AUDELS RADIOMANS GUIDE

Covering

RADIO

TELEVISION

INDUSTRIAL ELECTRONICS

PUBLIC ADDRESS SYSTEMS

by

E. P. Anderson

AUDELS RADIOMANS GUIDE

COVERING
THEORY
CONSTRUCTION
AND
SERVICING
INCLUDING
TELEVISION
ELECTRONICS

By
EDWIN P. ANDERSON

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FOREWORD

THIS BOOK, the author believes, will be of the utmost service, not only to the student and radio-electrician, but to anyone who wishes to be informed on this important field of science.

Radio equipment cannot be serviced or maintained by any predetermined set of rules or formulae, but it is necessary rather to understand the principles of electricity, radio and sound.

The main object throughout has been to present as briefly and clearly as possible a progressively arranged treatise with special emphasis on the fundamentals of radio, upon which all knowledge necessarily rests.

In view of the importance of radio in the field of air and marine transportation, several chapters dealing with marine and aircraft communications as well as the principles of the automatic alarm and the radio compass have been included.

It is hoped that the numerous illustrative examples which are introduced throughout the book, may in conjunction with the data supplied, suggest proper treatment of practical problems in design of radio apparatus.

EDWIN P. ANDERSON.

LIST OF CHAPTERS

Any one, and more especially the attentive student, can with the least trouble avail himself of the subject matter contained in this work by doing as indicated in the following old English couplet quoted by Chas. Reade.

"For index-reading turns no student pale,
Yet takes the eel of science by the tail."

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For Quick Reference in Answering Your Question or Problem

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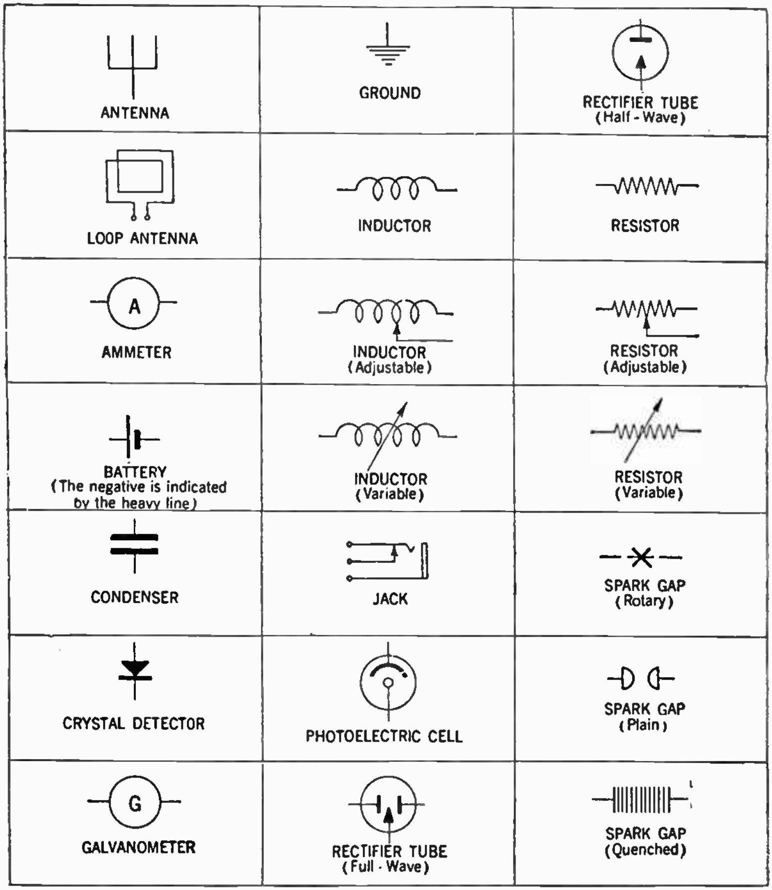
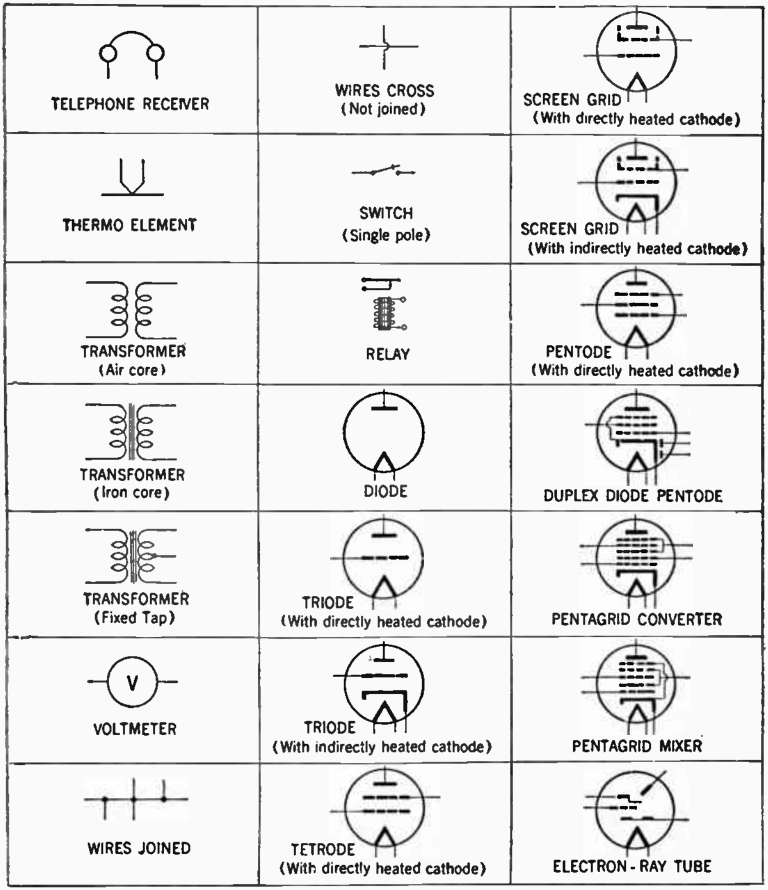
Radio Symbols

