flow has been given as 10 milliamperes which is intersected by the line AA' at 380 volts. Substituting the values as found in the foregoing formula:

$$\text{Power Output} = \frac{(74-10) \times (380-120)}{8} = 2080$$

milliwatts or 2.08 watts.

It is also possible to determine the percentage of second harmonic distortion from the values given in Fig. 83 using the following formula:

$$\text{Per cent Second Harmonic Distortion} = \frac{\frac{I\ \text{max} + I\ \text{min}}{2} - I_o}{I\ \text{max} - I\ \text{min}} \times 100$$

Substituting,

$$\frac{\frac{.074 + .010}{2} - .040}{.074 - .010} \times 100 = 3.1\%$$

The value of the load resistance should be such that the distortion shall not exceed 5 per cent, and may be determined more accurately by experiment from the results of the foregoing calculation. Ordinarily the plate-load resistance will be approximately twice the value of the plate resistance.

Frequency Response. An audio-frequency amplifier should be designed to pass as efficiently as possible a relatively wide range of audible frequencies. Otherwise, the reproduction will be greatly distorted and lacking in quality—timbre and overtones.

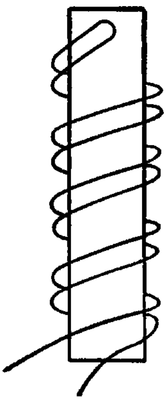


Fig. 84. A Non-Inductive Wire-Wound Resistance

The most efficient amplifier from the standpoint of frequency response is that using resistance coupling—a resistance-coupled amplifier. However, in order for a resistance-coupled amplifier to be the most efficient, it is necessary to use non-inductive resistances—carbon or special non-inductive wire-wound units. A non-inductive wire-wound resistance is made as shown in Fig. 84, the resistance wire doubled back to counterbalance any inductive effect that might be produced. Similarly, the capacitance used should be of the non-inductive type.

The essentials of a resistance-coupled amplifier are shown in Fig. 85. The resistance in the plate circuit, the value of which may be determined with relative accuracy by applying the formula for determining voltage amplification, causes a varying voltage drop across the resistance with each change in the flow of current in the plate circuit. The variations in potential are conveyed to the input circuit of the following stage through the coupling condenser which may vary between values of .1 microfarad and .006 microfarads, usually. (The condenser serves also to insulate the grid, blocking off the plate voltage.) The selection of the value of the condenser depends upon whether it is desired to oppose the flow of low-frequency impulses or high-frequency signals. A con-

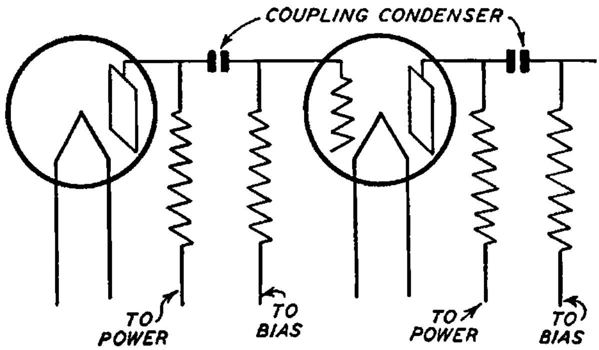


Fig. 85. A Resistance Coupled Amplifier

denser of small capacity will not oppose the flow of currents at high frequency as much as it will oppose the flow of current at low frequency. Conversely, a condenser of large capacity will permit the low frequencies to pass more readily than a condenser of small capacity.

The determination of the value of the resistance for use in the input circuit is usually a matter for experiment. In any event, it is relatively high, in the order of one-half megohm to two megohms according to the type of the tube and the design of the circuit. Instability will likely result if the resistance is too high, and if the resistance is too low the gain will be low also.

A properly designed resistance-coupled amplifier—with resistances of correct value in the output circuit and in the input circuit and the proper capacity of blocking condenser—will be characterized by highly efficient-frequency response, low distortion, and relatively low gain, the last-named characteristic being due to the inadvisability of using too high resistance in the plate circuit, thereby reducing the voltage on the plate.

The principles governing oscillatory circuits as previously explained pertain to circuits carrying audio frequencies as well as those through which radio frequencies are passing. Hence, the relationship that exists between the inductive and capacitive values in an audio circuit is a limiting factor in the ability of the amplifier to transfer from one stage to another the electrical interpretations of the sound variations.

It has been shown in the discussion of filters that a parallel circuit containing inductances and capacity will constitute a high resistance to the flow of alternating current at the resonant frequency of the circuit. Hence, if a circuit is tuned to resonance at, say, 1000 cycles, the flow of current at that frequency will be very low, and a curve representing the frequency response of the amplifier would show an appreciable drop at that particular point on the curve, which drop in current flow would be represented by a corresponding gain in amplification, due to a greater voltage drop across the coupling devices.

Various methods are developed to overcome the resonant effect in audio amplifiers. They are explained in detail in articles appearing from time to time in the technical publications, and with the proper understanding of the principles embodied in oscillatory circuits, coupled circuits, and filters the import of the developments may be analyzed readily.

There are two methods in common use for determining the frequency response of an amplifier. First, a signal of known characteristics is impressed upon the input circuits of the amplifier and measured with an output meter at the output terminals of the amplifier. Such a method requires a signal generator of the type known as an audio oscillator which may be tuned to deliver currents of various frequencies. The ratio between the input signal and the output signal may be recorded on a curve or graph from which it may be determined how faithfully the amplifier is transferring the energy at given audio frequencies. The second method is that which requires the use of the reproducing device delivering sound to a microphone that is connected to a recording unit, the characteristics of which have been checked. The former method, giving as it does the characteristics of the amplifier itself, enables the engineer to design a reproducer that will flatten out the curve—drop its response where the amplifier shows high gain, and increase its response where the amplifier gain is low—and adjust the overall performance. The second method gives an immediate true (as true as the variables in circuit design will permit) picture of the action of the amplifier and the sound creating devices.

Tone Control. In order to compensate for the likes and the dislikes of the users of radio and its allied accessories, such as amplifiers, the engineers have developed means to control the tone delivered by the amplifier and the reproducer. A tone control serves to change the constants of the circuit in such a way that the higher frequencies may be either emphasized or eliminated, or the lower frequencies may be accentuated or reduced.

Engineers and acousticians have learned that the human ear is extremely erratic in its functioning. It has been found that there are hardly two persons whose hearing is identical—therefore, it is logical that their tastes will differ in the matter of tonal response.

There are various methods for controlling the tone of an amplifier, any of which constitutes deliberate introduction of distortion into the circuit. Usually, however, it consists of a variable resistance and condenser—in series—placed in parallel with the primary or the secondary of the first audio transformer. The variation of the value of the resistance changes the constants of the circuit, and effectively either shifts the frequency response of the circuit up or down, or it cuts off the high or the low frequencies. A tone control may also consist of a network of condensers of varying capacity shunted across an inductance providing a means to change the resonant period of the circuit.

Push-Pull Amplification. Mention has been made of push-pull stages of amplification, and it is deemed advisable to describe briefly the principle upon which it functions.

A push-pull stage requires the use of two vacuum tubes—or a single tube designed with multi-electrodes to be used in place of the two tubes—and transformers of special design for both the input and the output circuits. Fig. 82 shows a stage of push-pull amplification in which transformer *T-1* consists of a primary winding and a center-tapped secondary; transformer *T-2* consists of a center-tapped primary and a secondary to feed the reproducing devices. Note that each of the outer terminals of the secondary winding of transformer *T-1* is connected to the grid of a vacuum tube, and that each of the outer terminals of the primary winding of transformer *T-2* is connected to the plate of the vacuum tubes. The grid bias for the tubes is provided through the center-tap of the secondary winding of *T-1*; the plate voltage is applied to the plates of the tubes through the center-tap of the primary of *T-2*.

As voltage is induced into the input circuit of the stage, let us say, for example, that the terminal at the top of the transformer *T-1* is positive, which would mean that the polarity at the lower terminal is negative. Thus, the bias on the grid of tube *V-1* would be made more positive, while the bias on the grid of tube *V-2* would be made more negative. As shown in previous paragraphs, more plate current would flow through the plate circuit of tube *V-1*, and less plate current would flow through the plate circuit of tube *V-2*.

As the alternating voltage swings, the upper terminal of transformer *T-1* becomes negative and the lower terminal becomes positive. Here now the grid of tube *V-1* is more negative, causing less plate-current flow, and the grid of tube *V-2* is less negative causing greater plate-current flow. The action of alternately pushing current through the primary of transformer *T-2* gave rise to the term "push-pull," which is literally true in amplifiers in which the grid of the tube is made positive with the positive alternation of the grid swing, causing it to actually pull while the other tube is pushing.

A push-pull stage of amplification acts in much the same manner as a full-wave rectifier in Class B amplifiers, correcting discrepancies that occur as a result of the large changes in grid voltage, and delivers to the output terminals of the amplifier an impulse that is of relatively low distortion.

Uses of Amplification. The discussion of amplification has been taken up in a general way. In the succeeding pages applications of the principles explained in this chapter will be discussed. It will be shown how the radio signals are amplified through radio-frequency amplifiers, through intermediate amplifiers, and through audio amplifiers. Regardless of the application of the principle of amplification, fundamentally an amplifier stage receives an impressed signal in its input circuit and amplifies either the voltage or the current—or both—and delivers to the succeeding stage or circuit a signal that has the characteristics necessary to meet the requirements of the design.

The selection of the classification of amplifier is at the discretion of the engineer who designs the circuit, as is the type of tube to be used, and the constants of the circuit. If low distortion is desired, it is logical, as shown in the preceding paragraphs, to employ a Class A amplifier. If it is desired to secure high voltage gain, tubes having a high amplification factor feeding into high resistance loads would be the normal selection. If greater power is required, and it can be obtained without introducing a too high percentage of distortion, a Class B amplifier may be used. In any event, the design of the circuit and the selection of the constants are determined by the use to be made of the device, and the purpose it is to serve.

A PENTAGRID CONVERTER METAL TUBE DEVELOPED IN THE LABORATORIES OF THE GENERAL ELECTRIC COMPANY AND PRODUCED BY THE RCA MANUFACTURING COMPANY

Courtesy of RCA Manufacturing Company

MODERN RADIO ESSENTIALS

CHAPTER X

SOURCE OF RADIO SIGNALS

In order to explain the principles involved in the reception of radio, and the conversion of radio signals into perceptible sound, it is necessary to sketch the manner in which the signals are produced. To do so involves a discussion of three electrical functions—microphones and their operation, oscillators, and modulation.

Microphones. A microphone is a device by means of which the varying pressure caused by sound vibrations is converted into electrical impulses of varying amplitude. The resultant electric wave form is essentially identical with the acoustic wave form—that of sound.

The earlier type of microphone, known as a carbon, or carbon-button microphone, consisted of a small cylinder filled with carbon granules and was connected to a diaphragm in such a way that as the diaphragm vibrated in accordance with the changes in sound pressure the carbon granules were compressed with greater or less pressure. The variation of the compression of the carbon granules increased and decreased the amount of resistance to the flow of electric current in the circuit. The increase and decrease of the resistance in the circuit causes corresponding changes in the amount of current flowing through the circuit, which changes are induced into coupled circuits, and amplified through the succeeding stages in accordance with the requirements.

Later types of carbon microphones employed two of the cylinder-containing carbon granules, one on each side of the diaphragm, so that as the pressure was decreased on one side of the circuit, it was increased on the other, and, as a result, variations of greater amplitude were obtained.

Whereas, the carbon microphones effect variations in the amount of resistance in the circuit, similar results may be obtained by changing the capacity, the inductance, or a magnetic field. Regardless of the method employed, the purpose of the microphone is to convert the sound pressures into electrical impulses of varying amplitude.

It must be understood that the diaphragm of the microphone responds to each sound individually, and that it actually vibrates backward and forward a given number of times per second, depending upon the pitch of the sound. In other words, the diaphragm of the microphone does more than to merely press inward as the sound pressure strikes it, and then return to its normal position as the air is rarefied. If the latter condition existed, any sound impressed upon the microphone would cause the same change in current flow as any other sound at the same pressure. So, if a sound caused by 500 vibrations per second is produced, the diaphragm vibrates 500 times a second, thereby increasing—and then decreasing—the resistance in the circuit 500 times each second, there being 500 condensations and 500 rarefactions of the air per second to cause a 500-cycle sound.

When a complexity of sounds is impressed upon the microphone diaphragm at the same time, the resulting vibration period is that caused by the given combination. For instance, if a note is struck on a piano at the same time that another tone is made by a saxophone, and another by a violin, the electrical impulse at any given instant will be that caused by the combination of the three tones, and can be no other. In view of the fact that the nature of the vibrations varies with different instruments, it is possible to distinguish readily between the various instruments or sounds.

Oscillators. It has been shown that a circuit which contains inductance and capacitance is an oscillatory circuit; that the condenser first stores the electrical energy on one of its plates, and then, due to the difference in electrical pressure gives up its energy; that the flow of the current through the inductance causes the static charge to change to a magnetic field; and that the counter electromotive force causes the magnetic field to collapse and force the current through the circuit to the other plate of the condenser, and so on many times per second. Also, it has been shown how electrical energy is transferred from one circuit to another by means of coupling. By coupling oscillatory circuits in combination with a vacuum tube, a device capable of amplifying and maintaining the flow of alternating current at high frequencies is formed, which device or circuit is known as an *oscillator*.

It appears that the discovery of the ability of a vacuum tube to amplify and sustain oscillations was discovered about 1914, and the fundamental circuits developed at that time are essentially identical with those of oscillating circuits.

A typical oscillator is shown in Fig. 86. With the application of proper operating voltages, alternating current will surge back and forth through the circuits at a frequency as determined by the relationship that exists between the inductance and the capacity of the circuit. In other words, the frequency at which the circuit oscillates will be the resonant frequency of the circuit as determined by the inductive and capacitive reactances.

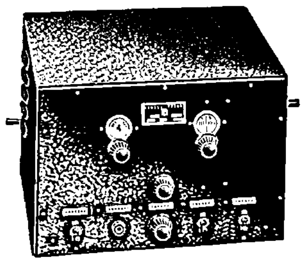


Fig. 86. A Radio Oscillator
Courtesy of Clough-Brengle Company

Starting of Oscillations. In the circuit shown in Fig. 87, closing the switch K in the filament circuit causes the filament element to become heated and electrons fill the glass envelope. However, so long as the plate circuit is open—no potential applied to the plate element—no current will flow in the output circuit. After the filament has become thoroughly heated and is emitting a full stream of electrons, the closing of the plate circuit causes a current to flow through the entire circuit including the inductance L-4. As the current builds up in the circuit, the magnetic flux around coil L-4 varies so that a voltage is induced in coil L-1 to which coil L-4 is coupled. The induced voltage is impressed upon the plate of condenser C and the windings of coil L-2—the coils L-1 and L-2 together with condenser C constitute an oscillatory circuit. Again there is a transfer of energy from the oscillatory circuit to the input circuit of the tube by means of the coupling between coil L-2 and L-3. The variations cause a swing of the grid voltage, thereby changing the value of the plate current, and an amplified signal of varying characteristics passes through the plate circuit to inductance L-4. The frequency of the alternations is determined in the oscillatory circuit and will be that as represented by the resonant period of the circuit caused by the relationship between the inductive and capacitive reactances.

It is not intended that the foregoing explanation of the process involved in starting oscillations requires that the filament must be turned on first and that the plate potential be applied later. However, such is the customary procedure in transmitting circuits, but in the circuits used for reception of radio signals all potentials are

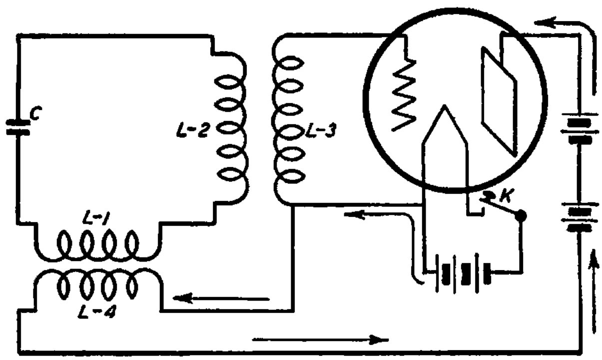


Fig. 87. Diagram of an Oscillator Circuit

applied simultaneously. In the latter case oscillation may be started in any one of a number of ways, in any event a flow of current that causes a transfer of energy from the plate circuit back to the grid circuit. Oscillation will continue so long as the potentials as required are applied to the tube elements, and provided there is sufficient coupling between the plate and grid circuits to permit a transfer of energy to sustain oscillation.

Radio-Frequency and Audio-Frequency Oscillators. An oscillator may generate alternating current at radio frequencies or audio frequencies, depending upon the constants of the circuits. The radio-frequency oscillator is a necessary part of a transmitter circuit, and delivers the high-frequency alternating current that constitutes the carrier wave cast off by the radio-station antenna. The audio-frequency oscillator is used largely in laboratories for experimental and test purposes. It is the radio-frequency oscillator then with which we are concerned in this treatise.

Carrier Wave. The *carrier wave* is the train of oscillations—high-frequency alternating current—sent into the air from the antenna of a transmitting station. It has voltage and current characteristics identical with those of any alternating current and its frequency is that at which the oscillatory circuit of the transmitter is resonant. The carrier has only one frequency, even though the resonant curve will show an increase in current flow at frequencies adjacent to the resonant frequency. Thus, a broadcasting station operating on 800 kilocycles transmits a carrier of 800,000 cycles, only.

The carrier wave virtually acts as a conductor over which the radio signals are made to pass. It, being a succession of high-frequency alternations, sets in motion the electrically charged particles in space and with the speed of light, the wave—or its effect—travels in all directions from the antenna of the transmitter.

The carrier has no dimensions when the frequency of the alternations is taken into account. In other words, if the carrier is 800 kilocycles, the current is alternating 800,000 times each second, and the wave is traveling through space at the approximate speed of 186,000 miles each second. If the carrier is 800 kilocycles, it cannot be considered to be from 799 to 801 kilocycles, or from 799,900 cycles to 800,100 cycles. It is 800,000 cycles, in exactly the same way that 60-cycle alternating current reverses its direction of flow 60 times each second—not 59 or 61 times a second.

However, it has never been found possible to design a circuit in which the carrier will maintain a constant frequency; there is bound to be a certain amount of shifting. By the use of crystals—the principal one of which is quartz—which generate a piezo-electric effect, the frequency of radio transmitters has been stabilized greatly. Then, due to the effect of temperature and other atmospheric conditions on the frequency with which the crystal oscillates naturally, temperature controls have been developed to maintain a temperature that varies only a fraction of a degree, and therefore, prevents a shifting of the oscillation period of the crystal. As a result of this development, the shift of the carrier frequency has been reduced to negligible limits. Still, however, the carrier cannot be said to have dimensions, because—taking again the 800,000-cycle example—if the frequency shifts to 800,050 cycles, the station is transmitting an 800,050-cycle carrier, which again has no width.

But, *a carrier does have amplitude,* a measure of the effect of voltage and current. The variation of the amplitude of the carrier through a process called *modulation* gives to the carrier the varying elements that make possible the reception of radio programs and the transposition of the radio signals into perceptible sounds.

Modulation. Modulation is the process by means of which the frequency or amplitude of a wave is varied according to the fluctuations of a signal wave.

It has been shown that the microphone serves to cause variations in the flow of current through the circuit of which it is a part in accordance with the changes in pressure against its diaphragm as created by sound waves in speech or other sounds. It has been shown, also, how an oscillator sustains the flow of a high-frequency alternating current which passes from the antenna of a transmitting station as the carrier wave.

If the carrier wave alone were transmitted, a receiving set when tuned to the carrier would deliver no sound, and as each successive carrier were passed, as in tuning a receiving set, there would be a sort of "click" similar to that obtained by closing any electric circuit.

On the other hand, if the changes in the flow of current caused by the changes in the microphone circuit are impressed upon the carrier frequency, the amplitude of the carrier is caused to vary, which variations are later translated into perceptible sounds that correspond to the variations in the microphone current.

Due to the process of modulation the band of frequencies required to transmit sound is caused to assume measurable proportions. There is a divergence of opinion among engineers concerning what actually takes place, but the most popular theory is that known as the *side-band theory,* which means that the channel required for the transmission of sound is twice the width of the frequency of the sound impulse being transmitted. Thus, if a 1,000-cycle tone is impressed upon a carrier of 800,000 cycles (800 kilocycles) the channel occupied by the modulated wave would be 799,000 cycles to 801,000 cycles, 1,000 cycles on each side of the carrier. Or, if a tone of 2,400 cycles were impressed upon the carrier, the channel would be 4,800 cycles wide. This is a frequency of 2,400 cycles on each side of the carrier frequency which necessitates radio broadcasting stations being separated 10,000 cycles apart.