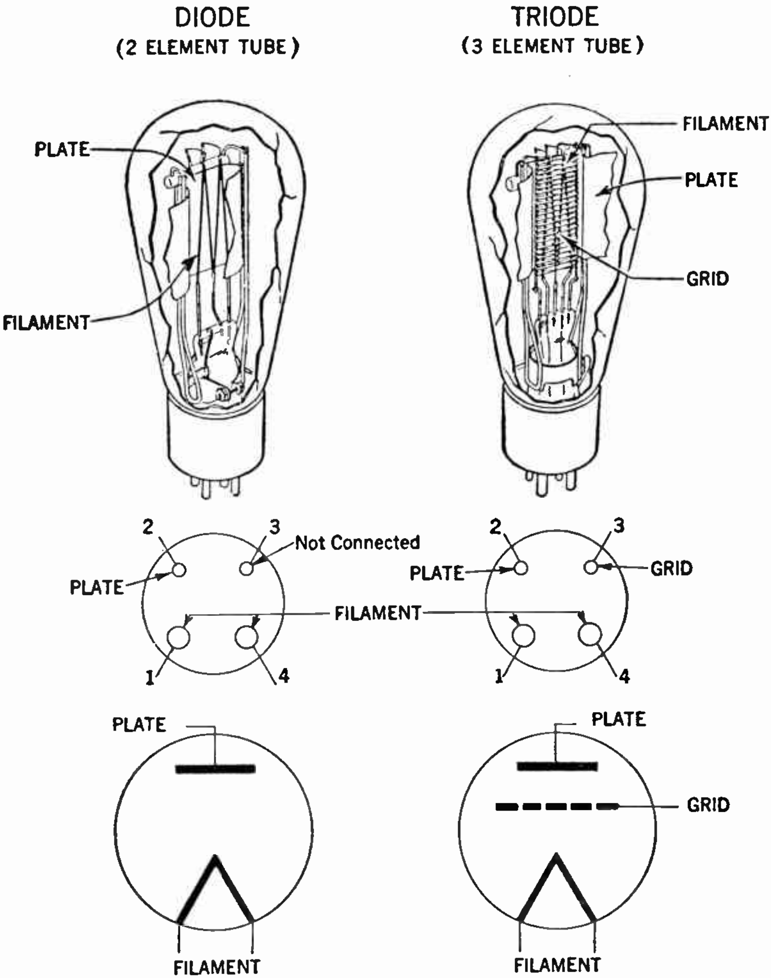
The following symbols have been adopted as standard by engineers and manufacturers, and should be used in making circuit diagrams—also for reference in reading diagrams.



Radio Symbols

In addition to symbols, given below, abbreviations are used for shortening descriptions. Abbreviations and formulas most commonly used are given on the following pages.





Views of two and three element vacuum tubes showing arrangement of prongs and wiring symbols (For details see chapter 12)

RADIO SECTION

CHAPTER 1

Radio Principles

Dr. Albert Einstein discards the theory of the ether usually presented by writers in an attempt to explain radio transmission. Dr. Einstein derides radio's ethereal medium as fiction, calling it a makeshift fabricated to explain something for which scientists have not had the correct explanation. Einstein believes it is *an electro-magnetic phenomenon;* so did Charles Proteus Steinmetz.

Shortly before his death Steinmetz said: "*There are no ether waves.*" He explained that radio and light waves are merely properties of an alternating electro-magnetic field of force which extends through space. Scientists, he contended, need no idea of ether. They can think better in the terms of electro-magnetic waves.

If a coil of insulated wire surround a piece of soft iron and a direct current be sent through the coil, it is called an electromagnet. The space around the coil is the magnetic field. When the current is increased the magnetic field increases. When the current is decreased the breadth of the field is reduced. If the current be reversed, the field is reversed. When an alternating current is sent through the coil the magnetic field alternates. The field becomes a periodic phenomenon or a wave, described by Steinmetz as "an alternating magnetic field wave."

Steinmetz, like Einstein, pointed out that the conception of the ether is one of those hypotheses made in an attempt to explain some scientific difficulty. He declared that the more study is applied to the ether theory the more unreasonable and untenable it becomes. He held it to be merely conservatism or lack of courage which has kept science from abandoning the ethereal hypothesis.

Steinmetz called attention to the fact that belief in an ether is in contradiction to the relativity theory of Einstein, since this theory holds that there is no absolute position or motion, but that all positions and motions are relative and equivalent. Thus, if science agreed that the theory of relativity is correct the ether theory must be abandoned.

No space will be wasted here in talking about ether waves. The space surrounding a wire that carries an electric current *is an electro-magnetic field*, that is, *a combination of a magnetic field and an electrostatic field.*

If the current and voltage alternate, the electro-magnetic field alternates; that is, it is a periodic field or an electro-magnetic wave. Thus, the broadcast listener who wants to forget the ether can think of the aerial wire at the transmitter, setting up electro-magnetic waves in a field of electric force, which now, the theories contend, fills all space and therefore every receiving wire is within the field. This field, however, is supposed to be in a state of rest until the broadcast transmitter causes it to vibrate.

The action of the transmitter is like tapping a mold of jello. Waves pass through it, and so radio waves are produced in the electro-magnetic field.

The transmitter taps the hypothetical medium, causing it to vibrate. The receiving set is designed to detect the vibrations and so intelligence is carried from one point to another.

It is well known that a stone thrown into a pond **causes** *ripples or waves on the surface of the water, which move away*

NOTE.—***As stated by Dr. Lee de Forest:*** Radio is simply a cause and an effect. The *cause* is the radio transmitter. It makes an electro-magnetic splash that sets up radio waves. These waves travel through space in all directions. The *effect* is the setting up of delicate currents in the aerial or loop. These delicate currents are detected and converted into audible sounds by means of the radio receiving set. Imagine a boy operating a paddle at one end of a pond of still water. Ripples are set up in the water. They travel farther and farther away from the paddle, getting weaker as they move along until they reach a piece of wood which bobs up and down as it rides the waves. Put a bell on the piece of wood, in order that it will ring with the action of the waves, this illustrates the mechanical parallel of radio communication.

from the point of disturbance in concentric circles of ever increasing diameters until they reach the shore. The number of waves breaking on the shore in one second is called the *frequency* of the wave motion, and the distance between them measured from crest to crest, is the *wave length*.

The waves are strongest at the point of disturbance and gradually become weaker as they travel away from that point, as shown in figs. 1 and 2. If the distance be sufficiently great they will become so weak as to be invisible.

FIG. 1.—Effect of throwing stone in still water; production of waves which radiate or travel from the point where stone enters the water, or "point of disturbance."

NOTE.—*According to Marconi radio waves go to outer space.* In his inaugural address at the second meeting of the Italian Society for the Advancement of Science Sept. 11, 1930, Sen. Guglielmo Marconi expressed belief that radio waves may travel long distances, even millions of miles, beyond the earth's atmospheric layer. He said that he did not see any reason why, as some scientists maintain, waves produced on the earth should not travel such a distance, since light and heat waves reach the earth from the sun, penetrating the atmospheric layer. He referred to observations of such scientists as Stormer and Pedersen and commented that the former had said that electrified particles derived from the sun and under the magnetic influence of the earth acted as a reflector of electric waves from the earth after they had passed the so called Kenelly-Heaviside layer.

Radio communication as has been explained is *a form of wave motion which occurs in an electro-magnetic field, these waves acting in a similar manner to water waves.*

In radio communication it is first necessary to create electro-magnetic waves in varying groups and of varying strength, and second to intercept them with apparatus capable of changing them to sound waves.

To create the waves it is necessary to have two surfaces separated by a distance of from ten to several hundred feet and to create between them an electrical pressure which changes its direction (first toward one surface then toward the other) hundreds of thousands of times a second.

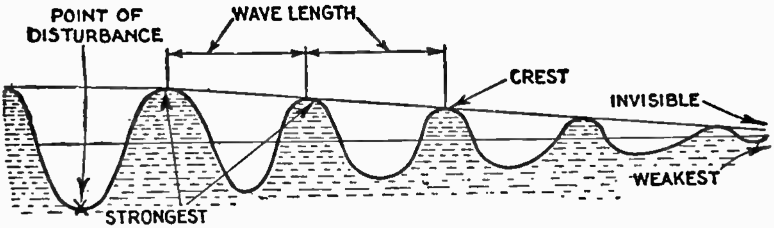


FIG. 2 —Sectional view of waves produced by throwing stone in still water, illustrating crest of wave, wave length and gradual weakening of the waves as they travel from the point of disturbance.

It is the common practice to use the ground for one surface and provide another surface by erecting a structure composed of one or more wires, insulated from the earth and suspended many feet above it.

Between these, by means of suitable transmitting equipment an electrical pressure is produced of from one to twenty volts which starts waves radiating out in all directions. These pressure waves are, however, only part of a radio wave. From any wire in which current is flowing are radiated electro-magnetic waves and radio waves are made up then, of both electro-magnetic and pressure electrostatic waves.

Comparing these waves to the action of hurling a rock into a pool of water, the amperes of electric current put into the antenna correspond to the size of the rock, while the volts of electrical pressure are equivalent to the force with which the rock is hurled. The larger the rock and the greater the force behind it, the bigger the splash and consequent waves. The more amperes of current flowing in the antenna circuit and the greater the pressure (volts) between antenna and ground, the stronger the waves radiated. These radio waves have similar characteristics to another class of waves—sound waves.

When the note C is struck on the piano (as in fig. 3) the sound waves vibrate 256 times per second and either a C tuning fork or a wire tuned to C and in the immediate vicinity will vibrate 256 times per second also. The two wires are said to be in resonance.

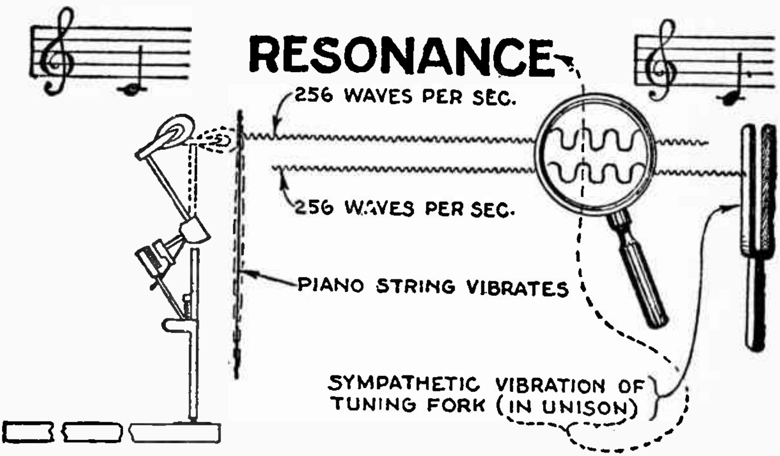
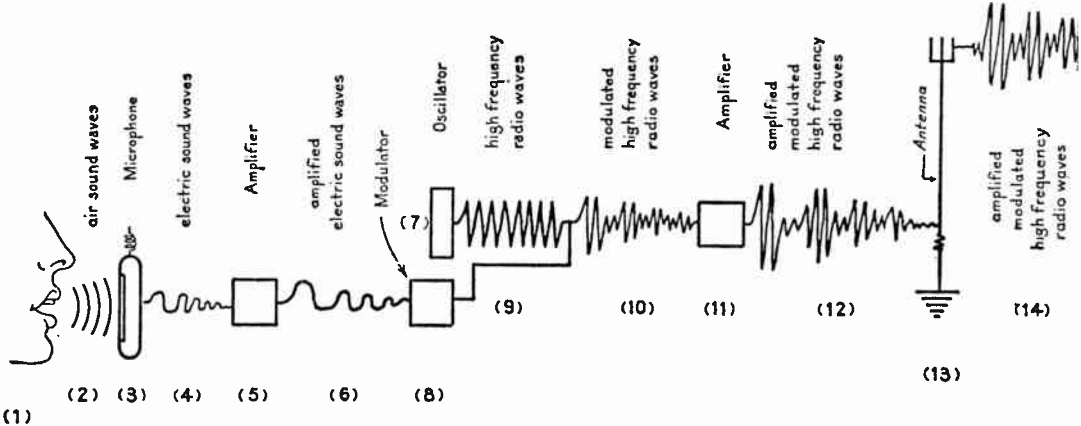


FIG. 3.—Sympathetic vibration of tuning fork with struck piano string when tuned to same pitch, illustrating the wave theory of radio.