As a result of the foregoing phenomenon, there is created a condition as represented by the illustration in Fig. 88. At *A* there is shown a representation of a carrier wave in which the pulsations are of equal amplitude. At *B* there is indicated the fluctuating current caused by the variations of sound pressure against the diaphragm of the microphone and the consequent increases and decreases in the

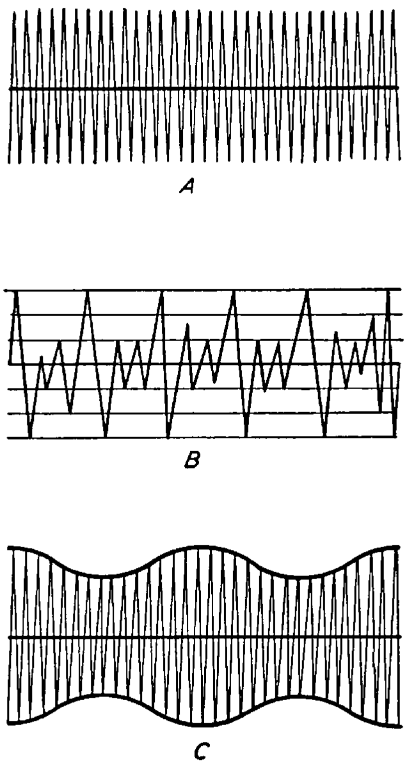


Fig. 88. Diagram Showing the Result of Microphone Current Acting on the Carrier Wave

value of the resistance in the microphone circuit. At *C* there is shown the combination of the waves represented by the first three peaks of *B* impressed upon wave *A*, the shaded portion being known as the *modulation envelope*.

Percentage of Modulation. By percentage of modulation is meant the part of the maximum amplitude that is used in the modulation of the carrier. One hundred per cent modulation means that the full amplitude of the carrier is used. Thirty per cent modulation means that only 30 per cent (average) is employed. A transmitter using 100 per cent modulation transmits a signal nearly 10 times as strong, effectively, as it would if it used 30 per cent modulation, with the same power in both instances. Increasing the percentage of modulation, therefore, increases the signal strength as the square of the increase.

The foregoing phenomenon is due to the fact that the strength of the signal is increased because of the greater variations in the modulated wave form. The alternations, instead of merely dipping, so to speak, actually approach the limits of zero to twice the maximum amplitude of the carrier, causing a greater signal voltage to be produced in the antenna circuit of the receiving set.

MODERN RADIO ESSENTIALS

CHAPTER XI

RECEIVING CIRCUITS

The Institute of Radio Engineers defines a radio receiver as "a device for converting radio waves into perceptible signals." By perceptible signals is meant signals which are, or may be, manifested in the form of sound waves which correspond to those which caused the variations to exist in the radio wave. We say "may be manifested" because in laboratory or experimental work the output of a radio receiver is often connected to a visual-indicating device for purposes of observation. On the other hand, if the same receiver were connected to a sound-reproducing device, the variations noted on the indicating instrument would set the air into motion to create sound waves. The antenna serves to collect radio waves and conduct them to the input circuit of the receiving set in which they are selected, amplified, demodulated, and further amplified as desired.

Generally speaking, the radio receiver is divided into six fundamental units: (1) The input stage, (2) the radio-frequency amplifier, (3) the demodulator (detector), (4) the audio amplifier, (5) the sound reproducer, and (6) the power-supply device. In the superheterodyne circuit there is added the oscillator and the mixer—sometimes referred to as the modulator stage. The intermediate amplifier of the superheterodyne receiver is a radio-frequency amplifier.

Radio Signals. Radio waves *may* be converted into perceptible signals without further amplification, provided the strength of the radio wave in the vicinity of the antenna is of sufficient strength. However, the application of reception under such conditions is very limited and in view of the fact that, aside from those used for experimental investigations, receivers that do not amplify the signals are rarely used, they shall not be taken into consideration here, except as necessary for illustrative purposes.

Collecting the Signal. It must be understood that the radio wave emitted from the antenna of a transmitter is a succession of alternating-current impulses of varying amplitudes, the variations being caused by the modulation of the sound frequencies upon the carrier wave. It has been shown how an electromotive force is established in a conductor when magnetic lines of force "cut" that conductor, and how the induced voltage rises and falls in accordance with the variations of the inducing voltage. Here, then, is the explanation of how the signal is impressed upon the antenna circuit of a radio receiver. The movement of electrical charges due to the alternations of the carrier wave act upon the antenna, setting up a flow of energy that varies in amplitude in accordance with modulation and which has the same frequency as the carrier.

Selecting the Desired Signal. It is evident that inasmuch as there are hundreds—in fact, thousands—of radio stations sending signals into space simultaneously, some means must be provided to isolate one particular wave from all the rest to avoid receiving an unintelligible jargon. The process of effecting the isolation is called *tuning,* and the circuits employed for the purpose are called *tuning circuits.* Furthermore, not only is it necessary to select one frequency from the lot, but it is quite essential to block out all other frequencies, and thus prevent current at the undesired frequencies from passing through the circuit.

Tuning Circuits. There are four electrical properties to be taken into account in the design of a tuning circuit, namely: inductance, capacity, resistance, and frequency. Frequency represents the basis for all determinations, and inductance and capacity constitute the determining factors. Inasmuch as resistance does not affect the frequency of the circuit, it applies only insofar as it affects the efficiency of operation.

The effect of inductance and capacity in an alternating-current circuit, and the relationship they bear to resistance to the flow of alternating current, have been shown together with an explanation of what is necessary to permit the circuit to oscillate. Also, it has been explained how a condenser of greater capacity requires a longer period of time to give up or receive the full charge, and, likewise, how a larger inductance requires a longer period of time in which to convert the current, being discharged by the condenser, into a magnetic field.

The time element introduced by the size of the inductance or the capacity is a determination of the frequency with which the current alternates. The current may be alternating at, say, 1,000,000 times per second, in which event the condenser must be capable of receiving the charge 2,000,000 times each second (1,000,000 times on each plate). If, however, the condenser is so large that one five-hundred-thousandth of a second is required to receive the charge, the current cannot alternate 1,000,000 times per second.

Similarly, the inductance builds up an electromagnetic field a given number of times each second according to the amount of the inductance, and if the value of the inductance be too high, more time must elapse before the counter electromotive force causes the magnetic field to collapse.

Capacity and inductance affect the flow of alternating current but in opposite directions. Their effect is known as reactance—

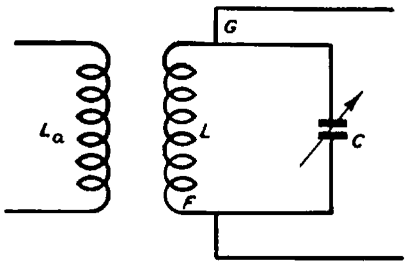


Fig. 89. Antenna Tuning Circuit

that created by capacity being known as capacitive reactance (negative reactance), and that created by inductance being inductive reactance (positive reactance). Both forms of reactance vary with frequency. Capacitive reactance decreases as the frequency is increased; inductive reactance increases as the frequency increases.

There will be one frequency at which the inductive reactance and the capacitive reactance are equal, in which event the reactances offset one another and current at that particular frequency will flow readily through the circuit, prevented from doing so only by the ohmic resistance that exists in the circuit.

In the tuning circuits of a radio receiver, the components are arranged in such a manner that one or the other—or both—may be varied so that currents at different frequencies will pass through the circuits, excluding the undesirable ones. In Fig. 89 there is an inductance, La, which, for purposes of illustration, will be considered as the antenna inductance. The current that is flowing in the antenna circuit causes an electromagnetic field around the inductance. Inductance L is coupled to La in such a manner that a current is produced in the circuit LC.

If the inductive and capacitive reactances in the circuit LC are adjusted so that they balance out at the frequency of the inducing current, an induced current will vibrate through the elements of circuit LC. If, on the other hand, the capacitive reactance is changed so that it opposes the flow of current at that frequency, current will not flow through the circuit, as would be seen if an ammeter were placed in series with the coil and the condenser. Please note that when the statement is made that "current will not flow" it is not meant that there will not be any current whatsoever, because delicate instruments may show a slight passage of current. However, for all practical purposes the slight current flow would be useless, and the circuit would be at its maximum efficiency at the time when the meter indicated an abrupt increase in current.

Here then is what transpires in a tuning circuit. The values of the capacitive and inductive reactances are adjusted to permit the greatest flow of alternating current at specific frequencies through the circuits, and to permit variation of either the capacitive or the inductive reactance—or both—to permit the flow of current at some other frequency, at the same time blocking out the undesired currents.

Calculations. Although the calculations involved in the design of tuning circuits is usually an engineering problem, it is well to include a brief summary here. It has been shown how the value of the inductance and that of the capacity are determining factors in the resonant frequency at which the circuit will permit the free flow of alternating current. Since the symbol for inductance is L and the symbol for capacity is C, the inductance-capacity relationship of a circuit is known as the LC value, which is the product of the value of the inductance and the capacity.

If the LC value of a circuit required to be resonant at a given frequency is known, and a condenser of a given capacity is available for the purpose, the inductance necessary to provide a resonant circuit with the given capacity may be determined by dividing the LC value by the value of the capacity of the condenser. Then knowing the value of the inductance the coil can be wound to suit the need. These *LC* values are given in Table V, in the Appendix.

The values in Table V have been calculated on the basis of wave length in meters, from one meter to 200 meters. Beyond 200 meters the values are given for each of the ninety-six broadcast channels from 550 kilocycles to 1,500 kilocycles.

If the capacity of the condenser to be used in a given circuit is known, the amount of inductance necessary to provide resonance at any given frequency may be determined by dividing the *LC* value as shown in Table V by the capacity of the condenser in microfarads. If it is desired to know what range a certain condenser will cover with a given amount of inductance, multiply the maximum capacity of the condenser in microfarads by the amount of the inductance in microhenries and refer to Table V to determine the highest resonant frequency. Then multiply the minimum capacity value of the condenser by the amount of the inductance and find the minimum resonant frequency by referring to Table V. The values represent the product of the value of the inductance in microhenries times the value of the capacity in microfarads. For example, a 200-microhenry coil will require .000125 microfarads of capacity to be resonant at 1,000 kilocycles ($.02532 \div 200 = .000125$). The inductance of coils used in radio-frequency coupling transformers usually ranges from 175 to 350 microhenries.

The formula for determining the amount of inductance in a coil, or to find the number of turns required on a solenoid of a given size to give the proper amount of inductance has been shown previously, but is repeated here for convenience:

$$L = \frac{.03948a^2n^2}{b}K$$

in which a is the radius of the coil in centimeters, n is the number of turns in the winding, b is the length of the coil in centimeters, and K is a constant, the value of which is found in Table IV and shown to be a function of $\frac{2a}{b}$. The radius of the coil (a) is the distance from the axis of the coil to the center of the wire. Also, one inch = 2.54 centimeters.

Amplification. Having effected a means to select the signal carried by one carrier frequency, at the same time blocking out all other carriers, the next step is to amplify the signal by means of a radio-frequency amplifier in order that it may be built up to sufficient strength to produce the proper effects in the demodulation stage—detector. The fundamental principles governing amplification have been explained and it should be pointed out that a radio-frequency amplifier in a radio receiver is usually a voltage amplifier; one in which tubes that have a high amplification factor are most often used. In other words, the primary purpose of the radio-frequency amplifier is to build up the signal voltage through successive stages until it will cause an appreciable swing in the grid voltage in the circuit where the signal is demodulated—the audio component removed from the radio-frequency component.

While it is true that a radio-frequency amplifier is required to increase the voltage, it is imperative that it do so without introducing appreciable distortion. Therefore, it is necessary to adjust the values of the component parts of the circuits so that the increase in voltage will not be so great as to cause the tubes to "spill over," that is, set up grid current or force them into oscillation.

In general there are two types of radio-frequency amplifiers, those known as the *tuned* type and those that are *untuned.* The tuned type of radio-frequency amplifier is one that may be adjusted to the desired signal. The untuned amplifier is a series of cascade stages so designed that they will permit the passage of a wide variation of preselected signals, or it may be used to build up all signals, the selection to be made after the build-up.

If we refer again to Fig. 89 and assume that at a given setting of the value of the condenser, the circuit is tuned to permit the free flow of current at 1,000 kilocycles (1,000,000 cycles), a difference of potential will exist between the points G and F, and that inasmuch as the adjustment of the reactances is not such that will allow the flow of current at other frequencies, there will be no appreciable potential difference at any except the frequency to which the circuit is adjusted.

In Fig. 90 we have taken the circuit as shown in Fig. 89 and combined with it the input elements of a vacuum tube of the triode type. The output elements are connected to an inductance indicated by L_p. Here, as the current vibrates through the inductance and capacity that make up the circuit LC, point G of the circuit is alternately positive and negative. Likewise, when point G is positive, F is negative, and vice versa. It will be noticed that G of the circuit LC is connected to the grid of the vacuum tube and that F of the circuit LC is connected to the filament of the tube. Thus, there exists a potential difference across the elements of the vacuum tube, a varying difference of potential, which causes the charge upon the grid to change, and as a result to cause a varying current to flow through the plate circuit of which inductance L_p is a part.

It is evident that the natural function of the radio-frequency amplifier is to build up the voltage from one stage to another, and

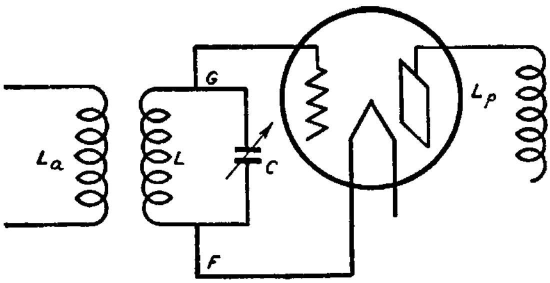


Fig. 90. A Stage of Radio Frequency

that the output of a stage is a reproduction of the input, including the audio component that is modulated upon the radio-frequency wave.

In the earlier models of radio receivers, known as the *tuned radio-frequency type*, the individual stages of radio-frequency amplification were provided with a means for adjusting the reactances, and usually employed a variable condenser for the purpose, the variation in capacity being better defined than changes in the inductance. As the processes of manufacture were developed, all stages were tuned by means of a single control. Unless some external method for increasing the amplification, such as regeneration, were used, such receivers usually required at least two stages of radio-frequency amplification to give the proper increase in voltage to operate the detector efficiently, due largely to the relatively low amplification factor of tubes that were available. The tuned radio-frequency type of receiver, however, if well designed, was simple of construction, and relatively efficient.

Regeneration. Regeneration is a form of oscillation by means of which *a portion* of the energy in the plate or output circuit is returned to the input circuit and serves to build up the strength of the signal. Excessive regeneration results in oscillation, which, being uncontrolled, prevents the tube from performing its function as an amplifier or demodulator. Regeneration was used extensively in the earlier designs of radio receivers and was effected by coupling the output and input circuits inductively or capacitively.

Regeneration may be caused by the coupling provided between the plate and grid elements of the triode, in which event a condition called "feed-back" is created. Hence, in sets known as *neutrodyne* circuits an external capacity was inserted between stages to com-

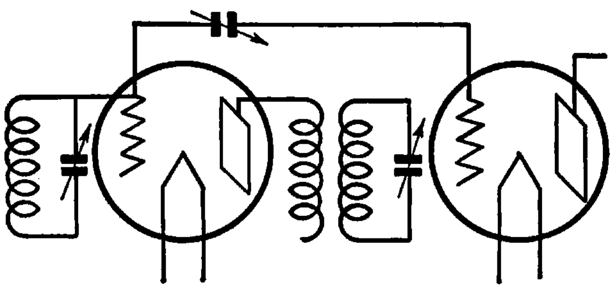


Fig. 91. The Neutrodyne Method of Controlling Regeneration

pensate for the interelectrode capacity, and to thereby eliminate the effects of regeneration and provide a more stable circuit. The neutralizing condenser, as it was called, was usually connected between the grid elements of adjacent tubes (see Fig. 91). It was of exceedingly low capacity and was usually of the semi-fixed type which permitted its adjustment to compensate for the changing of tubes having interelectrode capacities of unequal value.

Detection. Detection is the name applied to the demodulation of the radio signal, that is, the removal of the audio component from the modulated wave. It is necessary that the signal be divided thus, in view of the fact that a means must be provided to set up motions of the air to create sound, and mechanical devices will not respond to the high-frequency impulses as represented by the radio-frequency signal.

Strictly speaking, detection is a process of rectification in which the high-frequency alternating wave is converted into a series of fluctuating direct-current impulses. The most efficient detector would be one in which the process of rectification would be complete, one in which only one side of the alternating wave would be retained in its original form, eliminating the other side of the wave entirely. However, such efficiency of operation is very difficult, if not impossible, of attainment in practice.

The modulation of a radio-frequency signal by an audio-frequency impulse creates a series of varying impulses known as *wave trains*. This condition is brought about by what is called *damping*,

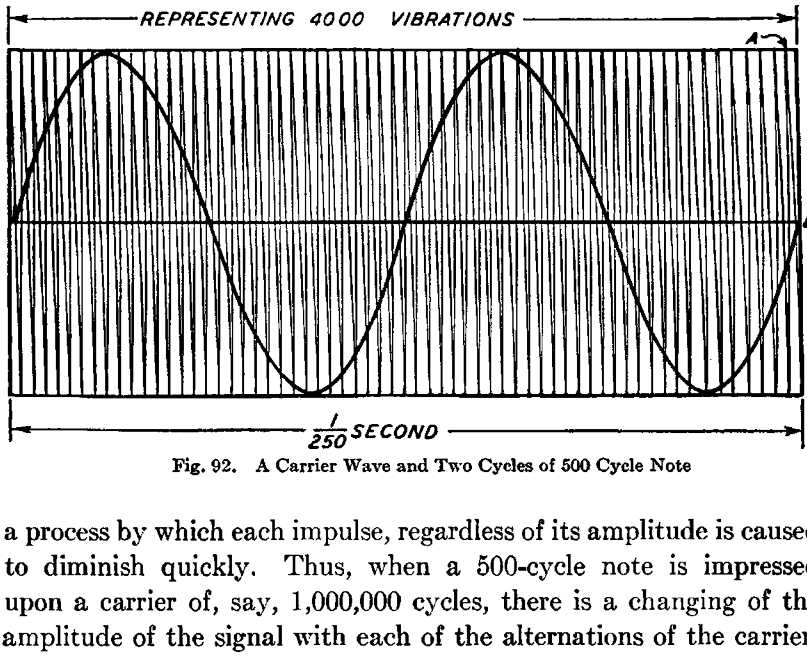


Fig. 92. A Carrier Wave and Two Cycles of 500 Cycle Note

a process by which each impulse, regardless of its amplitude is caused to diminish quickly. Thus, when a 500-cycle note is impressed upon a carrier of, say, 1,000,000 cycles, there is a changing of the amplitude of the signal with each of the alternations of the carrier, so that there exists a series of wave trains. To illustrate: one two-hundred-fiftieth of a second is required for two cycles of a 500-cycle note. If this were impressed upon a carrier of 1,000,000 cycles (1,000 kilocycles), the carrier would flow through 4,000 complete cycles in the period required for two cycles of the audible signal as shown in Fig. 92. Also, the audible signal would rise and fall in cyclic rhythm which would mean that the amplitude over the 4,000 vibrations of the carrier would rise twice from zero to maximum in one direction back to zero, to the maximum in the opposite direction and back to zero. The rising and falling of the amplitude caused by the audio signals establishes the wave trains mentioned earlier in this paragraph, shown in Fig. 93. It is the function of the detector to disassociate the wave trains from the remaining portion of the signal and to pass the electrical impulses to the amplifier stages, following the detector, which stages serve to create sound waves.

In general there are two types of detection, *grid detection* and *plate detection*. In the former, the rectification process takes place in the grid circuit, and is passed to the output circuit as rectified

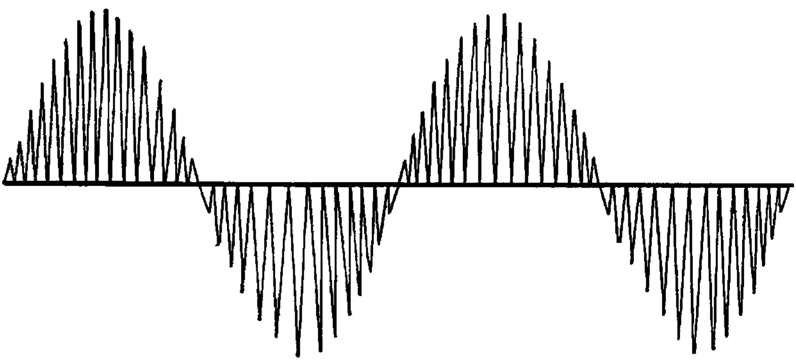


Fig. 93. The Result of Combining a 1000 Kilo Cycle and 500 Cycle Wave

pulsating direct current, and in the latter method the rectification process is effected in the plate or output circuit.

In receivers of earlier design in which the amplification in the radio-frequency amplifier was not so great, a great deal of emphasis was placed upon the sensitivity of the detector. However, by using tubes of high-amplification factor and with efficiently designed radio-frequency amplifiers, it is not so essential that a sensitive detector be employed, and more attention is placed upon the action of the circuit from the standpoint of distortion.

Grid Leak and Condenser. The circuit which employs a grid leak and condenser (grid detection) was considered highly satisfactory when modulation percentages were low. However, with an increase in the percentage of modulation, the inability to permit the leakage of charges off the grid causes the tube to "block" and introduce a high percentage of distortion.

There are numerous theories concerning the operation of the detector employing the grid leak and condenser, all of which are more or less complex in that in order to understand the action, it is necessary to visualize a process that takes place over a very short period of time. The most easily comprehended explanation is that which has to do with the movement of electrons and the application of electrical charges.

Consider a circuit, as shown in Fig. 94(A), containing an inductance *L*, tuned by a condenser, *C*, connected to a vacuum tube through a grid leak, *GL*, and a condenser, *GC*. The resonant circuit, *LC*,

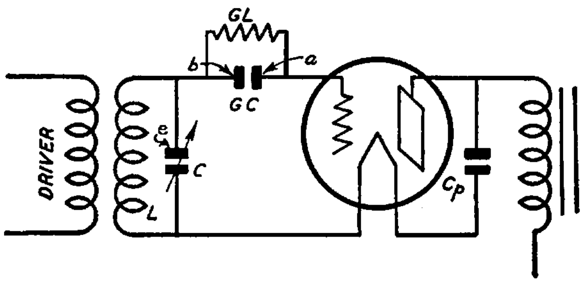


Fig. 94 (A). Diagram of a Detector Circuit

coupled to a driver circuit, has an alternating current flowing through it at a given radio frequency. An audio frequency is impressed upon the radio-frequency carrier, however, so that the amplitude of the alternations is increased—or decreased—according to the frequency of the audio signal. Hence, the alternating current flowing through the circuit *LC* is a series of wave trains. The grid return is through the positive side of the source of filament supply, which means that the grid is slightly positive with respect to the average potential of the filament.

As the current passes through circuit *LC*, connection *e* is alternately positive and negative. Also, at the time that *e* is positive, that side of the condenser *GC* indicated as *b* is likewise positive. The grid of the tube and the *a* side of condenser *GC* are normally positive because of being connected to the positive side of the filament source of supply.

The grid being positive naturally attracts some of the electrons moving from the filament to the plate. However, during the positive half of the cycle of the current flowing through *LC*, at which time *b* and *e* are likewise positive, the electrons on the grid are repelled by the positive charge on the *b* plate of the condenser *GC*. As the current swings through the negative half of the cycle, the *b* plate of *GC* becomes negative and the grid receives some of the negative charge. At the same time the negative charges on the plate tend to repel those on the grid.

Thus, it will be seen that the grid has accumulated a charge of electrons which it is forced to retain on account of the pressure from one side or the other during succeeding halves of the cycle of the current flowing in circuit *LC*. In order to prevent the accumulation of charges that would effectively "block" the tube and prevent it from functioning, a non-inductive resistance of high value is placed in the circuit to enable the excess charges to leak off the grid. The resistance is usually of one or more million ohms and should have the proper value to allow the leakage of excess electrical charges, but at the same time prevent the free flow of current to the grid.

It has been explained how the modulation of a radio-frequency carrier with an audio-frequency signal caused a series of wave trains. Due to the action of the grid leak and the condenser, the signal in the input circuit of the detector stage assumes a form shown above the line in Fig. 93. As a result of the change in the form of the signal wave, the output of the detector tube naturally follows a similar shape with the result that there is effected a predominance of the audio signal, which signal is still in a vibratory stage because of the radio-frequency component that remains.

The radio-frequency component is then removed by a combination of two elements. First there is the condenser C_p connected between the plate of the tube and the filament, and second, there is the primary of the transformer in the first audio stage. The latter effectively offers resistance to the flow of the alternating current, the former provides a path for the radio frequency to ground.

Grid-Bias Detection. In the grid-bias method of detection, the grid of the detector tube is biased, so that it operates on the bending portion of the grid-voltage plate-current curve. The *average* plate-current change is thus much greater than the normal plate current and the positive swings of the grid voltage cause far greater increases in the plate current during the positive half of the cycle than during the negative half of the cycle. See Fig. 79.

In using the grid-bias method of detection, distortion is deliberately introduced into the circuit, which distortion, while it causes a deviation of the wave form from that of the original, merely emphasizes the amplitude of one side of the wave train and practically eliminates the other side.

Grid-bias detection is more satisfactory for receivers operated where the station-signal strength is high, due to the fact that it is capable of handling a stronger signal without creating objectionable distortion. Hence the principal advantage of plate detection—plate rectification—is the ability to handle great volume.

Linear Detection. Linear detection is that form of demodulation in which the output of the detector varies directly as the amplitude of the signal voltage. The detector tube is operated with the proper potentials to give a grid-voltage plate-current characteristic curve that is practically a straight line and which cuts off sharply without the customary bend on the lower portion of the curve.

Operating the tube with a relatively high grid bias—near cut-off—the plate current is high during the positive half of the cycle and practically eliminated during the negative half of the cycle. A linear detector is operated with high plate voltage and high grid bias, the latter enabling the impression of high voltages on the grid of the tube, and because of the linear action as represented by the straight line indicating the grid-voltage plate-current characteristics, distortion is minimized.

The linear detector is less sensitive than the detector employing the grid condenser and grid leak and the grid-bias detector as described previously. However, in receivers having a high gain in the radio-frequency amplifier, the need for a detector of high sensitivity is less pronounced and greater stress can be laid upon the efficiency of the detector in rectifying the signal and effecting demodulation.

Power Detector. The power detector is essentially a linear detector which has the proper potentials to give an output voltage that will excite the grid of a final power amplifier tube. If the plate, grid, and carrier voltages are properly proportioned, the amount of distortion developed in a power detector will not be objectionable regardless of the percentage of modulation. However, with improper proportionments of the voltages, the detector may—in the case of too low carrier voltage—function as a grid leak and condenser detector, or—in case the carrier voltage is too great—set up distortion when the positive peaks are caused to change their form in accordance with the variations at the upper portion of the grid-voltage plate-current characteristic curve.

Detectors—General Summary. Detection is demodulation, the separation of the audio component from the radio-frequency carrier. It is in effect a rectification process, which changes the alternating current into a pulsating direct current, the rectified portion of the

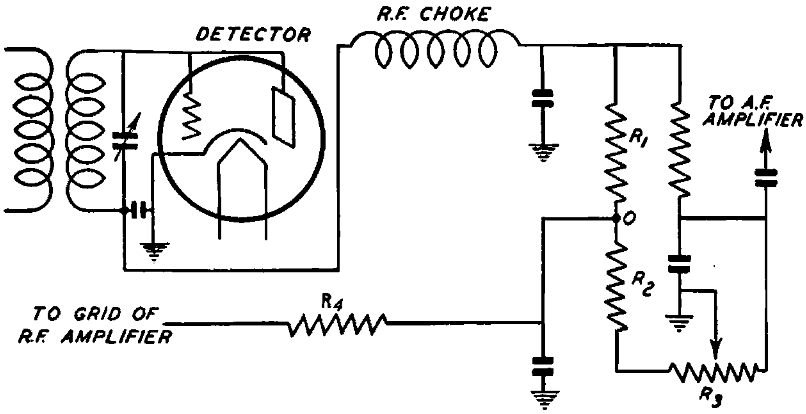


Fig. 94 (B). Automatic Volume Control Circuit

wave having the same general wave form as that part of the alternating wave that is on the positive side of the zero potential line. Various types of circuits are employed, depending upon the design of the tube to be used. With the general ideas of detector action in mind, the engineering data furnished by the tube manufacturers will be understood readily.

Automatic Volume Control. Automatic volume control is employed to minimize "fading" and to provide a more constant level of reproduction. It is accomplished by using the output of the detector tube—the second detector in the case of superheterodyne receivers—which is a rectified current to cause a change in the bias applied to the grid elements of tubes in the radio-frequency amplifier stages.

A typical example of an automatic volume control circuit is shown in Fig. 94(B). In this case a triode, in which the plate and grid are connected together externally, thereby forming a diode, is used as the second detector. In such a circuit no voltage is applied to the anode consisting of the combined plate and grid when there is no signal voltage, but when a signal voltage is applied a rectified current flows through the circuit comprising resistance units R_1, R_2, and a portion of R_3 to the ground and back to the cathode of the detector tube. R_3, it will be noted, is a variable resistance and serves as the manual volume control by varying the value of the resistance network. Any point on the circuit from R_1 to R_3 is negative with respect to the ground, when current is flowing in the circuit.

The current passing through R_1, R_2, and a part of R_3 increases as the strength of the signal voltage applied to the detector anode increases. And, as the current increases, the voltage drop across the resistance R_2 and a part of R_3 increases so that point O is made more negative with respect to ground than when a feeble current is flowing in the circuit. Hence, if point O is connected to the grid of tubes in the amplifier stages through a suitable resistor R_4 to provide a normal bias for the tubes, it is evident that if the signal strength increases, the bias on the grid of the amplifier tubes will be increased, less plate current will flow and the signal voltage will drop. However, if the signal voltage applied to the detector anode drops, current passing through the resistance network decreases, voltage drop decreases and the lowered grid bias causes higher plate-current flow.

There are numerous types of automatic volume control circuits. Some of them employ a separate tube, others do not. Regardless of the design, the principle involved is as shown herein, the rectified current causing a higher or lower voltage drop, and a resulting higher or lower bias on the grid of tubes in the amplifier stages.

Amplifiers. Having demodulated the signal, it is necessary to amplify the resultant series of waves and provide sufficient energy to actuate the mechanical device to create sound waves. The type of amplifier used depends to a certain extent upon the kind of demodulation used, in the case of power detection, for instance, it being found advisable to feed from the detector into a resistance-coupled amplifier in order to take advantage of the amplification of the tube without impairing the frequency characteristics of the audio signal. The value of the plate resistance should be selected in accordance with the recommendations of the tube engineers as shown in tube-engineering data furnished by the manufacturers.

Superheterodyne Circuits. The superheterodyne circuit, recognized as the most efficient receiving circuit, combines all the integral parts which have been described previously with the addition of two stages, known as the oscillator and the mixer stages. The mixer stage has often been misnamed the first detector stage.

The theory underlying the development of the superheterodyne circuit had to do principally with the efficiency of radio-frequency amplifiers as regards frequency. A radio-frequency transformer, while relatively efficient over a comparatively wide band of frequencies, will be most efficient at some given frequency. Hence, so reasoned the engineers, if a means could be provided to produce a carrier of a given frequency and modulate it with the incoming signal, a radio-frequency transformer designed to resonate at the given frequency would amplify more efficiently.

It has been shown how an alternating current of one frequency could be modulated upon an alternating current having another frequency to give a resulting wave form. In the case of modulating a radio-frequency carrier with the voice or audio frequencies, the resulting wave form is a series of wave trains the integral parts of which have varying amplitude in accordance with the summation—or subtraction—of the amplitude of the impulses of the carrier and the modulated frequency.

There is still another phenomenon, however, that is involved in the superheterodyne circuit. If an alternating current of, say, 100,000 cycles is generated and the circuit through which this current is flowing is coupled with another circuit in which an alternating current of 101,000 cycles is passing, there will be a resultant frequency of 1,000 cycles which, being within the range of audibility, may be heard through the proper coupling and sound-creating devices. Similarly, a 1,000-cycle beat note could be generated by coupling circuits of 100,000 cycles and 99,000 cycles, or any combination of oscillating circuits in which the difference between the two frequencies is 1,000 cycles. By the same principle, any given frequency can be produced by coupling two oscillating circuits in which the alternating currents have frequencies that differ by the amount of the desired frequency.

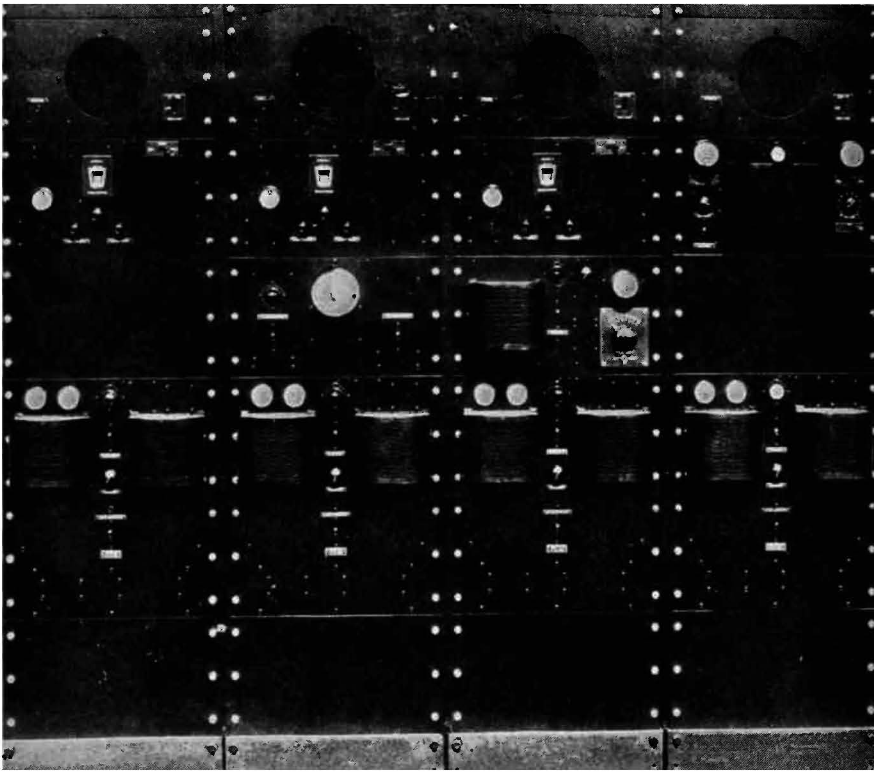
In the design of a superheterodyne circuit, the engineer first determines the frequency of the intermediate transformers to be used. The frequency selected cannot be in the broadcast band and must be one the harmonics of which will not coincide with the frequency assignment of a radio station. Best results have been obtained with a transformer tuned to the lower frequencies, below 300 kilocycles.

A stage of radio-frequency amplification may, and often does, precede the mixer stage—the first detector—to serve as a means to build up the incoming signal so that it will modulate more effectively the wave produced by the oscillator circuit.

The oscillator stage is the conventional type of oscillator provided with a condenser for tuning, and calibrated so that the frequency of the current generated will be different from the carrier wave by the number of cycles at which the intermediate transformers are designed to be resonant. It, too, is coupled to the input circuit of the mixer stage.

The output of the mixer stage is fed into the primary of the first intermediate transformer, which, together with the similar stages that follow, amplify the signal sufficiently to actuate the detector or demodulator tube.

Autodyne Circuit. The autodyne circuit is essentially a superheterodyne circuit in which the generation of the oscillator frequency and the mixing of that current with the antenna oscillations is effected in a single stage. The principal advantage is a lower cost of manufacture.



AN AMPLIFIER INSTALLED IN THE JEWISH MEMORIAL HOSPITAL, KANSAS CITY, MISSOURI
Wires are run from the amplifier to each room in the hospital. Patients can select one of several radio broadcasting stations or listen to the program being given in the Auditorium.
Courtesy of Operadio Manufacturing Company

MODERN RADIO ESSENTIALS

CHAPTER XII

REPRODUCING DEVICES

A discussion of the principles of acoustics has brought out the fact that sound is created by the repeated condensation and rarefaction of the air at periodic intervals. When the condensations and rarefactions occur at irregular intervals, the sound produced is known as *noise*; when they occur at regular intervals the sound produced is known as *musical tones* and may include the human voice. Other discussions showed how sound pressures are made to cause fluctuations in the flow of electrical currents, and how the varying electric currents are modulated on a carrier wave that is transmitted through space, picked up by the antenna of a radio receiver, amplified, and finally demodulated so that the current flow again becomes an electrical representation of the original sound pressures.

The fluctuating electric current, however, cannot act to set up a movement of the air to create the sound waves; it is necessary to provide a device that will react to the variations in current flow, causing the vibration of physical bodies that have the ability to create condensations and rarefactions of the air surrounding them.

The telephone receiver shown in Fig. 95, is such a device. It consists of a permanent horseshoe magnet, around each pole of which there is placed a coil of wire, the coils being connected in series so that current flows through both of them. The open terminals of the two coils are then connected to the source of fluctuating current. Near the pole pieces, is a thin metal disc, held tightly in position by the case of the receiver.

As the fluctuating current passes through the coils around the pole pieces, the magnetic field is increased and decreased with each successive part of the wave train, described elsewhere, so that the metal disc is caused to vibrate. The vibrations create varying pressures of the air to create sound.

The headphone, used widely in the early days of radio, and which constitutes a necessary piece of laboratory equipment, is an adaptation of the telephone receiver. It differs only in that it is shaped differently to enable the operator to hold it next to his ear by means of a band passing over the head, and in the amount of resistance in

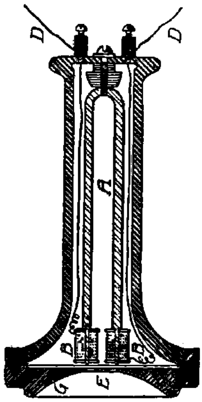


Fig. 95. A Telephone Receiver

the coils surrounding the pole pieces—the headphone used for radio being of much greater resistance than that used in telephone circuits.

As the development of radio progressed, the need became apparent for a reproducer that would permit several persons to hear the programs simultaneously. Consequently, there came the loud speaker, a device that is capable of setting large quantities of air in motion, but which requires more energy to actuate it. The first loud speakers were crude affairs, adaptations of the headphone. Later came the balanced armature types of speakers, in which an armature was balanced between the poles of a magnet and connected to a disc or cone that would cause a disturbance of the air when it vibrated. Fig. 96 shows a diagrammatical illustration of the balanced armature type of reproducer. In this case the armature is connected to a metal disc at the apex of a megaphone-like projector.

The most popular type of loud speaker is that which is misnamed the dynamic speaker. Actually the device should be known as an electro-dynamic speaker, but popular use of the former appellation has made it an acceptable term. The dynamic speaker derives its name from the fact that instead of having a permanent magnet such as is found in the headphone and in other types of loud

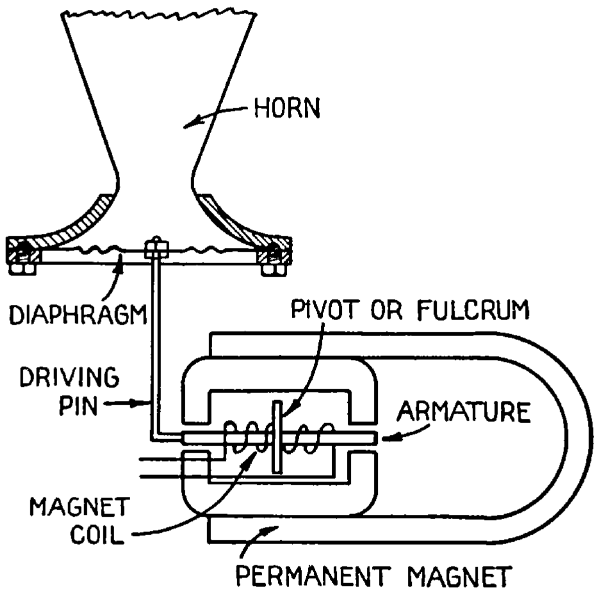


Fig. 96. The Balanced Armature Type of Speaker

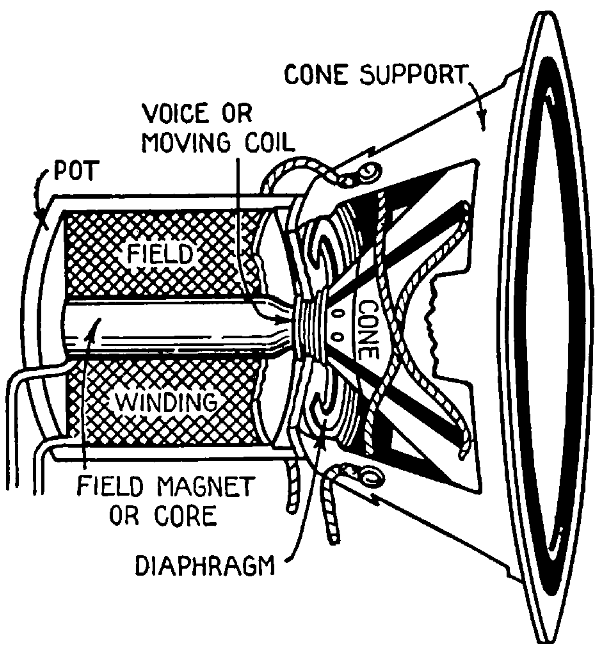


Fig. 97. A Cutaway View of a Dynamic Speaker Unit

speaker units, an electromagnetic field is produced by passing a direct current through a coil around a soft-iron core, thereby forming an electromagnet.

The construction of the dynamic speaker is illustrated in Fig. 97. Direct current passing through the field coil which is around the core, sets up a flow of magnetic flux that passes through the core to the outside case called the "pot." The "pot" continues around in front of the field coil until it nearly touches—but does not quite touch—the front end of the core. Thus, there is an air gap across which the flux flows, shown in Fig. 98.