The waves radiated by a radio transmitter always have a definite number per second and in order to hear a station, the receiving equipment must be put in resonance with the waves radiated by the transmitter. This operation is known as tuning.

BROADCASTING PRINCIPLES



Vibration of vocal cords of speaker (1) producing sound, causes air to vibrate in front of mouth (2) which in turn causes the thin diaphragm of microphone (3) to vibrate. The microphone changes the mechanical vibrations to varied electric currents (4); an amplifier (5) amplifies these currents as at (6). An oscillator, or radio wave producing, device (7), in the meantime, produces radio waves (9) for broadcasting. A modulator (8) modulates or changes these radio waves to travel as sound waves. The varied currents (6) enter the modulator (8) and cause the radio waves (9) to flow out as at (10), conforming to the electric sound waves. An amplifier(11) amplifies the modulated radio waves, to give them more power, as at (12); these waves enter the antenna (13) and travel out into space as at (14)—going in all directions ready to be picked up by receiving antennas.

CHAPTER 2

Physics of Sound

Production of Sound.—When air is set in vibration by any means, sound is produced provided that the frequency of vibration is such that it is audible. If a violin string in tension be plucked, as in fig. 1, it springs back into position, but due

FIG. 1.—Sound produced by vibration of violin string.

to its weight and speed, it goes beyond its normal position, oscillates back and forth through its normal position, and gradually comes to rest. These vibrations produce sound.

As the string moves forward it pushes air before it and compresses it, also air rushes in to fill the space left behind the moving string. In this way the air is set into vibration. Since air is an elastic medium, the disturbed portion transmits its motion to the surrounding air so that the disturbance is propagated in all directions from the source of disturbance.

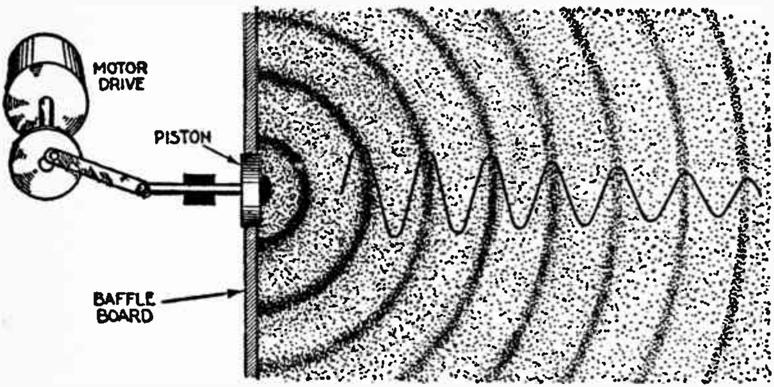


Fig. 2.—Generation of sound waves by the rapid oscillation of a light piston. *As the piston oscillates* the air in front of the piston is compressed when it is driven forward, and the surrounding air expands to fill up the space left by the retreating piston when it is drawn back. Thus a series of compressions and rarefactions (expansion) of the air is the result as the piston is driven back and forth. Due to the elasticity of air, these areas of compression and rarefaction do not remain stationary but move outward in all directions, as shown.

If the string be connected in some way to a diaphragm such as the stretched drum head of a banjo, the motion is transmitted to the drum. The drum, having a large area exposed to the air, sets a greater volume of air in motion and a much louder sound is produced.

If a light piston several inches in diameter, surrounded by a suitable baffle board several feet across, be set in rapid oscillating motion (vibration), as in fig. 2, by some external means, sound is produced.

Propagation of Sound.—If the atmospheric pressure could be measured at many points along a line in the direction in which the sound is moving, it would be found that the pressure along the line at any one instant varied in a manner similar to that shown by the wavy line of fig. 2.

To illustrate if extremely sensitive pressure gauges could be set up at several points in the direction in which the sound is moving it would be found that the pressure varied as indicated in fig. 3.

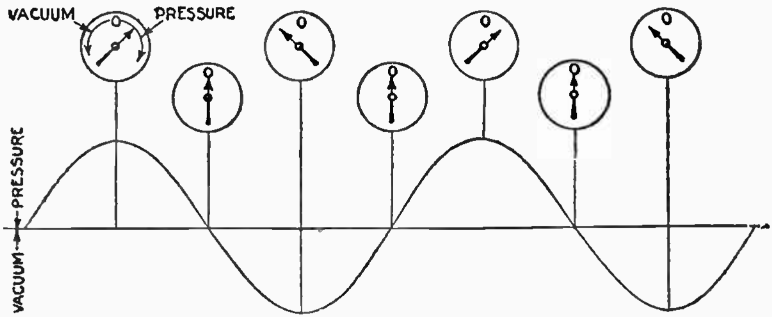


FIG. 3.—Diagram illustrating pressure variations due to sound waves. ***It should be noted*** that the type gauges shown, register pressure ***above*** atmospheric when the pointer moves to the right of the vertical, and ***vacuum*** or pressure ***below*** atmospheric when it moves to the left of the vertical.

Again, if a pressure gauge be set up at one point and the eye could follow the rapid vibrations of the points it would be found that the pressure varied at regular intervals and in equal amounts above and below the average atmospheric pressure. The eye, of course, cannot see such rapid vibrations, but it *can* see wave motion in water, however, which is very similar to sound waves with the exception that water waves travel on a plane surface, while sound waves travel in all directions.