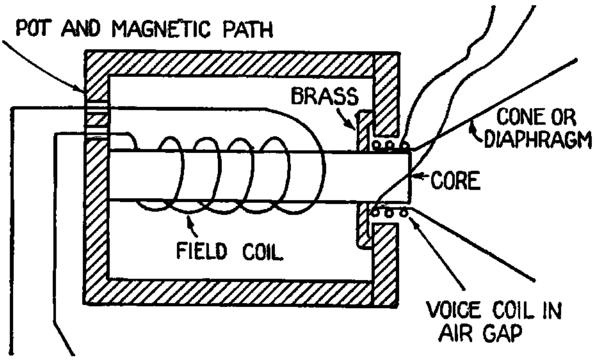


Fig. 98. Diagram of Construction of Dynamic Speaker Field

Into the air gap there is inserted a small coil attached to a cone. The terminals of this coil are connected to the output of the receiver or amplifier. When no current is flowing through the voice coil, there is no movement of the cone unless the current flowing through the field coil is fluctuating, in which case the cone will vibrate according to the variations in the field current. However, when a signal is passed through the voice coil, the magnetic field set up around the turns of the voice coil causes a movement inward or outward in the magnetic field that exists in the air gap. The movement of the voice coil causes the air next to the cone to be condensed or rarefied accordingly, and if the variations of the current flowing through the voice coil are within the audible frequencies, the condensations and rarefactions of the air will be represented as sound.

The principles involved in the operation of a dynamic speaker are explained in detail elsewhere. It is shown how an electromagnet is formed by passing a current through a coil of wire surrounding an iron core. The effect obtained by passing a conductor through a magnetic field, or otherwise disturbing the flux is also explained, and these two principles constitute the fundamentals of the operation of the dynamic type of loud speaker.

The Baffle. The ability of a loud speaker to reproduce low frequencies is determined largely by the size of the baffle. The purpose of the baffle is to prevent a collision between the sound wave emanating from the front of the cone and that which is produced at the back of the cone. Such a collision would neutralize, to a certain extent, the effect of air condensations and rarefactions, and would prevent the reproduction of low-frequency impulses.

There are two general types of baffles, the flat type and the box type. The box-type baffle must be well ventilated in the rear, to prevent distortion caused by the sound waves rebounding from the hard surface of a back wall, and colliding with new waves being given off. Fig. 99 shows the two types of baffles used, the one at the

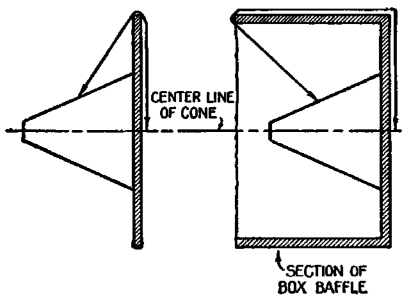
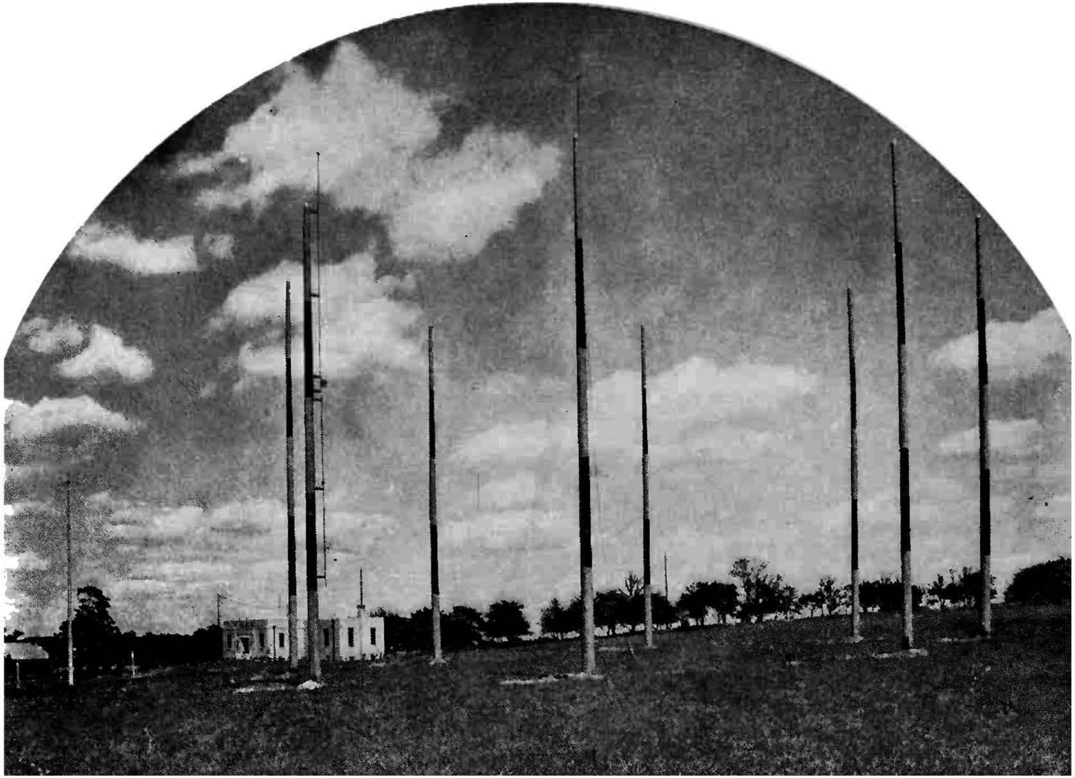


Fig. 99. Flat and Box Type Baffles

left being a flat-type baffle, the one at the right being a box-type baffle.

The approximate minimum frequency that a speaker will reproduce with a given baffle can be determined by measuring the free distance, as shown by the arrows in the illustration. A speaker having a baffle that measures approximately 32 inches, is capable of reproducing tones of about 100 cycles. If the baffle is 64 inches it will permit the speaker to reproduce tones of about 50 cycles. In either case, it is necessary that the amplifier be capable of delivering the low frequencies to the speaker unit. It is not often that frequencies lower than 100 cycles are desired outside of experimental laboratories.



THE SHORT-WAVE ANTENNA SYSTEM USED BY KDKA, PITTSBURGH, PA.
Courtesy of Westinghouse Electric and Manufacturing Company

MODERN RADIO ESSENTIALS

CHAPTER XIII

ANTENNAS

Generally speaking, the principal purpose of a radio receiving antenna is to collect radio signals (extract as much electrical energy as possible from passing electromagnetic waves) and direct them to the circuits of a receiving set.

A simple form of antenna consists of a conductor (usually placed in a horizontal position) connected to a radio receiver by means of

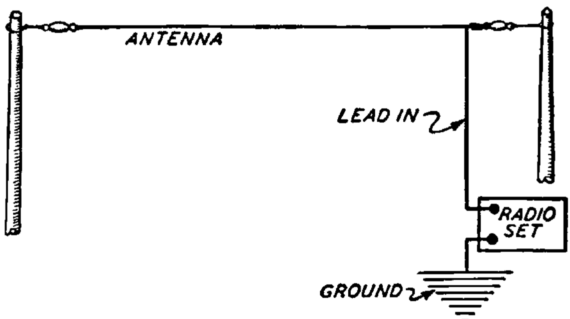


Fig. 100. A Simple Antenna System

another conductor called the lead-in, as shown in Fig. 100. Inasmuch as the lead-in in the illustration is connected at one end of the overhead conductor, the entire structure forms an **L**, which gives rise to its being called an "**L**-type" antenna. Had the lead-in been connected at the center of the horizontal wire, instead of at one end, the construction would have formed a **T**, known as a "**T**-type" antenna.

Both the "**L**-type" and the "**T**-type" antennas are highly efficient in collecting radio signals, but they are equally efficient in picking up electrical interference such as atmospheric and "man-made" static, as explained in detail on the following pages.

Radio Waves. *Radio wave* is a commonly used term to designate the energy of varying amplitude that is radiated from a transmitting antenna in the form of electromagnetic waves. Unless directional characteristics are incorporated in the transmitting antenna design, the waves of electrical energy that escape into free space travel in all directions from the transmitter at a speed of 300,000,000 meters (186,000 miles) per second.

Radio waves consist of a static field and a magnetic field. The static field is perpendicular to the surface of the earth and is carried along on the magnetic field which moves parallel with the earth's surface and therefore at a right angle with respect to the static field. The waves travel through a nonmagnetic medium known as the hypothetical "ether," but when they come in contact with a conducting medium, such as a radio receiving antenna, they serve

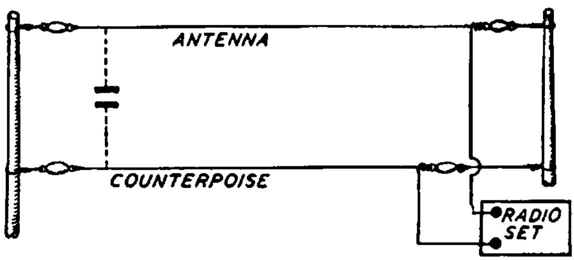


Fig. 101. A Counterpoise Antenna System

to induce a voltage in the conductor and establish a flow of current that is directed through the input circuit of a receiving set by way of the lead-in.

Antenna Systems. The antenna system for a radio receiving set consists of the conductor that serves as the antenna, the lead-in, and the ground. In some cases, a device known as a counterpoise, as shown in Fig. 101, is used instead of the ground, in which event there exists between the antenna and the counterpoise a potential difference that makes possible the induction of a voltage and the flow of current in the antenna circuit.

Fig. 102 shows how the waves, coming in contact with the wire that serves as the antenna, cut the conductor and induce a voltage in accordance with the principles explained in the earlier parts of this treatise.

Assuming that the antenna circuit consists of the overhead conductor and the ground, the condition shown in Fig. 102 is established. The overhead conductor becomes one plate of a condenser of low capacity, the exact value of which is dependent upon the length of the antenna and the distance it is placed above the ground or any metallic substance that may be connected to the ground.

It must be remembered that in the installation of an antenna on the roof of a house, the distance from the antenna to the ground is that distance from the antenna to any other conductor that runs parallel with the antenna wire itself and which is connected through a metallic circuit to the ground.

Some engineers believe that the electrostatic field existing between the overhead conductor and the ground serves to cause further radiation in all directions, setting up an additional electro-

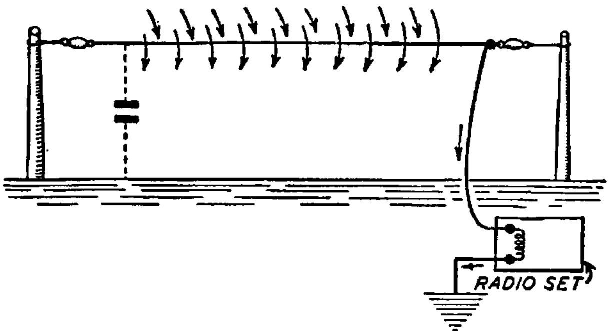


Fig. 102. Action of Radio Waves on Antenna

magnetic field that increases the effect of the incoming waves. But the more commonly accepted explanation of the antenna system is that it is an oscillatory circuit, consisting of the inductance of the antenna, plus that of a coil installed in the receiver, and the condenser formed by the antenna and the ground or counterpoise.

It is assumed that the electrons, first drawn to the antenna, surge back and forth in the circuit, causing the creation of a varying electromagnetic field that results in a movement of the electrons from the antenna to the ground and back to the antenna, repeating the operation at a given frequency as explained in preceding chapters.

Antenna Efficiency. Any antenna system will be more efficient at one given frequency than at any other, due to the fact that the antenna circuit, as explained, will be resonant at that frequency or one of its harmonics. Therefore, since it is evident from the foregoing explanation that the antenna system is an oscillatory circuit comprising an inductance and a condenser in series, and in which inductive and capacitive reactances exist as in all series resonant circuits, the resonant frequency will be that at which the reactances balance, permitting the free flow of current through the circuit.

In addition to the inductive and capacitive reactances, there exists a resistance to the flow of high-frequency alternating current. This high-frequency resistance may be high enough to retard the flow of current, even though the circuit may be resonant to a given frequency. Hence, in order that the circuit may be tuned sharply, the reactance should be high compared to any high-frequency resistance that exists.

In order to provide a resonant condition to insure the maximum extraction of energy from passing radio waves, the antenna must have an electrical length corresponding to one-fourth, one-half, or an exact multiple of the full wave length of the signal being received. As long as radio receivers were designed to operate in one band—broadcast, 60-meter, 30-meter, or police, for example—an antenna resonant at a frequency midpoint in the band was considered satisfactory. Multi-band receivers introduce complexities however, but even so, by making a proper choice of dimensions, an antenna system can be designed to resonate at one-half wave length in one of the short-wave bands, and at one-fourth wave length in the broadcast band.

The length of the antenna may be determined by the wave length of the signal being received. Thus, an antenna, to resonate in the 60-meter band, should be 60 meters, 30 meters, or 15 meters long, full-wave, half-wave, and quarter-wave, respectively (1 meter =39.37 inches). Quarter-wave antennas are generally of the "Marconi" type which makes use of a ground at the lower terminal, but half-wave and full-wave antennas are usually of the "Hertzian" type in which the lower terminal is connected to a counterpoise.

The doublet type of antenna, shown in Fig. 103, is used almost exclusively for short-wave reception. Such an antenna consists of two conductors of equal length joined together through insulators to form a continuous flat-top construction. Such an antenna is highly efficient when signals to which it is resonant are received, but is inefficient when the signals are not at the resonant frequency. A half-wave doublet consists of two flat-top parts, each of which is one-fourth the wave length of the signal to be received, but if the full directional effects of the antenna are to be made use of, the maximum over-all length of the flat-top portion should be $1\frac{1}{4}$ wave lengths. The doublet is frequently referred to as a di-pole antenna.

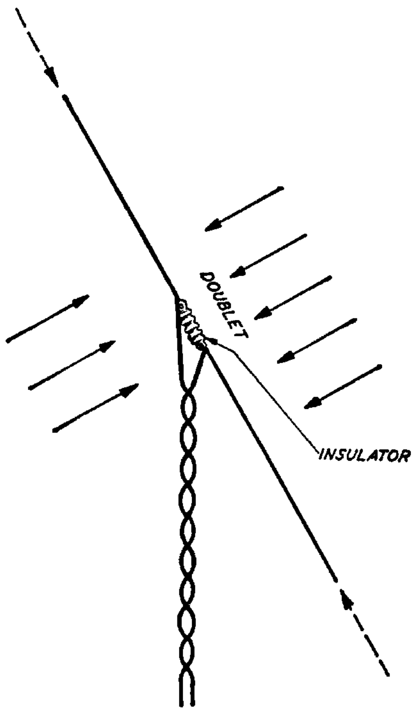


Fig. 103. Solid Arrows Indicate Plane of Maximum Doublet Pick-up, while Dotted Arrows Show Plane of Minimum Pick-up. Proper Orientation May Be Used to Reduce the Pick-up of Noise Interference

The length of a doublet antenna may be ascertained by means of the following formula:

$$l = 1.25\frac{v}{f}$$

where l = over-all length of the flat-top.
v = velocity of the radio wave in meters per second.
f = frequency in cycles per second.

Doublet antennas obtainable on the market have an over-all length of about 60 feet. If the foregoing formula is applied, it will be found that the over-all length of a doublet antenna to resonate at 21 megacycles (21,000,000 cycles) will be 17.8 meters or 58.4 ft., each half-section being 8.9 meters or 29.2 ft.

Another development, known as the double-doublet type antenna, is designed for use in the short-wave bands to resonate at frequencies not harmonically related. Such an antenna is shown in Fig. 103A.

Radio Interference. Interference, as applied to radio reception, can be classified, generally, as atmospheric static and "man-made"

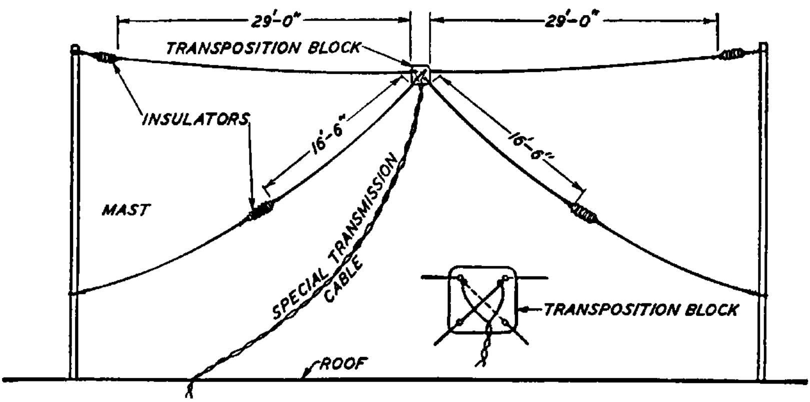


Fig. 103A. The Double-Doublet Type of Antenna

static. It causes annoying sounds to emanate from the loud speaker of the receiving set, interfering with the clarity of reproduction of radio programs. Atmospheric static causes irregular crackling sounds; "man-made" static usually is more regular, a buzz, for example, or a series of clicks, or some similar noise.

Atmospheric static, present in the atmosphere at all times in greater or lesser degrees, is caused by friction between clouds or dust particles, and may originate at a point many miles from the receiving set. Clouds consist of minute bodies, each of which may be electrically charged. When two groups of such electrically charged bodies collide, the transference of energy from one to the other sets up an electrical disturbance that is radiated through the ether for great distances. Similarly, when a cloud passes through a region of dust-saturated atmosphere, the cloud and the dust particles have a tendency to attain an electrical balance; that is, to bring about a normal relationship between the positive and negative charges on the surface of the cloud and the dust particles. Changes in temperature also cause dust particles, as well as clouds; to travel at varying rates of speed, so that the charge carriers move more haphazardly and collide more frequently. A transference of electrical charges, all for the purpose of striking the normal electrical balance, results from each collision or rubbing.

"Man-made" static is caused by the operation or the switching on and off of electrical machines and appliances. Certain types of motors, flashing signs, door-bells, electrically operated toys, electric railways operated by overhead or otherwise exposed trolleys, and various types of motor-driven home appliances are common interference-creating devices. Wherever an arc appears, such as between the brushes and the commutator of a motor, switch contacts, or electric trolley and feeder wire, a high frequency discharge occurs. Again, in certain types of heating units, such as heating pads, the surging of electric current through the element causes vibrations that change the inductive or capacitive constants of the circuit, thereby creating varying electromagnetic waves, which, on reaching the radio receiver, are amplified and emitted as scratching, buzzing, or crackling sounds from the loud speaker. Usually the effects of "man-made" static are confined to small areas, although it frequently happens that wide areas are affected, chiefly by transmission over power lines or other conducting media.

Combining Radio Waves and Interference. The electrical discharge between clouds or dust particles, as well as that caused by lightning, is a high-frequency transference of energy—an electrostatic discharge.

When the radio wave, traveling through the hypothetical "ether," passes through an area in which an electrical disturbance is taking place, the electrostatic discharge is carried along on the radio wave. It is generally, though not universally, believed that the combination of the electrostatic discharge with the radio signal changes the shape of the radio wave, that the amplitude characteristics are acted upon by the electrostatic charge, and that the influence of such variations in amplitude will be extended to every receivıng antenna beyond the place where the electrical disturbance occurs. Thus, suppose a radio wave originating in New York City and traveling west passes through an electrical storm centering about Cleveland. Although the storm itself does not reach as far as Chicago, electrical discharges in and around Cleveland apparently change the form of the radio wave so that the signal impacted on

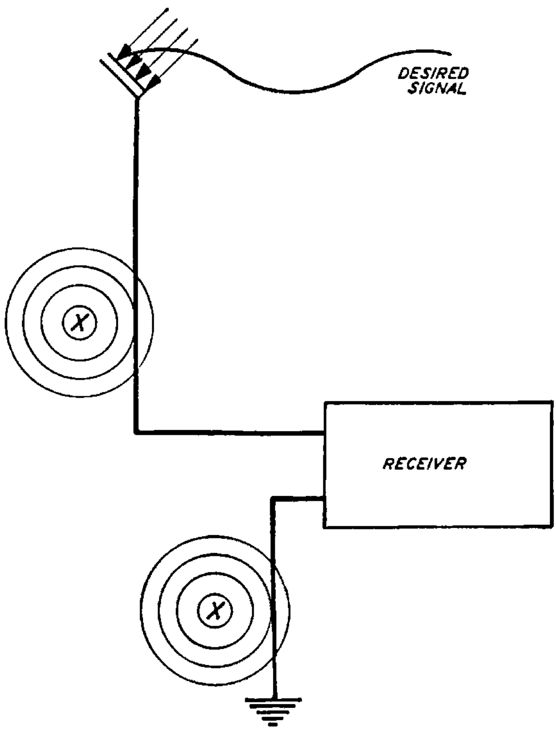


Fig. 103B. Electrical Disturbances at Points Marked "X" Enter the Receiver with the Desired Signal and Issue from the Speaker as Annoying Interference

antennas in Chicago, or other points west of Cleveland, combine the original signal with its amplitude component changed in accordance with the strength of the electrostatic discharges.

Atmospheric static tends to paralyze temporarily the circuits of a receiver, thereby blotting out reception for a brief interval. The impulse, energizing the antenna system, forces it to oscillate at the resonant frequency of the system until the energy has been dissipated. Each tuned circuit in the receiver, in turn, is forced to oscillate at whatever frequency it may be tuned at the instant, and the length of time required for the energy to reach a minimum will be greater in tuned circuits having high gain. Atmospheric static appears to have what might be called a "universal" frequency, which makes it virtually impossible to keep it out of receiver circuits by means of a wave trap.

"Man-made" static, on the other hand, usually has a definite frequency, determined by the length of the power line it energizes, and from which the interference is radiated, and the length of time that such static is sustained depends entirely on its nature. A click caused by the turning off of a switch will last only an instant, but may be pitched high or low, depending on the length of the power line energized by the electrical disturbance. The pitch of the frying

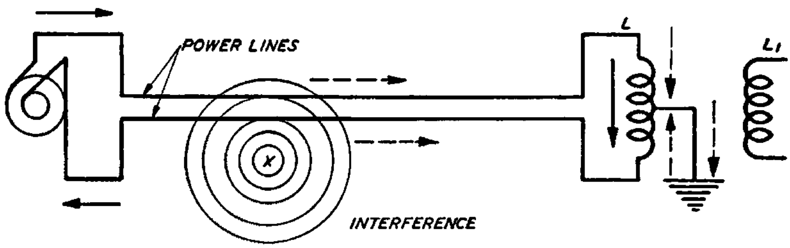


Fig. 103C. Desired Current, Indicated by Full Arrows, Flows around Complete Circuit Setting up Magnetic Field around Coil L. Interference Current Flows through Coil L in Phase Opposition, Preventing the Setting up of a Magnetic Field. Energy Appearing in L_1 Will Be Due Only to the Desired Current Flow in L

noise created by a given motor does not vary as long as its installation is not disturbed; and the noise continues as long as the motor is operated.

Assuming that the receiving antenna is installed in accordance with recommended practice, the horizontal portion may be placed high enough to be out of range of "man-made" static. In such installations, then, some of the interference of the "man-made" type is combined with the radio signal in the lead-in (see Fig. 103B) which may pass through one or more interference regions between the overhead structure and the receiving set.

"Man-made" static may also enter the receiving circuits by way of the power line that supplies the receiver, but in such cases the interference can usually be trapped out by means of a condenser of from .001 mfd. to .1 mfd. connected from one side of the power line to the chassis of the receiver, provided the chassis is well grounded.

Fig. 103C shows the desired current and interference current entering a set by way of the power line.

Most radio receivers incorporate the filter condenser in the power circuit to prevent the entrance of interference due to line surges and transients when door-bells are rung, telephones dialed, or electric lights turned on or off.

Static Eliminators. From time to time since radio was popularized, so-called "static eliminators" have appeared on the market.

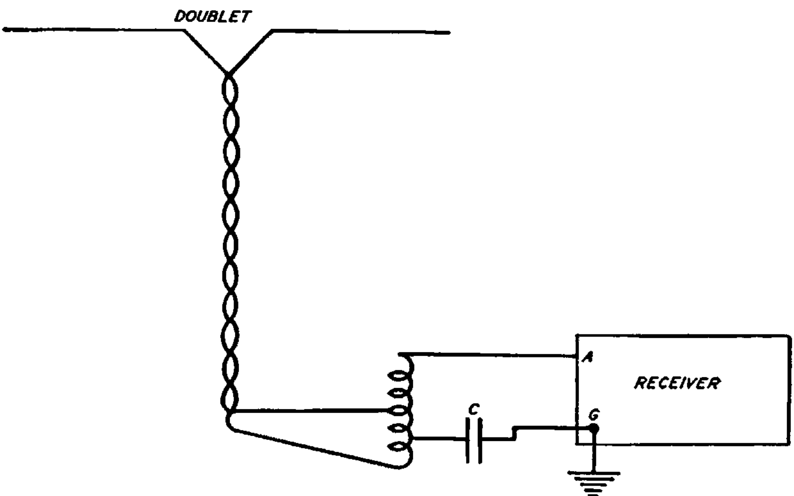


Fig. 103D. Antenna System Providing Noise Reduction Only on Short-Wave Bands

Such devices usually were advertised as "antenna eliminators" as well, and claims were made that the device would do away with the antenna as well as eliminate the annoyance of static crashes. However, it is obvious that since the form of the radio wave is changed by electrostatic discharges, any reduction in the static will likewise reduce the signal pick-up, and that additional amplification will result in the reappearance of the static.

Transmission Lines. Cross-talk and inductive effects in telephone circuits are eliminated by means of a balanced transmission line, which has made possible the use of multi-wire cables.

The same principle is applied to noise-reducing antennas, a balanced transmission line replacing the single-conductor lead-in to eliminate extraneous noises or signals picked up by the lead-in itself.

A transmission line is a conductor or system of conductors used to transfer electrical energy from one device to another without adding or imposing its characteristics on either device. Its most common form is a "twisted pair" of conductors. The co-axial cable is another example. A balanced transmission line is one employing a transmission line in combination with transformers.

One method of using the balanced transmission line in noise-reducing antennas is shown in Fig. 103D. One of the conductors in the transmission line is connected to each of the separate parts of the flat top, and to its respective terminal of the primary winding of a coupling transformer. The center of the coupling transformer primary winding is connected to ground.

Noise Reducing Antennas. It has been stated that atmospheric static appears to have a "universal" frequency; and it has been shown how the amplitude characteristic of the radio wave is changed when the wave passes through an area in which an electrical disturbance is taking place. It is logical to assume, therefore, that as long as amplitude modulation is the governing factor in the shape of a radio wave, little can be done by way of developing an antenna system that will eliminate the effects of atmospheric electrical disturbances from the desired signal. Experiments in the use of frequency modulation being conducted by Major Edward H. Armstrong promise to accomplish the elimination of most, if not all the interference caused by electrostatic discharges in free space. Noise-reducing antennas are designed to reduce insofar as possible the effects of "man-made" static on radio reception.

Early models of radio receiving sets were so lacking in sensitivity that they required an antenna with a horizontal conductor anywhere from 100 feet to 150 feet in length in order to obtain enough signal pick-up for efficient operation. It was further recommended that the installation be made in such a way that the lead-in would be as short as possible.

The need for large antenna signal pick-up was obviated by the development of more highly sensitive multi-band receiving circuits. More compact antennas were made possible, due to the fact that the horizontal portion could be materially reduced. However, there was no appreciable improvement in the signal-to-noise ratio of the received signal, and such slight improvement as did occur was due to the fact that although both signal and noise pick-up were reduced proportionately in the shortened antenna, the amplification and selector stages in the receiving circuits gave added impetus to the broadcast signal, due to the resonance gain in the tuned circuits.

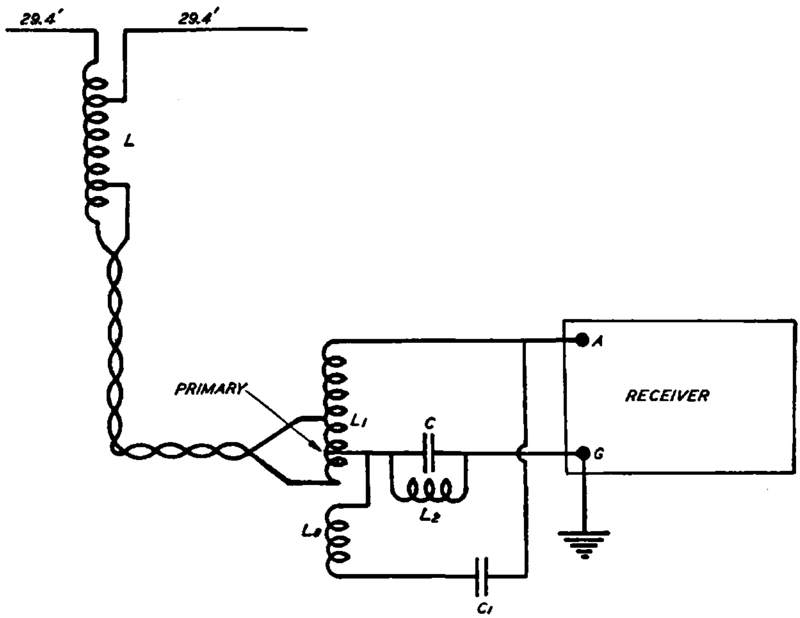


Fig. 103E. Antenna System Providing Noise Reduction in Broadcast and Short-Wave Bands

The indoor type of antenna is generally a poor collector of signal energy, and at the same time may be located in the heart of a noise area. The use of such an antenna with all-wave radio receivers is not recommended under any circumstances. If a receiver operating on an indoor antenna is free from noise, it means only that the antenna is not in a static area; it does not mean that noise has been eliminated by such methods.

One type of noise-reducing antenna that produces a cancellation of noise in the short-wave bands, but not in the long-wave bands, is shown in Fig. 103D, while a more elaborate type that is effective in broadcast as well as short wave bands is shown in Fig. 103E.

How Noise is Reduced. The signal energy picked up in the doublet portion of the antenna is fed to the receiving circuits by a transmission line, which, according to definition, does not add its dimensional characteristics to those of the flat-top portion; provided, however, that its length is not a multiple of the length of the doublet. The transmission line, which is a twisted pair in weather-proof covering, terminates at its base in a coupling transformer, preferably of the autoformer type, because of less leakage and also because of the simplification in construction and consequent lower cost.

If the doublet is to be used for the reception of short-wave signals only, the center-tap of the primary of the autoformer can be connected directly to ground. However, if such a connection is made, a switching arrangement to disconnect the ground must be provided in order to adapt the doublet to broadcast frequencies, at which time the doublet is used as a conventional **T**-type antenna. Therefore, in order to accomplish automatic switching, the center tap is connected to the ground through a small condenser, which permits the flow of high-frequency signal energy and allows operation in the short-wave bands, but isolates the coil from ground at broadcast frequencies, because of the high reactance of the condenser to the relatively low frequencies of the broadcast band. The condenser in the circuit causes a slight loss of signal energy in the broadcast band, but the reduction of noise in the short wave bands is so great (from 5 to 50 times) that it is greater than would be obtainable by using a standard antenna and lead-in arrangement.

The all-wave noise-reducing antenna system requires the use of a second autoformer at the junction of the flat-top portion of the antenna and the transmission line. The lower transformer has two secondaries, the broadcast band using half the primary and the remaining turns of the secondary of the autoformer, the short-wave band employing a separate coil that is inductively coupled to the primary winding.

The complete system is shown in Fig. 103E. Short-wave signal energy picked up in the doublet causes a flow of current which produces a voltage drop in the upper few turns of transformer *L*, induces a voltage in the lower turns of *L* by electromagnetic induction, and causes a difference of potential across the upper terminals of the transmission line which, in turn, produces a current flow in the transmission line and the primary turns of L_1 of the lower transformer. Voltage is induced in L_3, which is coupled to L_1, by electromagnetic induction. This voltage is applied to the receiver terminals through a condenser, C_1, that has low impedance at the high frequencies.

Noise that is picked up in the transmission line produces like polarization, or in other words, a potential difference is not established between the two wires at any given point. Thus, if at any given position a wire is positive with respect to the upper terminal of the transmission line, a like point on the other wire will also be positive with respect to its upper terminal. A flow of noise current is set up in the transmission line, but as the current traverses the lower transformer primary it will set up magnetic fields in phase opposition. Each, therefore, cancels the other, so that no noise energy is induced in short-wave coil secondary L_3, and the noise energy is passed to ground through C and L_2. C_1L_3 resonates in the short-wave band, C_1 being relatively small (.0001 mfd.) while L_3 is large. C_1 is designed to have high impedance to broadcast frequencies.

In the broadcast band the doublet acts as a **T**-type antenna with the vertical lead-in picking up the signal while the flat-top portion acts as a capacity load. Signal energy that is picked up in the lead-in flows down the transmission line in phase; that is, it travels down both wires in the same direction. A cancellation of this part of the received energy is brought about in the primary of the lower transformer. Signal current also flows into the flat top, traversing the large section of inductance L in its movement.

An out-of-phase voltage is produced in the transmission line through transformer action, the large portion of coil L being intimately coupled with the lower few turns. The re-induced transmission-line voltage causes a flow of current down the transmission line through the primary of the L_1, and voltage is induced across the whole of coil L_1 by autotransformer action. The voltage thus produced is applied to the antenna and ground posts of the receiver, the upper portion of L_1 being connected directly to the antenna terminal of the receiver while the lower part connects to the ground through coil L_2. Coil L_2 loads the antenna, causing a partial resonating effect in the broadcast band. The in-phase currents, originally picked up by the lead-in, cancel out as explained in the preceding paragraph.

The noise-discrimination effect of the system is workable in the broadcast band when the source of pick-up is near the receiver end of the transmission line, the reduction being inversely proportional to the distance from the receiver to the noise-coupling point. If the noise is coupled near the upper transformer, no reduction will be effected, and noise picked up in the flat top will be conducted to the receiver the same as is the broadcast signal energy.

The condenser C and the coil L_2 are in the nature of a trap circuit resonating in the four-megacycle (4,000,000 cycle) band, which is desirable because of the poor efficiency of the **T**-type antenna and doublet at this frequency. No noise reduction can be obtained in the band.

An efficient ground is highly desirable in using all-wave antenna systems. The ground wire should be as short as possible, for it, too, is a portion of the complete antenna system and as such is capable of picking up interfering noise and carrying it to the receiver, see Fig. 103B. Actual earth connection, cold water pipes, metal building frames, and steam or hot-water radiators make effective ground connections, stated in the order of preference.

A SHIELDED ROOM IN WHICH RADIO RECEIVERS CAN BE TESTED FOR SENSITIVITY AND SELECTIVITY WITHOUT INTERFERENCE FROM NEARBY ELECTRICAL MACHINES AND CIRCUITS
Courtesy of Stromberg—Carlson Telephone Manufacturing Company

MODERN RADIO ESSENTIALS

CHAPTER XIV

AUTO RADIO

The principles involved in the design and operation of radio for use in mobile equipment such as automobiles are identical in all respects with those that have to do with the construction of a radio for the home. However, numerous problems have presented themselves, the solving of which has necessitated great expense and considerable effort on the part of engineers.

An auto radio, in order to satisfy the purchaser, must have high sensitivity—capable of reproducing the signals from stations that are at great distances. This condition is true particularly if the owner of the car is accustomed to making long trips through the country. It is not so true for the car owner who spends the greater part of his time in the vicinity of a metropolitan area where numerous broadcasting stations are located.

The fact that the car is effectively insulated from the ground through the rubber tires gives rise to the exclusive use of the counterpoise antenna system, an antenna of one sort or another being used in conjunction with the frame work of the car which serves as the counterpoise—or vice versa.

The ignition system of the motor gives forth a continuous series of highly damped, oscillating impulses, which, when picked up by the antenna system and carried to the receiver are represented in the form of clicks. When the car motor is running slowly as at idling speeds, the clicks are very pronounced, but are heard as a "hiss" when the motor is operating at high speed. It has been necessary, therefore, to eliminate the ignition interference, a problem that has offered many obstacles.

With it all, there is nothing that can be said about either the antenna system or the elimination of ignition interference, except in a general way in view of the rapid changes in the design of automobile bodies, and the development of interference elimination by the engineering laboratories.

As an example of one change that has taken place, it is well to mention that which affects in particular the antenna system. Whereas prior to 1934 practically all cars were constructed so that a portion of the top was a combination of cloth and wood (no metal), the cars designed during the latter part of 1934 were all-steel, the body made of one piece or two pieces joined together solidly at the top, eliminating the possibility of using a mesh or network of wires as an antenna.

The antenna system for use with an auto radio is necessarily one which has a relatively high capacitive reactance, because no matter what type of antenna might be used, the capacity between the antenna and the counterpoise is greater than that which exists in the average home set installation. The input circuit of the receiver must be designed to meet the condition.

Early types of auto-radio installations employed batteries to supply energy to the plate circuits of the receivers. As the development continued, however, different types of power-supply devices were developed, among them being the converter, a device that operates off the car storage battery and generates either a high-voltage direct current or alternating current, as the case might be, and the vibrator, a device that operates off the car storage battery also, but which, through a pair of vibrating contacts and associated apparatus sets up a high-voltage fluctuating current.

In the event that the converter previously mentioned generates direct current, there is no necessity for using any rectifying system in the receiver circuit in order to supply direct current for the plate potentials, but a filter is required to eliminate the ripple. However, if the generator produces alternating current, it then becomes necessary to employ the necessary rectifying and filtering circuits.

The vibrator normally produces a current that fluctuates sufficiently to give it alternating characteristics, thus requiring a rectifier and filter. One type of vibrator is known as the synchronous or self-rectifying type and requires no additional apparatus to supply the direct current for the plate circuits.

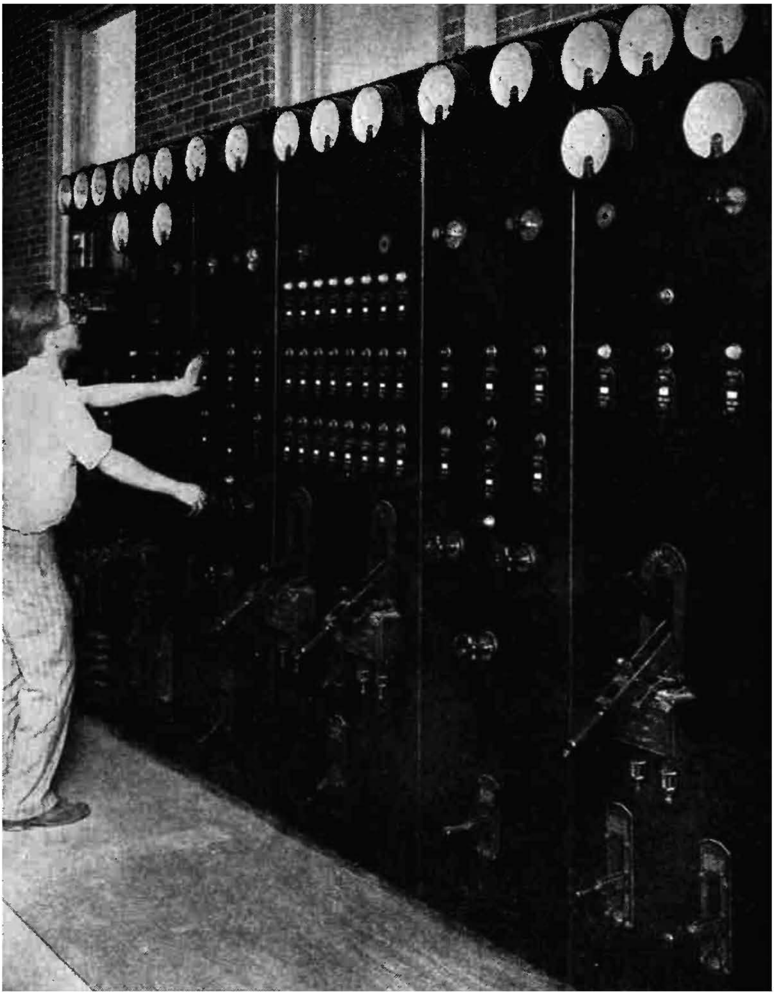
Interference ignition has been an equally difficult problem in radio installations made in airplanes and automobiles. As each cylinder fires, a spark is produced by the high potential difference that exists between the electrode of the spark plug and the block of the motor. In view of the fact that a condenser is used in the ignition circuit, the discharge across the plug is actually a series of oscillations the frequency of which is dependent upon the constants of the circuit.

One method of eliminating the effect of ignition interference was the use of a high-value non-inductive resistance in series with each spark plug, and another high-value non-inductive resistance in series with the distributor and the ignition coil. In addition thereto, it was found advisable to use shielding on the high-tension wires leading from the distributor to the individual spark plugs. Experiments on the test block, however, demonstrated that the high resistance caused an appreciable loss of current, and reduced the force of the spark across the terminals of the plug.

As a result of engineering investigations, it has been possible to design circuits for mobile radio in which the elimination of ignition interference is effectively accomplished by means of an adjustment on the set itself. The circuit employed varies with the different makes of receivers, but essentially it consists of a network that permits the free flow of signal current but by-passes the current of the interfering signal to the chassis of the car. The generator and starter of the car may cause interference also, but this type of interference can be effectively by-passed to ground by means of a condenser.

Tires moving rapidly across the pavements develop electrostatic potentials which may be eliminated usually by using a sweeping contact between the hub of the wheel and the car frame.

Each installation of an auto radio actually constitutes an individual problem. It is necessary to know the set that is being installed, as well as the type of car in which the installation is being made. These qualifications can be learned only by experience. Likewise with the power-supply devices. The generator is simply a motor and a generator, combined with a suitable filter. The vibrator is a device in which the reed, vibrating like the armature of an ordinary buzzer, serves to make and break contact in a circuit and cause the magnetic field to build up and collapse regularly and rapidly. The moving field serves to permit the building of high voltages to supply the requirements of the circuits.