In the case of water as a medium for wave propagation, if a pebble be dropped into a still pool, as in fig. 4,— and starting at the point where the pebble is dropped, waves will travel outward in concentric circles, becoming lower and lower as they get farther from the starting point, until they are so small as not to be perceptible, or until they strike some obstructing object.

FIG. 4.—Effect of throwing a stone into still water; it produces waves which travel outwardly in expanding, concentric circles from the point where the stone enters the water or *point of disturbance.*

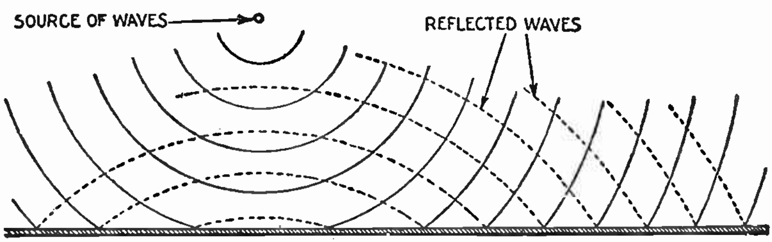


FIG. 5.—Reflection of waves from a plane surface.

If the pond be small it will be noticed that the waves which strike the shore will be reflected back. If the waves strike a shore that is parallel with the waves, they will be reflected back in expanding circles, as in fig. 5.

If the waves strike a hollow or concave shore line as in fig. 6 the reflected waves will tend to converge (focus) to a point.

Comparing water and air as media for wave propagation, water waves travel in *expanding circles* and air waves in *expanding spheres*.

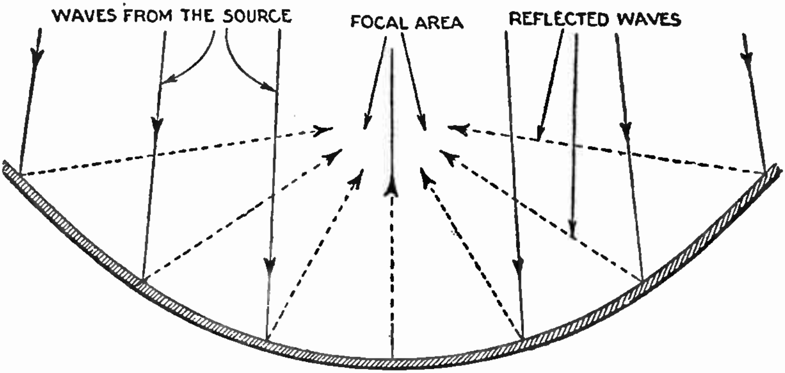


FIG. 6.—Reflection of waves from a curved surface. The solid lines show the direction of the original waves and the dotted lines show the direction and focusing of the reflected waves. Focusing of waves results in their reinforcement, which may cause them to build up to considerable proportion at one point.

Sound waves are reflected in a manner similar to water waves, causing echo and reverberation. If the sound waves focus at a point, loud and dead spots are produced.

Wave motion has certain definite characteristics and these characteristics determine:

1. Loudness;
2. Pitch;
3. Tone.

Loudness.—By definition, loudness is ***relatively high intensity of sound.*** Loudness (or amplitude) is determined by the amount of difference in pressure between the maximum compression and the maximum rarefaction. This corresponds in water waves to the vertical height of the crest above the trough of the wave. Loudness is illustrated in fig. 7.

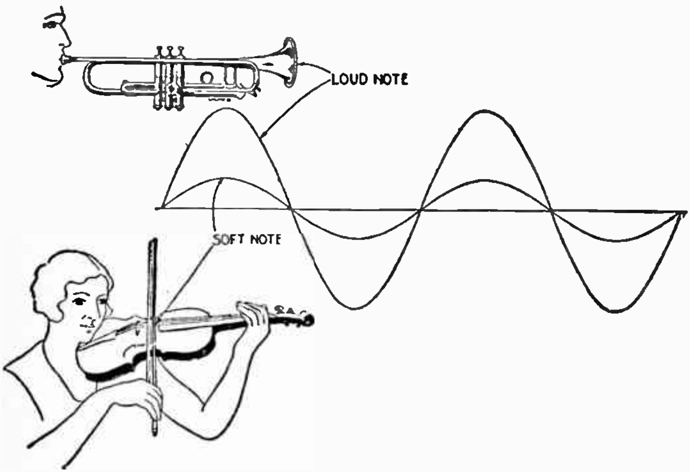


Fig. 7.—Properties of wave motion illustrating what causes loudness of tone.

Pitch or Frequency.—*Any one of a series of variations, starting at one condition and returning once to the same condition is called a cycle.* Observe some point on the surface of the water in which waves exist and it will be noticed that at this point the water will rise and fall at regular intervals. At the time at which the wave is at its maximum height the water begins to drop, and continues until a trough is formed, when it rises again to its maximum height. Accordingly, all the variations of height which one point on the surface of the water goes through in the formation of a wave, is a *cycle* of wave motion.

The number of cycles a wave goes through in a definite interval of time is called the frequency. Therefore the number of times

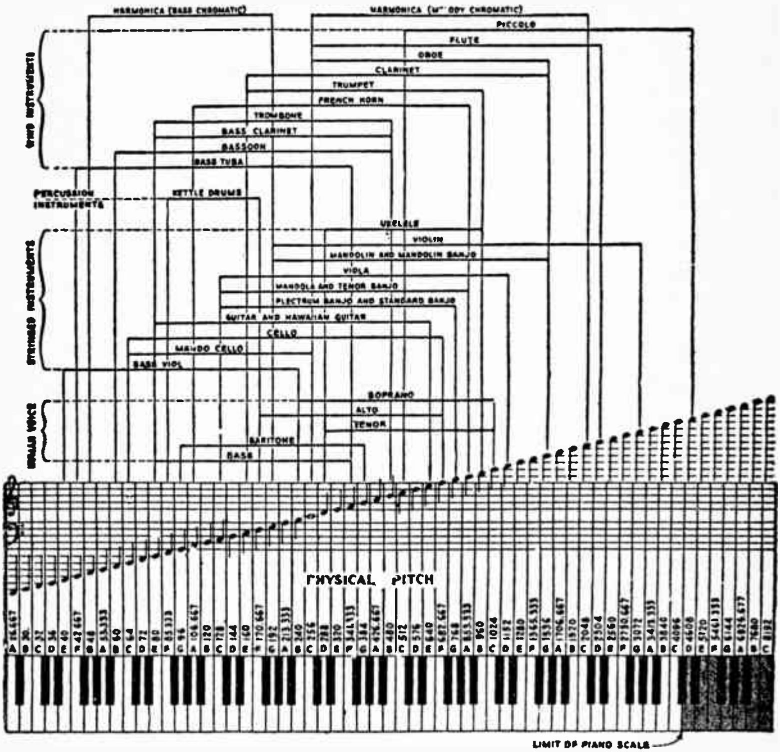


FIG. 8.—Musical pitch chart for piano, voice and various instruments. This chart represents the relation between the musical scale and the piano keyboard, giving the frequency of each note in terms of complete vibrations, or cycles, according to the standard used in scientific work such as the scientific scale based on middle C at a frequency of 256 cycles. The piano keyboard covers nearly the entire range of musical notes and extends from 26.667 cycles to 4,096 cycles. The piccolo reaches two notes beyond the highest note of the piano. The extreme organ range, not shown on the chart, is from 16 cycles to 16,384 cycles, scientific or physical pitch, as it is usually called. Music seldom utilizes the full keyboard of the the piano, the extremely high notes and extremely low notes being seldom used. Therefore a reproducing device which reproduces all frequencies from 50 to 4,000 cycles would be satisfactory in reproducing musical notes.

the water rises or falls, at any point in one minute would be called the frequency of the waves per minute, expressed as the *number of cycles per minute.*

In sound, the number of waves per minute is large, and it is more convenient to speak of the frequency of sound waves as the number of waves per second, or, more commonly, as the number of cycles per second. Thus, a sound which is produced by 256 waves a second is called a sound of a frequency of 256 cycles.

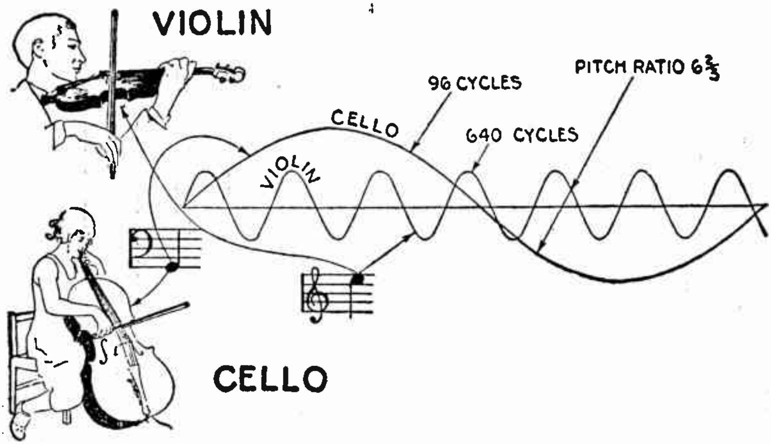


Fig. 9.—Properties of wave motion illustrating *pitch.*

When speaking of sound, cycles always mean cycles per second.

Considered from the standpoint of traveling waves, frequency is determined by the number of complete waves passing a certain point in one second, and this, of course, is equal to the number of vibrations per second generated at the source.

Fig.8 is a chart showing pitch frequencies corresponding to the various keys of the piano and range of the human voice and various instruments.

Tone.—By definition tone is *sound in relation to volume, quality,* duration and pitch; specifically, in acoustics, a sound that may be employed in music, having a definite pitch and due to vibration of a sounding body; opposed to sound as mere noise.

By common usage in music, tone generally means the *timbre* or *quality of sound.*

A pure note of a given pitch always sounds the same, and the frequency of this note is termed its *fundamental* or *pitch frequency.* However, notes of the same pitch from two different kinds of instruments do not give the same sound impression. This difference is due to the presence of *overtones,* sometimes called *harmonics.*

Consider again the case of a taut string which is plucked to set it in vibration.

If the string be plucked at its exact center, it will vibrate as a whole and give a very nearly pure note; but if it be plucked at some other point, say one-third of the length from one end, it will vibrate as three parts as well as a whole, and a change of tone will be noticed. If the string be plucked indiscriminately, various tones will be heard, all of the same pitch.

Hollow cavities built into the bodies of the various musical instruments give them their characteristic tones, because the air chambers, called resonance chambers, strengthen overtones of certain frequencies and give a very pronounced tone to the instruments.

Other instruments have built into them means of suppressing certain overtones, which help to give them their characteristic sounds. The frequency of an overtone is always some multiple of the pitch frequency; that is, the second overtone has twice the frequency of the pitch note, and the third overtone, three times the frequency, etc.

Overtones of twenty times the frequency of the pitch note are present in the sounds of some musical instruments, but overtones of this order are important only when the pitch note is low, because the frequency of the twentieth overtone of even a moderately high note would be beyond the ability of the human ear to detect.

Overtones give character and brilliance to music, and their presence in reproduced sound is necessary if naturalness is to be attained.