THE POWER SWITCHBOARD PANELS USED TO CONTROL THE FLOW OF A 60-CYCLE ALTERNATING CURRENT TO THE RADIO APPARATUS IN A RADIO BROADCASTING STATION

Courtesy of Westinghouse Electric and Manufacturing Company

MODERN RADIO ESSENTIALS

CHAPTER XV

POWER SUPPLY

In order that the feeble signals impressed upon the antenna connected to a radio receiver—or produced by the microphone connected to an audio amplifier—may be effectively amplified, it is necessary to introduce power from an external source, which source is known as a power-supply unit or device. Batteries of the wet or dry variety served to furnish the power required to operate radio apparatus in the beginning, and continue to be used for the purpose in areas where electric power is not available. Electrically operated power-supply devices have been developed for use in those areas where electric power is provided.

In the previous chapters that have related to vacuum tubes, it has been shown how the positive charge upon the plate element of the tube serves to attract the negative charges given off by the cathode—or filament—thereby causing a current to flow in the output circuit of the tube. It is evident that if the charge upon the plate element were alternately positive and negative, as it would be if alternating current were impressed upon the plate, the plate would attract the electrons during the positive half of the cycle and repel them during the negative alternation with the result that the signal impressed upon the speaker would have a regular vibrating period corresponding to the frequency of the alternating current impressed upon the plate elements. Therefore, it is further evident that it is necessary to convert the alternating current into direct current in order that the charge upon the plate may be positive at all times.

In Chapter VII, "Vacuum Tubes," the principles involved in converting alternating current to direct current by means of a diode vacuum tube were explained. It was shown how by using a single plate element or anode one-half of the alternating wave was eliminated, but when another anode is used, the resultant wave assumes the form created when a coil of wire is rotated through a magnetic field—the current flows in the same direction, but pulsates by rising from zero potential to a maximum, and then returning to zero again.

Pulsations, such as delivered by a rectifier tube, would cause variations in the output of a circuit as shown further in Chapter VII under the heading "Grid-Voltage, Plate-Current Relationship." Each of the pulsations, causing a varying plate voltage would cause a corresponding rise and fall in the flow of plate current. Therefore, it is necessary to introduce apparatus to eliminate the variations and to provide as nearly continuous flowing direct current as possible.

Filters. A filter as applied to a power supply device is a combination of the proper electrical units to effectively produce a continuous flowing direct current for distribution to the plate circuits of the various stages of a receiver or amplifier. It consists of condensers and inductance units.

The subject of filters was discussed generally in Chapter VIII, and again in Chapter V it was shown how a fluctuating current flowing through an inductance causes a counter electromotive force that opposes the flow of the fluctuating current; and how a condenser stores a charge and then releases it into the circuit when the pressure is released. Both of these phenomena are applied to the operation of a filter in a power supply device.

Fig. 104 shows a combination of the circuit shown in Fig. 58 and a filter network.

Due to the action of a rectifier tube of the full-wave type a 60-cycle alternating current will produce 120 pulsations which must be filtered out in order for the current flow to be continuous. A half-wave rectifier produces 60 pulsations. In other words, a full-wave rectifier produces twice as many pulsations as the original current; a half-wave rectifier produces the same number of pulsations as the frequency of the current supplied to the device. Higher frequencies are filtered with greater ease than the lower frequencies, which means that the 120-cycle impulse is filtered out with greater facility than a 60-cycle impulse.

In the design of a filter circuit to eliminate the ripple in the current delivered by a rectifier tube it is necessary to design what is known as a "trap," a filter that will prevent the flow of alternating current and at the same time permit the free flow of direct current. Referring to Fig. 71 and the text which accompanies it in Chapter

VIII, it will be seen that alternating current is prevented from flowing in that portion of the circuit in which the choke coil—an inductance—is connected and that direct current is prevented from flowing in the circuit in which a condenser has been connected. On the other hand, however, the alternating current flows through the circuit in which the condenser is placed, and the flow of direct current is retarded in the circuit containing the inductance only by the ohmic resistance of the inductance itself, which, in most instances, is negligible.

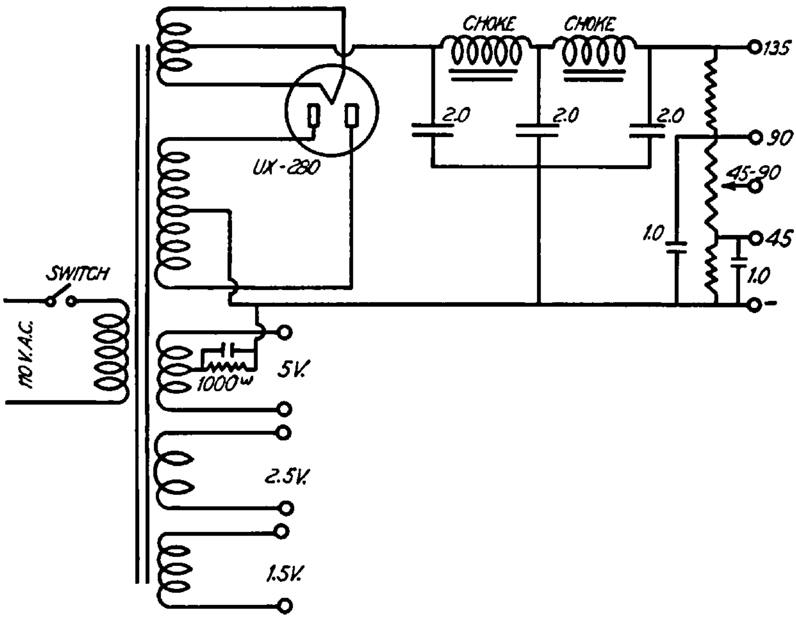


Fig. 104. Arrangement of Choke Coils, Condensers, and Resistances in a Power Supply Unit

Referring now to Fig. 104, the alternating current—or pulsations delivered by the rectifier tube—are effectively stopped by the inductance units (chokes) in the positive side of the circuit, but the condensers connected between the positive and the negative sides of the circuit provide a path for the alternating-current impulses by alternately charging and discharging the plates of the condensers.

Fig. 105 shows the relative wave form of the current in a power supply device. That in the primary winding of the power transformer is usually low-voltage alternating current. One of the secondary windings "steps down" the voltage for the filament of the rectifier tube. Another secondary winding "steps up" the voltage in order to provide voltages prescribed for the circuits of the

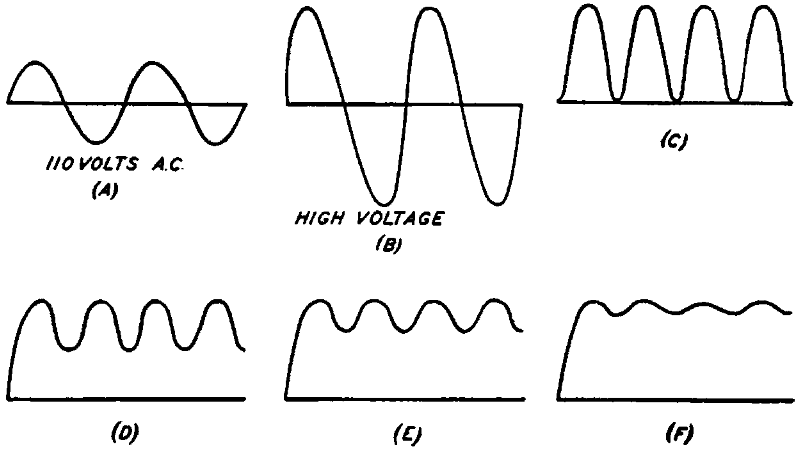


Fig. 105. Curves Showing the Result of Passing Alternating Current (*A*) through a Transformer (*B*), Rectifier Tube (*C*), and Filters (*D*, *E* and *F*)

radio receiver or amplifier. The two secondary windings deliver an alternating current that has a wave form identical with that which is passing through the primary winding.

After passing through the rectifier tube, however, the wave form changes perceptibly, as shown at *C* in Fig. 105. Each of the alternations above the zero line at *B*, Fig. 105, have been retained, and the space between them has been filled with other alternations. The current is now pulsating, but does not reverse its direction of flow.

The first condenser in the filter network assumes a charge during the time when the voltage is increasing in each of the alternations, and gives up its charge during the period when the voltage is decreasing so that the current has a wave form similar to that shown at *D*, Fig. 105, before it reaches the first choke coil.

The counter electromotive force set up in the choke coil retards the flow of the pulsating current, and the peak voltages tend to increase the charge upon the plates of the first condenser, thus giving it a still greater charge to fill in the valleys between the peaks of the wave. So, at the output of the first choke coil the current has assumed the form as shown at *E*, Fig. 105.

After the current has passed through the second portion of the filter network, during which time it is subjected to the same process as during the first half of the filter, it assumes a practically steady voltage at *F*, Fig. 105, such variations as remain being negligible in their effect upon the radio or amplifier circuits.

The circuit shown in Fig. 104 represents the fundamental type of power supply unit. In practice, it may be found unnecessary to use more than one choke because a single choke may serve to effectively produce a continuous flow of direct current. The field coil of a loud speaker may be used as one of the choke coils, or the field coil may serve as the only choke coil required, because of its high inductance.

Voltage Divider. It is necessary to make provision for the voltages of different values in order to supply the proper potentials to the various elements of the vacuum tubes in the radio or amplifier stages. Fig. 104 shows the voltage divider used in earlier models of power units, the resistance unit being connected directly between the positive and negative sides of the line so that there is a constant load on the circuit.

The calculation of the values of the resistance units to provide

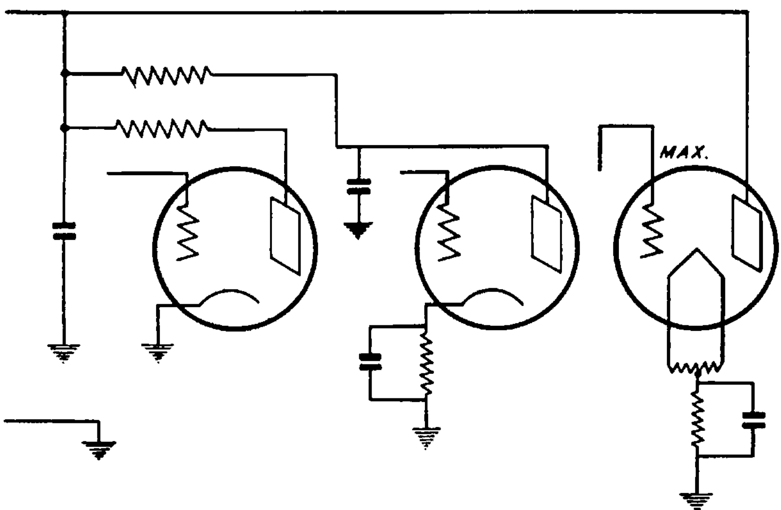


Fig. 106. A Voltage Divider Using Individual Resistance Units

a given voltage involves an application of Ohm's law, E=IR. Thus, by knowing the value of the drop in voltage and the current that will be drawn at that particular potential, the resistance may be calculated readily. In a voltage divider such as shown in Fig. 106, it is necessary also to allow for parasitic drain, which allowance is made in that part of the divider nearest the negative side of the circuit. The drain allowed is added to the normal current drain for each of the steps from negative, and as each succeeding resistor is calculated the total current drain—parasitic and that drawn by the radio or amplifier circuits—is used as the value of I in the formula.

Another method to provide for the distribution of the voltages is to use a resistance unit for each voltage value. Here again, the amount of resistance is determined by applying Ohm's law, taking into account the current drain and the drop in the voltage from the maximum potential. An example of a circuit using individual potential-drop resistance units is shown in Fig. 106.

Direct-Current Power Supply Devices. A power supply unit to provide power for a receiver or amplifier to operate directly off the power lines supplying direct current differs from one that is used in an alternating-current circuit only in the elimination of the rectifier circuit, including the transformer. The ripple that has been shown to exist in a rectified alternating current is present also in commercial direct current, although not so predominant. Filters consisting of condensers and filter chokes serve to eliminate the ripple and provide a continuous flowing direct current which may be divided and directed to serve the respective purposes as shown in the preceding paragraphs.

In view of the fact that most of the direct current used commercially is 110 volts, and since it has been shown that direct-current voltage cannot be "stepped up" by means of transformers, the radio receiver or amplifier must be designed to operate at a little less than 110 volts, or a means must be provided to obtain a higher voltage. There are three methods of obtaining the higher voltages. First, a circuit incorporating a voltage-doubling vacuum tube may be used; second, a generator operating off the 110-volt direct-current system and generating a higher direct-current voltage may be used; or third, a vibrator similar to that used to provide the power for automobile radio receivers may be employed. In either event, the principles embodied in their use have been explained in this text, and it is necessary to ascertain the physical specifications of the particular device that is used.

APPENDIX

TABLE V

Calculations of Resonant Circuits

Wave Length Meters	Frequency Kilocycles	LC Value	Wave Length Meters	Frequency Kilocycles	LC Value
1	300,000	.00000028	39	7,692	.000428
2	150,000	.00000113	40	7,500	.000450
3	100,000	.00000253	41	7,317	.000473
4	75,000	.00000450	42	7,143	.000497
5	60,000	.00000704	43	6,977	.000520
6	50,000	.00001013	44	6,818	.000545
7	42,857	.00001379	45	6,666	.000570
8	37,500	.00001801	46	6,522	.000596
9	33,333	.0000228	47	6,374	.000622
10	30,000	.0000281	48	6,250	.000649
11	27,273	.0000341	49	6,123	.000676
12	25,000	.0000405	50	6,000	.000704
13	23,077	.0000476	51	5,880	.000732
14	21,428	.0000552	52	5,770	.000761
15	20,000	.0000633	53	5,660	.000791
16	18,750	.0000721	54	5,560	.000821
17	17,647	.0000813	55	5,450	.000851
18	16,666	.0000912	56	5,360	.000883
19	15,789	.0001016	57	5,260	.000912
20	15,000	.0001126	58	5,170	.000947
21	14,286	.0001241	59	5,080	.000980
22	13,636	.0001362	60	5,000	.001013
23	13,044	.0001489	61	4,918	.001047
24	12,500	.0001621	62	4,839	.001082
25	12,000	.0001759	63	4,762	.001117
26	11,538	.0001903	64	4,688	.001153
27	11,111	.0002022	65	4,615	.001189
28	10,714	.0002207	66	4,546	.001226
29	10,345	.0002367	67	4,478	.001263
30	10,000	.000253	68	4,412	.001301
31	9,677	.000270	69	4,348	.001340
32	9,375	.000288	70	4,286	.001379
33	9,091	.000307	71	4,225	.001419
34	8,824	.000325	72	4,167	.001459
35	8,571	.000345	73	4,110	.001500
36	8,333	.000365	74	4,054	.001541
37	8,108	.000385	75	4,000	.001583
38	7,894	.000406	76	3,947	.001626

TABLE V (Continued)

Calculations of Resonant Circuits

Wave Length Meters	Frequency Kilocycles	LC Value	Wave Length Meters	Frequency Kilocycles	LC Value
77	3,896	.001669	115	2,609	.00372
78	3,846	.001712	116	2,586	.00379
79	3,798	.001757	117	2,564	.00385
80	3,750	.001801	118	2,542	.00392
81	3,704	.001847	119	2,521	.00399
82	3,659	.001892	120	2,500	.00405
83	3,615	.001939	121	2,479	.00412
84	3,571	.001986	122	2,459	.00419
85	3,529	.002034	123	2,439	.00426
86	3,488	.002082	124	2,419	.00433
87	3,448	.002130	125	2,400	.00440
88	3,409	.002180	126	2,381	.00447
89	3,371	.002229	127	2,362	.00454
90	3,333	.002280	128	2,344	.00461
91	3,297	.002331	129	2,326	.00468
92	3,261	.002382	130	2,308	.00476
93	3,226	.002434	131	2,290	.00483
94	3,192	.002487	132	2,273	.00490
95	3,158	.00254	133	2,256	.00498
96	3,125	.00259	134	2,239	.00505
97	3,993	.00265	135	2,222	.00513
98	3,061	.00270	136	2,206	.00521
99	3,030	.00276	137	2,190	.00528
100	3,000	.00281	138	2,174	.00536
101	2,970	.00287	139	2,158	.00544
102	2,941	.00293	140	2,143	.00552
103	2,913	.00299	141	2,128	.00560
104	2,885	.00304	142	2,113	.00568
105	2,857	.00310	143	2,098	.00576
106	2,830	.00316	144	2,083	.00584
107	2,804	.00322	145	2,069	.00592
108	2,778	.00328	146	2,055	.00600
109	2,752	.00334	147	2,041	.00608
110	2,727	.00341	148	2,027	.00617
111	2,703	.00347	149	2,013	.00625
112	2,679	.00353	150	2,000	.00633
113	2,665	.00359	151	1,987	.00642
114	2,632	.00366	152	1,974	.00650

TABLE V (Continued)

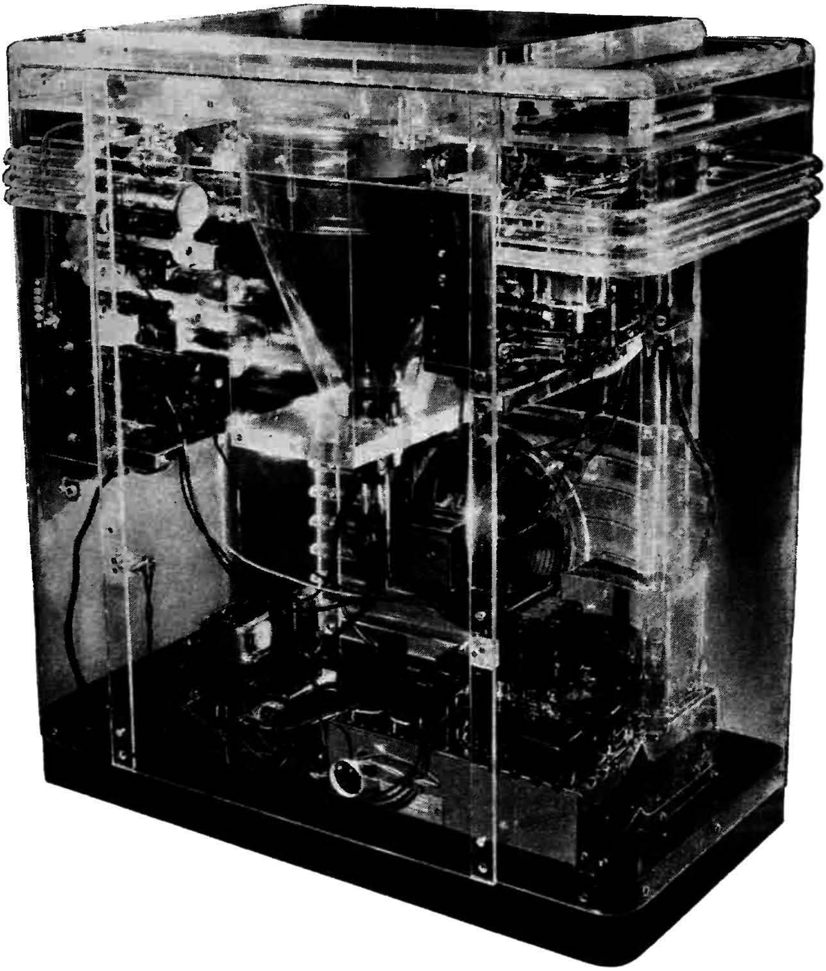
Calculations of Resonant Circuits

Wave Length Meters	Frequency Kilocycles	LC Value	Wave Length Meters	Frequency Kilocycles	LC Value
153	1,961	.00659	191	1,571	.01027
154	1,948	.00668	192	1,563	.01038
155	1,936	.00676	193	1,554	.01048
156	1,923	.00685	194	1,546	.01059
157	1,911	.00694	195	1,539	.01070
158	1,899	.00703	196	1,531	.01081
159	1,887	.00712	197	1,523	.01092
160	1,875	.00721	198	1,515	.01103
161	1,863	.00730	199	1,508	.01115
162	1,852	.00739	200.0	1,500	.01126
163	1,841	.00748	201.4	1,490	.01142
164	1,829	.00757	202.7	1,480	.01157
165	1,818	.00766	204.1	1,470	.01173
166	1,807	.00776	205.5	1,460	.01189
167	1,796	.00785	206.9	1,450	.01205
168	1,786	.00794	208.3	1,440	.01222
169	1,775	.00804	209.8	1,430	.01239
170	1,765	.00813	211.3	1,420	.01256
171	1,754	.00823	212.8	1,410	.01274
172	1,744	.00833	214.3	1,400	.01292
173	1,734	.00842	215.7	1,390	.01311
174	1,724	.00852	217.4	1,380	.01330
175	1,714	.00862	218.9	1,370	.01350
176	1,705	.00872	220.6	1,360	.01370
177	1,695	.00882	222.2	1,350	.01390
178	1,685	.00892	223.1	1,340	.01411
179	1,676	.00902	225.6	1,330	.01432
180	1,667	.00912	227.3	1,320	.01452
181	1,658	.00922	229.0	1,310	.01476
182	1,648	.00932	230.8	1,300	.01499
183	1,639	.00943	232.6	1,290	.01522
184	1,630	.00953	234.4	1,280	.01546
185	1,622	.00963	236.2	1,270	.01571
186	1,613	.00974	238.1	1,260	.01596
187	1,604	.00984	240.0	1,250	.01622
188	1,596	.00995	242.8	1,240	.01648
189	1,587	.01005	243.9	1,230	.01675
190	1,579	.01016	245.9	1,220	.01702

TABLE V (Continued)

Calculations of Resonant Circuits

Wave Length Meters	Frequency Kilocycles	LC Value	Wave Length Meters	Frequency Kilocycles	LC Value
247.9	1,210	.01731	361.4	830	.03684
250.0	1,200	.01760	365.9	820	.03774
252.1	1,190	.01789	370.0	810	.03866
254.2	1,180	.01821	375.0	800	.03960
256.3	1,170	.01852	379.7	790	.04060
258.2	1,160	.01882	384.6	780	.04164
260.8	1,150	.01914	389.6	770	.04268
263.4	1,140	.01946	394.8	760	.04380
265.5	1,130	.01980	400.0	750	.04495
267.8	1,120	.02016	405.4	740	.04630
270.3	1,110	.02052	410.9	730	.04767
272.7	1,100	.02090	416.7	720	.04907
275.2	1,090	.02130	422.5	710	.05051
277.8	1,080	.02171	428.6	700	.05198
280.4	1,070	.02213	434.9	690	.05348
283.4	1,060	.02255	441.2	680	.05501
285.7	1,050	.02299	447.7	670	.05658
288.5	1,040	.02343	454.5	660	.05823
291.3	1,030	.02389	461.5	650	.05998
294.1	1,020	.02436	468.7	640	.06185
297.0	1,010	.02483	476.2	630	.06383
300.0	1,000	.02532	483.9	620	.06593
303.0	990	.02582	491.8	610	.06808
306.1	980	.02634	500.0	600	.07040
309.3	970	.02688	508.5	590	.07288
312.5	960	.02746	517.2	580	.07551
315.8	950	.02804	526.3	570	.07827
319.1	940	.02864	535.8	560	.08119
322.6	930	.02926	545.5	550	.08428
326.0	920	.02991			
329.7	910	.03059			
333.3	900	.03129			
337.1	890	.03201			
340.9	880	.03275			
344.9	870	.03351			
348.8	860	.03429			
352.9	850	.03511			
357.1	840	.03596			



TRANSPARENT PLASTIC TELEVISION RECEIVER ON VIEW AT THE NEW YORK WORLD'S FAIR

Courtesy of R. C. A. Manufacturing Co., Inc., Camden, New Jersey

TELEVISION IMAGE, AS PICKED UP ON RECEIVER CONSTRUCTED IN ELECTRONICS LABORATORY, NEW YORK CITY

The Picture of the Boy Scout is from a News Reel Film Depicting the Handicraft and Other Activities of the Scouts, from NBC Transmissions.