The combined result of all the partial or overtones gives the quality or timbre of the tone, that is the peculiar characteristic sound as of a voice or instrument. A great variety of tone is found in the orchestra as exemplified by the strings, wood wind, brass and reed choirs. See figs. 10 to 13

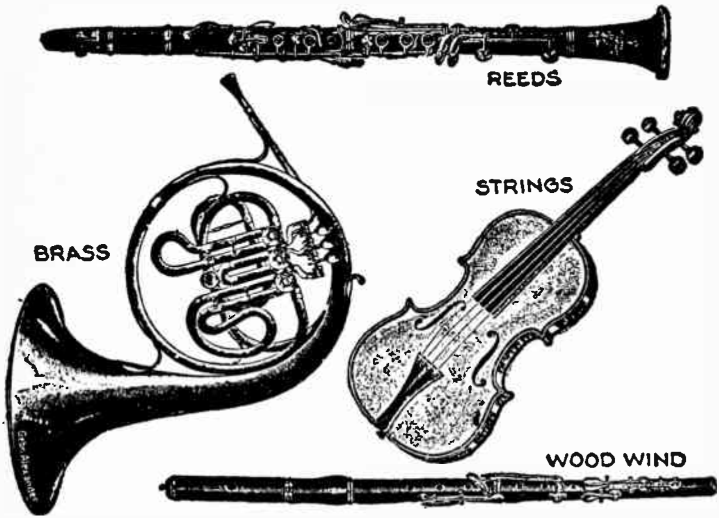


Fig. 10 to 13.—Familiar instruments of the orchestra illustrating the great variety of tone produced by the various "choirs" to which these instruments belong. It is because of this great variety of tone that the orchestra is the finest medium for musical expression. *It should be noted* that even the best organs represent a very poor attempt to imitate the orchestra—it cannot be done. Such impossible instruments as the cornet, saxophone, etc. are not employed in any legitimate orchestra.

A reproducing device which reproduces frequencies from 50 to 6,000 cycles will cover very well all the notes and overtones necessary for naturalness and distinctiveness.

In singing, the range of notes covered is approximately from 64 to 1,200 cycles, extreme limits, but this range cannot be covered by one person's voice. The frequency of 1,200 cycles does not represent the highest frequency used in singing, because overtones of several times the frequency of the note are always present in the human voice. The presence of the overtones gives the pleasing quality to songs. This quality of the singing voice is called *timbre*. The timbre of the voice transmits the emotions of joy, sadness, etc., from the performer to the audience, and therefore is very important in the enjoyment of vocal music.

Wave Length.—By definition the wave length (of a water wave for instance) is *the distance between the crest of one wave and the crest of the next wave.* This distance remains the same as long as the wave continues, even though the wave becomes so small as to be hardly perceptible.

Frequency in wave motion is related to wave length.

All waves produced do not have the same wave length. A small pebble dropped into a pond will produce a wave of short length, but a large stone will produce a wave of correspondingly longer length. In sound the wave length is dependent upon the frequency of the source. Similarly, in sound the wave length of a sound wave is *the distance between the point of maximum compression of one wave to the point of maximum compression of the next wave.*

Sound travels at different speeds in different substances, thus it travels at a much higher speed in water and steel than in air.

NOTE.—*Voicing* is the art of obtaining a particular quality of tone in an organ pipe and of procuring uniform strength and quality throughout the entire stop. Voicing is one of the most delicate and artistic parts of the organ builder's art, and it is seldom, if ever, that a voicer is good at both flue and reed voicing.

NOTE.—*Percussion instruments* such as drums and the various accessory traps produce the greatest pressures that are used in music. Although the fundamental frequency of the notes which they emit is fairly low, the notes are particularly rich in tones of higher frequency, which may extend as high as 10,000 cycles. Although these higher tones die out rather rapidly, they are essential to good definition.

NOTE.—*The organ, piano and harp* have the greatest compass and cover a frequency range from about 16 to 4,000 cycles. All three of these instruments are characterized by a rather prominent first overtone, so that their effective range extends as high as 8,000 or 9,000 cycles.

NOTE.—*According to Prout* "the *cornet* is a vulgar instrument whereas the *trumpet* is a noble instrument." The only excuse for a cornet is that it is easier to play than a trumpet. Non-musical instruments, such as the cornet and saxophone, if they must be heard, should be confined to 2nd and 3rd rate taxi-dance halls in order that cultured and discriminating ears may not be profaned.

In the latter medium it travels about 1,100 ft. per second. An illustration of the fact that time is required for sound to travel from one place to another is shown by a steam whistle at a distance of several hundred yards. If it be observed when blown, it will be noticed that the "steam"* can be seen coming from the whistle a considerable length of time before the sound of the whistle is heard. Sounds of all frequencies, or pitches, travel at the same speed. The speed at which sound travels divided by the frequency gives the wave length of the sound wave.

A knowledge of wave length is necessary for the proper construction and location of baffle boards and horns in theatres.

Speech.—The sounds of speech are divided into two classes, vowels and consonants. The vowel sounds are used in the pronunciation of the letters *a*, *e*, *i*, *o*, *u*, and sometimes *y*, in the formation of words.

These letters are also used in combination to indicate other vowel sounds. The pitch frequencies of the vowel sounds in male voices range from 110 cycles to 140 cycles. For female voices the range is from 230 to 270 cycles. The characteristic frequencies, or overtones of the vowel sounds, however, reach frequencies of 3,300 cycles. So important are these overtones that the pitch frequency can be entirely eliminated without noticeably changing the sound sensation produced on the human ear. The full range of frequencies used in vowel sounds is from 110 cycles to 4,800 cycles.

The pitch frequency of the vowel sounds are produced when air is blown through the vocal cords.

The vocal cords are two muscular ledges in the air passage of the throat. When these muscles are taut there is a narrow slit between them, which sets the air passing through into oscillation. The sound produced by the vocal cords is changed by the cavities of the mouth.

The shapes of the cavities continuously change as a person speaks, making it possible for him to produce a wide variety of sounds, all of very nearly the same pitch frequency.

*NOTE.—*The white cloud* seen issuing from a steam whistle usually called "steam," is not steam but a fog of minute liquid particles produced by *condensation*. The term is misused above simply for convenience. Steam is invisible.

Consonant sounds are usually produced without the aid of the vocal cords.

Most of these sounds are produced by the lips and teeth, as in the pronunciation of *th*, *s*, and *f*. The range of frequencies covered by consonant sounds is from 200 to 8,000 cycles, but most consonant sounds have frequencies of less than 6,000 cycles.