PHOTOGRAPH SHOWING DETAIL OF TELEVISION IMAGE ON SCREEN

The Photograph Shows What Was Seen on the Screen of the Laboratory Receiver of Electronics Magazine During a Showing of the Motion Picture Film "Gunga Din" on the Day that the Regular Television Service Was Inaugurated by the National Broadcasting Company.

Photos, Courtesy of Beverly Dudley, Associate Editor of Electronics

ELECTRONIC SCANNING

By 1935, a picture-dissecting method known as electronic scanning had made such progress in the television laboratories that practically all research on the use of mechanical devices for the purpose was discontinued in the United States. The motor-driven rotating disc, having apertures to permit the passage of light at given positions at specific instants, was replaced by the cathode-ray tube with its electron "gun," which produces a weightless, inertialess beam of electrons and controls its movement.

Laboratory experiments disclosed that electronic scanning had numerous advantages over mechanical methods, and that the results obtained were distinct improvements. Among the most important advantages and improvements may be mentioned:

First, the detail of the picture. Due to the physical limitations imposed upon any moving mass, the mechanical scanning devices could not be operated at sufficiently high speeds to maintain clarity. Frequently the characters were indistinguishable because instantaneous differentiations in the various degrees of shading were impossible due to the slow speed of the disc and the size of picture area covered by the beam of light that passed through the aperture in the disc. Electronic scanning eliminates both of these obstacles. The electron beam is capable of following extremely rapid variations of control impulses, can be speeded up to cover the entire picture area many times per second, and, since the electron stream is very small, it covers an extremely small part of the picture at any given instant, and thereby dissects the image in great detail.

Second, the source of light for the reproduction of a mechanically scanned television picture, as has been shown, was a gas-filled lamp consisting of two plates, one of which glowed with an instantaneous intensity according to the nature of the impulse at a given instant. Besides providing insufficient illumination to reconstruct the picture, the gas-filled tubes did not respond quickly enough to variations in the strength of the current delivered to its electrodes to prevent a carry-over effect that was manifested by irregular outlines. The electron stream created by the electron "gun" in the cathode-ray tube, when directed against the fluorescent screen on the end of the tube (see Fig. 58), causes an illumination that is intensely bright, thus providing an intensity of light comparable to that of the ordinary motion picture screen. At the same time it reacts to minute variations in current strength, so that there is no noticeable carry-over due to lag in response to current changes.

Third, synchronism between the scanning device at the transmitter and that at the receiver must be maintained at all times in

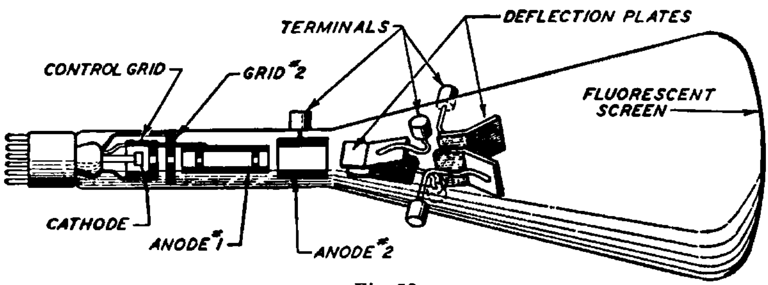


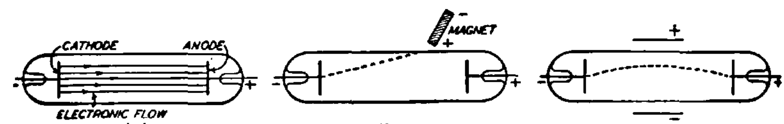
Fig. 58

order for the picture to be properly reconstructed and kept within the "frame." Mechanically operated devices placed a great deal of dependence on the frequency of the power lines feeding the transmitter and the receiver for synchronization but, regardless of the frequency control apparatus employed on the lines, it was necessary to make adjustments at intervals in order to synchronize the picture at the receiver with that at the transmitter. Electronic scanning makes possible the transmission of a synchronizing signal each time the electron stream starts across the picture area, and the receiver, responding to the synchronizing signal, keeps the reproduced picture in proper alignment.

Crookes Tube. The history of the cathode-ray tube goes back to the early part of the nineteenth century when Sir William Crookes, an English chemist, conducted experiments with potentials applied to electrodes in vacuum tubes. His experiments resulted in the discovery of the electron and paved the way for the development of the tubes of the present day in which an electronic stream emitted by one of the electrodes casts a beam upon a special screen that enables the eye to perceive certain effects that are produced.

A form of the Crookes tube is shown in Fig. 59 at (*a*) with the cathode and the anode as indicated. When a potential difference reaches the proper value, the cathode, a negatively charged electrode, gives off particles that are attracted by the anode upon which there is a positive charge. The electronic stream is said to have no weight and no inertia, so that the energy required to control it is negligible. The speed with which it can be controlled is determined by the limits of the controlling devices or circuits.

The designation of the stream of electrons as cathode rays was



(a) (b) (c)
Fig. 59

made some years after the discovery by Crookes, and the nomenclature was evolved from the fact that the electrons were emitted by the cathode.

The stream of electrons emitted by the cathode of a tube such as the Crookes cell can be deflected in any direction desired by means of an electric field. The deflection of the stream is shown in Fig. 59 at (*b*), in which a tube of the same type as that shown in Fig. 59 at (*a*) is used for demonstration purposes. An ordinary bar magnet placed alongside the tube, as shown, will draw the stream to it. Had it been reversed end for end, the stream would have been deflected downward, repelled by the magnetic field of opposite polarity.

An electrostatic field may also be utilized for deflecting the electronic stream; in fact such an arrangement is used, in effect, in those tubes that are used for television reproduction. In other words, if two plates were placed one on either side of the electron stream, as shown in Fig. 59 at (*c*), and a positive charge were placed on the upper plate with a negative charge on the lower one, the stream of electrons would be deflected from the negative plate toward the positively charged one, and the amount of deflection would depend, among other things, upon the charge on the plates.

Then, too, a solenoid coil placed alongside the tube would serve a similar purpose. When the current flowed through the coil in one direction, the stream would be deflected in the direction of the positive field; and if the direction of flow of the current were reversed, the electron stream would be deflected in the opposite direction.

Braun Tube. The tube about which the television developments center is that known as the Braun tube, the elements of which are shown diagrammatically in Fig. 60. The Braun tube is merely an

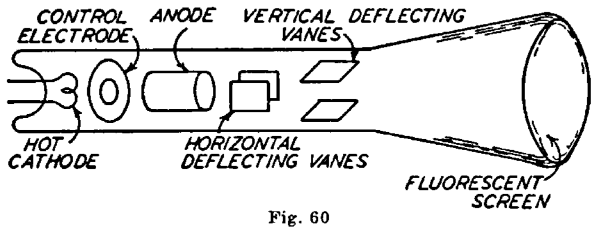


Fig. 60

improved form of the Crookes tube, the improvements being of such a nature as to provide greater efficiency and flexibility. Among the improvements is the use of the hot cathode.

Television reproduction demands a high degree of brilliance, and, as in the case of the development of glow lamps, so with the cathode-ray tubes, it has been found that the hot-cathode type of emitter will provide a greater flow of electrons with a corresponding

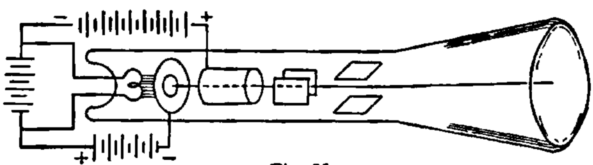


Fig. 61

increase in brilliance. Consequently, referring to the diagram, Fig. 61, attention is called to the filament type cathode, which is similar to that found in ordinary electronic devices in which a flow of electrons is created by the application of heat caused by the passage of an electric current through a filament element.

The electron-emitting element is called the cathode, as shown. Near it is a metal disc, solid except for an aperture through the center, through which the electrons flow on their way to the anode. The disc acts in a manner similar to the grid of an ordinary vacuum tube and serves also to permit the passage of a thin stream of the electrons, returning those which strike the metal itself to the filament through the associated circuit. In this way those electrons which pass through the center of the disc are the only ones that flow to the anode, the metal cylinder to the right of the control electrode.

The potential difference existing between the anode and the cathode of the Braun tube is extremely high so that the electrons gain an enormous speed. They continue through the anode between the first pair of plates, shown in Fig. 60 as the horizontal deflecting vanes. If there is no charge upon the horizontal deflecting vanes, the stream continues in a straight line and passes between the second pair of plates, designated as the vertical deflecting vanes. Here, again, if

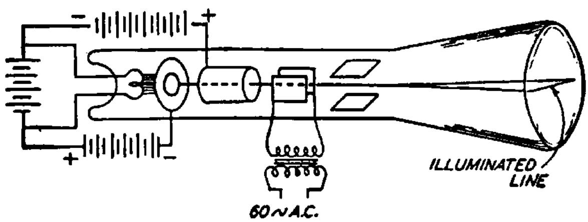


Fig. 62

there is no charge on the plates or vanes, the stream continues to flow undeflected to the end of the glass tube.

The end of the tube is specially treated to make it fluorescent, so that the spot where the electron stream strikes the glass will be visible. A chemical compound of calcium, tungsten, and zinc silicate is one of the fluorescent materials. If there are no charges upon the deflecting vanes, the stream of electrons will strike directly in the center of the fluorescent screen and will be manifested as a brilliant point of light.

Let us assume that a slight difference of potential is applied across the horizontal deflecting vanes, and that the current which is thus applied be alternating. When one of the vanes is charged positively, the other will be negative so that the electron stream will be deflected toward the vane which has the positive charge. When the direction of flow of the current reverses and the vane that was negatively charged takes a positive charge, the stream of electrons will move toward the other vane, and so on. If the alternations are impressed fast enough, the illumination of the fluorescent screen will appear as a line.

Fig. 62 illustrates such a condition. The cathode is connected to a source of electrical energy, a negative potential is applied to the control electrode, and the anode is charged positively. Since the horizontal deflecting vanes are connected to the opposite terminals of an alternating-current source of supply, the electron stream is alternately drawn toward one and then the other of the vanes as the direction of flow changes in the circuit. On account of the fluorescence

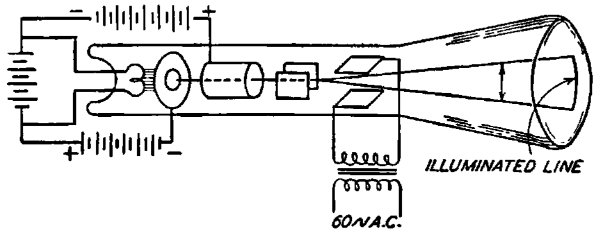


Fig. 63

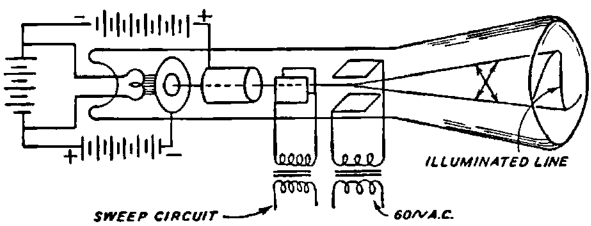


Fig. 64

of the screen on the end of the tube, the stream causes a line to appear thereon. If, however, the frequency of the alternations were slower, so slow, in fact, that the eye could follow the movement, the illumination would appear as a spot of light moving from side to side.

If the source of alternating current is disconnected from the pair of horizontal deflecting vanes and connected to the vertical deflecting vanes, as shown in Fig. 63, the illuminated line on the fluorescent screen will be vertical; again, if the frequency of the alternations were slow enough for the eye to follow, the illumination would appear as a spot of light moving vertically on the screen.

Thus, it is seen that the stream of electrons is deflected in accordance with the nature of the charge on the deflecting vanes and may be moved either upward, downward, or from side to side. It is evident then that if a charge is placed upon both sets of vanes, the stream may be directed to other positions on the fluorescent screen.

Fig. 64 shows the Braun tube with an alernating-current source of supply connected to the vertical plates and a sweep circuit connected to the horizontal deflecting plates. The result will be as shown on the end of the tube, and if the alternating current is pure, that is, true alternations with respect to time, a true sine wave will appear on the screen. The set-up as shown in Fig. 64 is that for an oscilloscope in which the characteristics of alternating currents may be studied with facility and accuracy.

Cathode-Ray Tube. The cathode-ray tube was developed originally to replace the string oscilloscope used in the observation of electrical phenomena and one of its earliest applications to radio was to determine the amount of ripple existing in the output of a "B" supply device. The string oscilloscope lacked the ability to follow rapid variations because of the inertia of its moving element. The beam of electrons, substantially inertialess, follows the wave form of the current being investigated, allowing the study of frequencies far beyond the limits imposed by the mechanical type of oscilloscope.

The first cathode-ray oscilloscope was constructed by Braun in 1897. A scientist named Hess had suggested the use of such a device prior to that date but had not actually put it into operation. The original Braun tube made use of a cold cathode and depended upon a high voltage (10,000 to 100,000 volts) to set up the flow from the cathode. About this time it was found that the cathode-ray beam actually consisted of high-velocity electrons having a definite mass and electrical charge. The electron stream in the Braun tube was controlled to beam size by the use of a gas placed in the tube after evacuation. The high voltages necessary to actuate the Braun cold-cathode type tube restricted its use. However, in 1905 Wehnelt applied the use of a heated cathode as the electron emitting source, thus reducing the anode voltage to a value of from 300 to 2000 volts. Gas was used also in this tube to obtain beam focus, but the effect of the gas was found to be so harmful to the cathode emission material that the life of the tube was limited by positive ion bombardment to a few hundred hours.

The tube developed by the Western Electric Company in 1922 made use of a metal shield placed in front of the Wehnelt cathode to prevent emitter deterioration, and the life of the tube was accordingly increased.

The modern cathode-ray tube consists essentially of an *electron gun* capable of producing an emission of electrons from a heated point source, a system of control electrodes used for shaping, accelerating, and directing this beam, a means for deflecting the beam according to a preconceived pattern, and a fluorescent screen which is activated by the beam to produce light impulses. The assembly is housed in a glass envelope which is evacuated to a high degree. The cathode-ray tube is available in a variety of sizes and shapes, and is rated according to the diameter of the fluorescent screen, ranging from a minimum diameter of 1 inch to the larger sizes, designed specifically for television, having screens of from 14 to 18 inches in diameter.

Fig. 58 shows the construction of a cathode-ray tube that is suitable for general purposes. The electron stream may be deflected by either the electromagnetic or electrostatic method, or a combination of both, depending on the nature of the phenomena to be observed. This tube, with slight modifications, forms the basis of the modern television receiver, the television image being viewed on the fluorescent screen that is activated by electronic bombardment in accordance with the pattern of the object being televised.

Interlaced Scanning. The electron stream makes 441 horizontal sweeps in the vertical plane to effect one complete scanning, including the synchronization impulses. Thus, it is referred to as 441-line scanning.

The practice of offsetting the scanning of the picture area is employed in electronic television and is known as *interlaced scanning*. Each time the electron stream traverses the screen in a horizontal direction, it moves downward in a vertical direction the width of two lines. The process is continued until the bottom of the picture area is reached, when the stream is deflected to the upper part of the picture area, starting in at the second line from the top, and again, by moving two lines downward with each horizontal sweep, fills in the portions of the area not energized on the first scanning.

Thus, while the television picture is actually scanned at the rate of 30 frames per second, the effect of 60 frames per second is attained, while the band width necessary for transmission is that required for only 30 frames per second.

The Television Camera. In televising a scene, it is necessary to focus the image sharply on a photo-electric surface, which means that an optical lens system is required. The apparatus is known as a *Television Camera*. There are two distinct types of television cameras: the *Iconoscope,* developed by V. K. Zworykin, and the *Image Dissector,* developed by P. T. Farnsworth.

The Iconoscope, Fig. 65, is an electronic device contained in a glass envelope in the form of a globe having a long tapering neck. A mica sheet, having one side covered with a metallic coating and the

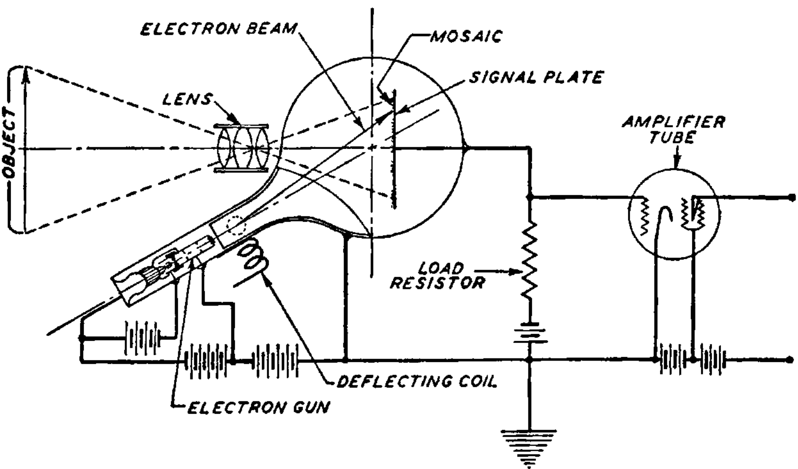


Fig. 65

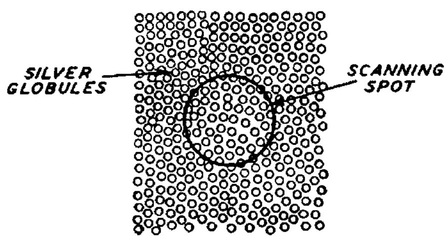


Fig. 66

other side coated with photo-emissive material, is placed inside the globe. The coating of active material, called the *mosaic,* see Fig. 66, is composed of a large number of minute photo-electric cells, each of which is insulated from the others. The metallic plating on the back of the mica sheet acts as a signal plate and connects to the picture amplifier. The silver globules on the photo-emissive side of the mica are formed by reducing particles of silver oxide sprinkled on the surface of the mica. When the silver oxide particles are heat treated, they form individual drops of silver that are sensitized by exposing them to ceasium vapor and further heat treatment.

The mica sheet is placed in such a position that it lies in the focal plane of the camera's lens system. Thus, light reflected from the image to be televised is sharply focused on the mosaic plate, and the photo-electric emission of electrons will take place from each minute photo cell in accordance with the incident light striking it. Thus at a given instant the space immediately in front of the mosaic will contain an "electron" image of the scene being televised at that instant. The mosaic plate is also exposed to a beam of electrons emanating from an electron gun housed in the tapering neck of the Iconoscope. Thus, the mosaic is under actuation from two sources, from the light source as reflected from the scene being televised, and from an electronic bombardment. The electron gun is similar to that used in a standard cathode-ray tube, as previously described. When the proper operating voltages are applied to the various elements of the gun, a sharply focused stream of electrons is emitted toward the center of the mosaic plate.

Deflection of the electron beam to enable it to cover every point on the mosaic may be accomplished by means of electrostatic deflection plates built into the neck of the tube, by a magnetic field set up by properly energized, externally mounted coils, or by a combination of electrostatic and magnetic deflection devices.

Near the junction of the globe with the neck, a portion of the glass wall of the Iconoscope envelope is coated on the inside with a metallic film that serves as an accelerating anode for the electron gun and as a collector anode for the electrons emitted from the mosaic plate.

In operation, an image is focused on the mosaic surface (by means of a lens system outside the tube) in the same manner as an image is focused on the plate, film, or ground glass of an ordinary camera. The varying degrees of light intensities on the different portions of the mosaic cause the respective portions of the mosaic to emit proportionate numbers of electrons which are attracted to the collector anode on the inner wall of the glass envelope. The signal plate resembles a large number of small condensers charged to varying degrees. Due to the fact that the active material on the mosaic is deficient in electrons, it forms a group of positive plates of a condenser. By directing a stream of electrons at the mosaic these charges may be equalized. When an electron beam discharges a portion of the mosaic, a surge of current flows from the metal back-plate to the electron gun; it is this current, flowing through a load resistor, that develops the signal voltage from the tube.

The signal, in order to be useful, must be taken from the mosaic in a predetermined order that is reproducible at the receiving station. This process, called *scanning,* consists of moving the electron stream across the mosaic at a uniform rate of speed, and making it fly back to the starting point to resume its uniform motion on another horizontal plane. After the electron stream traverses the plate in the horizontal direction, it is moved in a vertical direction at a much slower uniform rate, experiencing the same type of "fly back" at the bottom of the picture.

To accomplish such a scanning action, voltages of saw-tooth wave-form are impressed on deflection plates, or currents of saw-tooth wave-form are made to flow through deflection coils. Because the electron gun is not perpendicular to the signal plate, the length of the electron beam is variable from the top to the bottom of the picture, and since the deflection is proportional to the length of this electron beam, an effect known as *the keystone effect* is noticeable. This is corrected in practice by modulating the horizontal-sweep amplitude by the vertical-sweep signal and by slightly altering the vertical wave-form.

Varying the amplitude of the scanning voltages changes the portion of the mosaic plate in actual use, which gives an illusion of changing distance. Variation of the direct-current component supplied to the deflection plates or coils may be used to shift the usable portion of the picture to different parts of the mosaic plate to cause an illusion of rotation.

Such a tube may be operated under conditions similar to those necessary for motion-picture photography and has a resolution more than adequate for the 441-line scanning.

The Image Dissector tube, by use of a slightly different procedure, obtains similar results. The tube is constructed in a tubular glass envelope with a flat end. On this flat end the photo-emissive material is deposited on a transparent metallic coating. At the opposite end of the tube is a small target or anode, which, in the more complicated tubes, is replaced by a small aperture that opens into an electron multiplier. The inner surface of the glass wall of the tube is coated with a metallic film to act as a collector. A strong magnetic field along the axis of the tube is necessary, as well as the cross-magnetic fields, to produce the scanning action.

When in operation the Image Dissector has the image focused on the treated end of the tube. Being photo-emissive, the various portions of the surface will emit electrons in accordance with the light intensity. The tube is placed in a strong, uniform magnetic field that is parallel with the axis of the tube. The magnetic field causes all the electrons leaving the surface to assume a direction perpendicular to the flat end of the tube so that the cross section of the electron beam is the image focused on the active material. The entire beam is then moved across the target in a pattern similar to that in the Iconoscope. Striking the anode, the electrons flow through a load resistance back to the screen, developing the signal voltage. The coating on the wall of the tube serves to collect the electrons that do not strike the anode.

A tube such as has just been described has a very low output; so low, in fact, that the signal-to-noise ratio would be unfavorable. Therefore, in order to increase the signal output, the target is replaced by a nonconductive plate in which there is a small aperture which allows the portion of the beam being utilized at any particular instant to pass through to another section of the tube in which is placed an electron multiplier. The electron multiplier is a device that makes use of secondary emission to produce current amplification, and in this manner the sensitivity of the tube is increased several thousand times.

Transmission of Television Signals. The transmitted television signal, besides carrying the picture modulation, must also convey much other information to the receiving apparatus. By common accord, an increase in light incident on the camera tube causes a decrease in radiated power. At 75 per cent to 80 per cent modulation a so-called *black level* is set and any modulation in excess of this value produces the so-called *blacker-than-black* condition at the receiver. Modulation in this blacker-than-black region has no effect on the cathode-ray tube in the receiver, so in this region pulses necessary to keep the scanning circuits at the receiver and the transmitter in synchronism are transmitted.

For the horizontal scanning, one pulse is transmitted at the beginning of each line. To obtain vertical synchronism at the end of each vertical sweep, the wave form of the horizontal synchronizing pulses are altered so that, by the use of the proper circuit at the receiver, a single pulse is obtained. These pulses were originally generated mechanically, but are now produced by a complex system of multi-vibrators and wave-form changing circuits. Because the amplitude of the video signal bears no relation to the average brilliancy of the scene being televised, it is necessary to insert a direct-current component which will vary the picture intensity at the receiver.

Due to the fact that the picture signal is complicated in form and composed of abrupt changes, the frequency range for equipment used to transmit it must be very great. To transmit pictures of 441 lines at 30 frames per second, a band width of 3.5 megacycles (3,500 kilocycles) is necessary to preserve the detail. A band width of four megacycles (4,000 kilocycles) or greater is preferable.

The amplification of signals requires the use of special wide-band amplifiers termed video amplifiers, in which special forms of resistance coupling are used. To reduce the effect of shunting the high frequencies to ground due to inter-electrode and wiring capacities, the plate load resistance is made abnormally low. In order to compensate for this by-passing of the high frequencies a small inductance is inserted in series with the plate load resistance to provide a higher impedance plate load as the frequency increases. To compensate for losses in low-frequency gain a portion of the plate load resistance is shunted by a condenser to eliminate a portion of the resistor for the high and middle frequencies to boost the low frequencies.

By the proper choice of components, the time delay of the system is kept very nearly constant over the entire range. The video amplifier is usually over-corrected to compensate for attenuation in the lines to the transmitter and in the modulating system. To obtain sufficient gain under these conditions, special tubes have been developed which have high grid-to-plate transconductances. Since video amplifiers do not amplify the direct-current average picture intensity, this component is removed and reinserted at the modulator tube grids.

The generation of the radio frequency energy necessary for the transmission of television images is made difficult by the high frequencies involved. The stability of the crystal controlled oscillator is a desirable feature, but crystals are not available for the ultra-high frequencies at which television transmissions take place. To provide this desirable control, quartz crystals with natural frequencies near six megacycles are used, and a series of frequency multipliers are used as buffer amplifiers. After the desired frequency has thus been obtained, it is passed through one or more intermediate power amplifiers until sufficient radio frequency power is available to drive the modulated stage.

Grid bias modulation is used to modulate the transmitted carrier. The necessity of using grid modulation is imposed by the difficulty in obtaining video frequency voltages of sufficient magnitude for plate modulation. The modulator tubes, which are connected in parallel, are direct-connected to the final amplifier grid circuits, thus providing for the transfer of the direct-current average brightness component from the modulators to the modulated tubes.

To accommodate the television signal in the six-megacycle channels allotted for the purpose, it is necessary to suppress one of the side bands. In practice the low-frequency side band has been chosen for suppression, and side-band elimination is accomplished by the use of co-axial filters in the transmission line to the antenna. Such filters are designed to cut off at a frequency approximately .75 megacycles lower than the carrier. The final stage is modulated 50 per cent, in the conventional sense, to allow for a modulation gain that will occur in the receiver.

The antenna characteristics for television vary from those of most ultra-high frequency applications in that they must be capable of radiation without noticeable attenuation over a wide band of frequencies. Dipoles of special shapes overcome this restriction. Because of high frequencies involved, transmission is limited to line-of-sight distances. Therefore, the horizon is considered the limit of dependable signals and this distance, in miles, varies approximately as the square root of the height, in feet, of the antenna above the ground. At a height of 400 feet the radius of the horizon is approximately 24 miles, while if the height is increased to 900 feet the radius increases to approximately 37 miles.

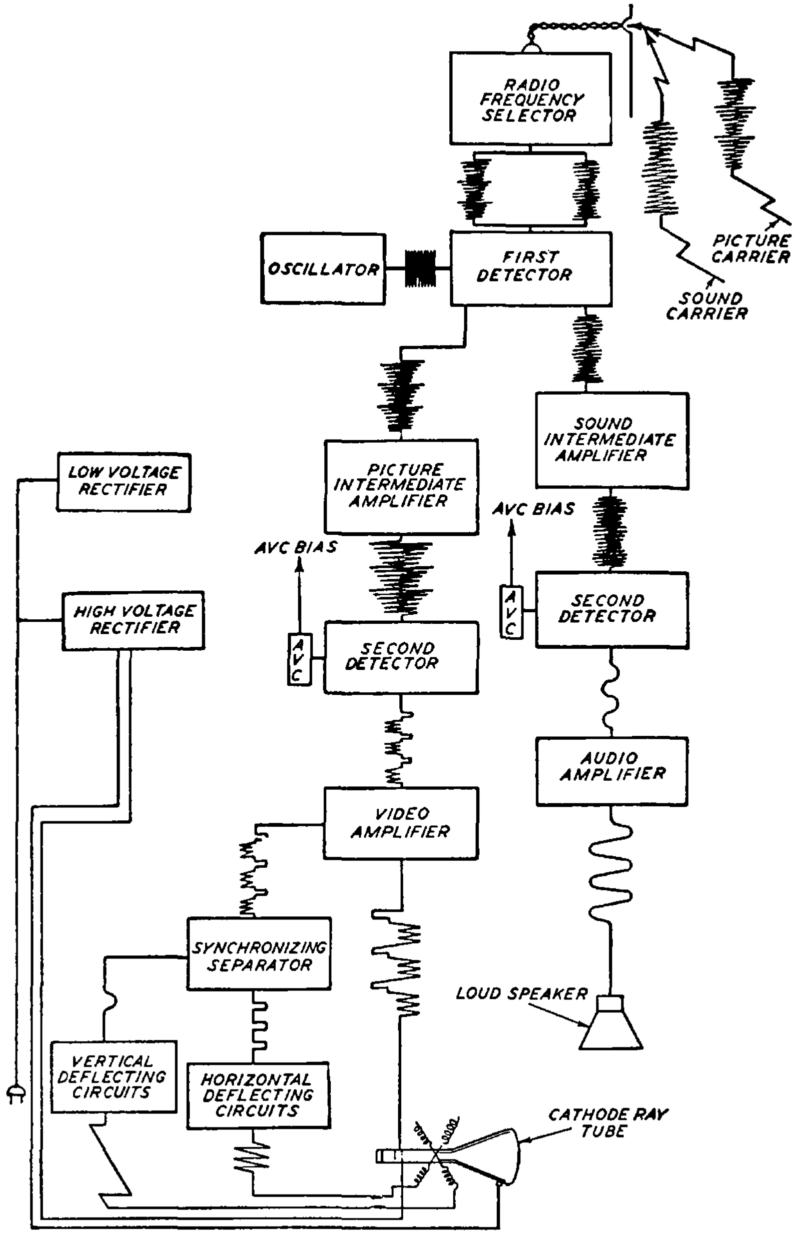
A second transmitter is required to transmit the sound that accompanies the televised action. Such a transmitter consists of a radio frequency unit similar to that used for picture transmission with the exception that the final amplifier and antenna systems are not required to pass as broad a band of frequencies. The audio-frequency equipment is similar to that used in broadcast stations with a possible improvement in frequency characteristics allowable because the channel is not limited to a width of ten kilocycles.

Television Receivers. Television receivers are generally of the superheterodyne type and follow the general arrangement shown in the block diagram of Fig. 67.

Tracing a signal through such a receiver, the signal comes in to a radio frequency selector ahead of the mixer, the input circuit of which is arranged to tune very broadly. This is accomplished through the use of band pass circuits or by using very high circuit damping. The main purpose of such a stage is to improve the signal-to-noise ratio and prevent radiation from the mixer stage, a stage that is sometimes omitted.

Following the R-F stage is a mixer stage (first detector) where the frequencies of the signals are reduced. The video (picture) intermediate frequency usually operates within the band of frequencies from 8 to 14 megacycles and the oscillator is adjusted accordingly. Because at the present time only about seven of the nineteen frequency bands allotted to television are practical, the first two units of the receiver are push-button tuned. The R-F and mixer stages are made to tune broadly enough to admit both the picture and the sound signals. The usual procedure calls for a separate oscillator tube, but receivers that employ converter tubes have also been designed.

The signal at the plate of the mixer section, which contains the audio intelligence, is taken off through a special circuit designed to have little by-passing effect on the video. This signal follows one of two methods of treatment. It may be passed through an amplifier designed to operate at a high intermediate frequency (approximately 9 megacycles), or it may be fed to another mixer section which again reduces the frequency to, say, one of the commonly used intermediate frequencies (465 kc.). After sufficient amplification has taken place, the signal is fed to a second and perhaps a third detector. After proper audio amplification the audio-frequency currents are fed to a


RADIO FREQUENCY SELECTOR
PICTURE CARRIER
SOUND CARRIER
OSCILLATOR
FIRST DETECTOR
SOUND INTERMEDIATE AMPLIFIER
LOW VOLTAGE RECTIFIER
PICTURE INTERMEDIATE AMPLIFIER
AVC BIAS
AVC BIAS
HIGH VOLTAGE RECTIFIER
A V C
SECOND DETECTOR
A V C
SECOND DETECTOR
AUDIO AMPLIFIER
VIDEO AMPLIFIER
SYNCHRONIZING SEPARATOR
LOUD SPEAKER
VERTICAL DEFLECTING CIRCUITS
HORIZONTAL DEFLECTING CIRCUITS
CATHODE RAY TUBE

loud speaker. Some television receivers are designed with the audio section as a conventional all-wave receiver, tuned to an intermediate frequency, the television receiver serving as an ultra-high frequency converter.

Following the video signal from the plate of the mixer (first detector) tube, it is fed to a special video intermediate frequency amplifier, designed to pass a band width of 2 to 4 megacycles with a reasonably flat response curve. It consists of from 2 to 5 stages using high transconductance tubes coupled with band-pass coupling units. This section is aligned in connection with the radio frequency section to produce a response curve that falls off to one-half of its flat-top value at the video carrier frequency. At a frequency .75 megacycles higher than the video carrier, the attenuation should be large; while at a frequency .75 megacycles lower, the response curve should reach its flat-top value. Under such conditions, the 50 per cent modulation at the transmitter will produce, in effect, a 100 per cent modulated signal at the receiver second detector.

The second detector of the video section requires special treatment. The load resistor is necessarily low in value to minimize the by-passing effects of circuit capacities. The ratio of signal frequency to intermediate frequency may be as low as 2 to 1, so the usual expedient of shunting the load resistor to eliminate the carrier component of the rectified signal is useless. A low-pass filter therefore is an integral part of the second detector load.

A video amplifier, composed of one or more wide-band amplifiers similar to those used at the transmitter, follows the video second detector. The number of stages is dependent on the connection of the second detector, since the modulation possesses polarity. If the connections are such that the grounded side of the diode load resistor is negative, an odd number of stages are required; while if the grounded side is positive, an even number of stages are required, assuming negative modulation.

The signal from the last video stage passes to a direct-current restoration diode and on to the cathode-ray tube where it is impressed upon the first or control grid to modulate the electron beam in accordance with the light intensity at the transmitting camera.

A portion of the video signal is fed into an amplitude (synchronizing) separator which removes synchronizing pulses from the telecast signal and further amplifies them. The synchronizing pulses are passed on to a wave-form sensitive circuit that feeds the horizontal pulses to a high-frequency sweep-generator and creates the vertical synchronizing pulses that are fed to a low-frequency sweep-generator.

The separated pulses are further amplified and then applied to a saw-tooth oscillator to control its frequency. Saw-tooth oscillators may take one of three common forms: The first is a gas triode operating as a relaxation oscillator; the second and third are forms of grid-blocking oscillators, the first of which depends on the blocking of a floating grid, the second depends on violent oscillation to produce grid-blocking. The latter two forms require an additional discharge tube to obtain a saw-tooth wave-form. The oscillators are followed by amplifiers which feed the sweep signals to the horizontal and vertical deflection coils or plates.

In the cathode-ray receiving tube, the action of the Iconoscope is put in reverse. The electron beams, in both the Iconoscope and the cathode-ray tube, follow the same pattern; and the current caused by the light in the Iconoscope causes light in the cathode-ray tube. Since the spot in the cathode-ray tube is at least the width of one line, the entire scanned area appears to be a homogeneous picture, even though at any instant only one small spot is being illuminated.

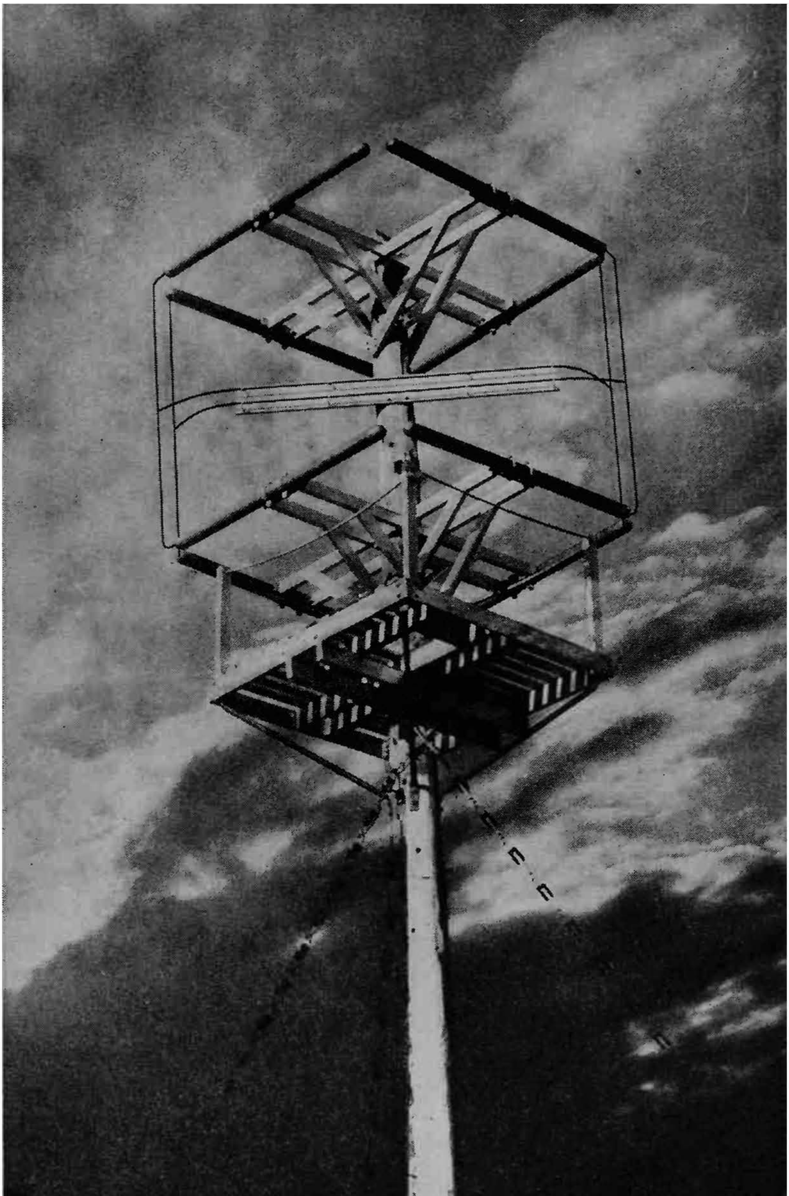
The cathode-ray tube is available in a variety of types and sizes that range from a screen diameter of 1 inch to those having a diameter of 18 inches. The anode voltages range from 700 volts to 7,000 volts, approximate values.

Special metal shields are placed over the chassis of television receivers and are equipped with interlocking switches to serve as protection against the dangerously high voltages supplied to the tube.

Frequency Bands. The following frequencies have been set aside by the Federal Communications Commission for television services.

Megacycles	Megacycles	Megacycles
* 44– 50	156–162	234–240
* 50– 56	162–168	240–246
* 66– 72	180–186	258–264
* 78– 84	186–192	264–270
* 84– 90	204–210	282–288
* 96–102	210–216	288–294
*102–108		

* Bands that are in practical use at the present time.



THE NEW CUBICAL TELEVISION ANTENNAE

There are 8 copper tubes, each 4 inches in diameter and about 7½ feet or one-half wave in length.

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