Hearing.—The actual mechanism of hearing is not very well understood, but certain facts regarding the ability of the ear to register sounds of various frequencies has been determined very accurately.

The range of frequencies which the average person can hear is from about 20 cycles to 17,000 cycles, but a comparatively large amount of sound energy is required before the ear can detect sound of extremely low or extremely high frequencies.

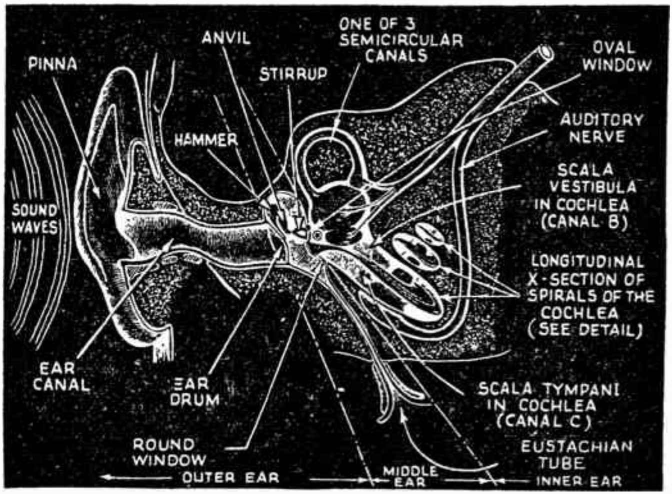


FIG. 14.—Internal Structure of the Human Ear.

The ear is most sensitive to frequencies between 500 cycles and 7,000 cycles; also, the ear is most sensitive to changes of pitch and changes of intensity of sound in this same band of frequencies.

NOTE.—*Woman's speech* in general is more difficult to interpret than man's. This may be due in part to the fact that woman's speech has only one half as many tones as man's, so that the membrane of hearing is not disturbed in as many places. It may be inferred therefore that the nerve fibres do not carry as much data to the brain for interpretation. The greatest differences occur in the case of the more difficult consonant sounds. In woman's speech these sounds are not only fainter but require a higher frequency range for interpretation. A range of from 3,000 to 6,000 cycles for man's voice corresponds roughly to a range of from 5,000 to 8,000 cycles for woman's voice. Since the ear is less sensitive in the latter range and the sounds are initially fainter, their difficulty of interpretation is greater.

NOTE.—When sounds containing a number of tones are increased in loudness, the lower tones in the sound deafen the auditor to the higher tones. This deafening or masking effect becomes very marked when the sound pressure of the lower tones is greater than twenty sensation units. In the case of speech, this effect impairs the interpretation of the higher pitched sounds. The best loudness for the interpretation of speech corresponds to a sound pressure between 0 and 20 sensation units. If the sound pressure be less than this, the fainter sounds are inaudible. If the sound pressure be greater, the masking effects impair the interpretation of these sounds.

CHAPTER 3

Radio Fundamentals and Ohm's Law

The Structure of Matter.—It is now a well known fact that all matter is made up of submicroscopic particles. These particles which are the smallest into which matter can be subdivided and still retain the properties of the original substance, are called *molecules*.

Molecules of different substances vary greatly in complexity, ranging from extreme simplicity in some substances to very great complexity in others. All molecules, however, may be broken up into simpler constituents called atoms, of which there are more than ninety distinct kinds known, each representing one of the chemical elements from which all matter is constructed.

Only a few elements, however, appear in the molecules of any one of even the most complex substances. An element, then is a fundamental substance composed of only one kind of atom. In some elements, the molecules are composed of single atoms; in other elements, two or more like atoms are associated together to form the molecule. Of the more common elements are hydrogen, oxygen, nitrogen, carbon, iron, copper, etc.

Carrying the analysis still further, atoms are well known to have complex structures. In accordance to the most widely accepted modern physical picture of the atom, it corresponds roughly to a miniature of our solar system. Corresponding to the sun in the solar system is the nucleus of the atom which, in general, is a very small, compact structure composed of a combination of extremely minute particles called *protons*, *neutrons*, *positrons* and *electrons*.

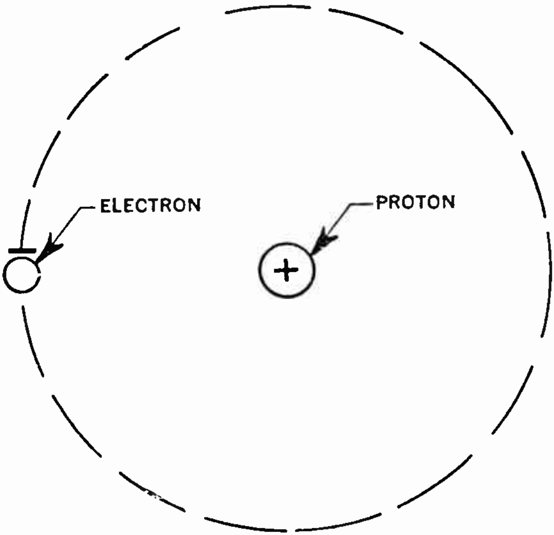


FIG. 1.—Structure and electronic orbit of the hydrogen atom.

The *proton*, whose mass may be taken as the unit of atomic weight has a positive charge equal in magnitude, but opposite in sign, to that of the electron. Its mass is very large compared with that of the electron or of the positron.

The *neutron* has very nearly the same mass as the proton, but is uncharged. The *positron* may be regarded as the ultimate unit of positive charge just as the electron is the ultimate unit of negative charge. The positron has the same magnitude of charge as the electron and very nearly the same mass. Practically all the mass of the atom is associated with the small, dense nucleus. Revolving about the nucleus in orbits at relatively large distances from it, are one or more electrons.

The simplest of all atoms is that of hydrogen, whose nucleus consists of a single proton with a single electron revolving about it. The two charges revolve about each other in space much like a whirling dumbbell, except that there is no rigid connection between them. See fig. 1.

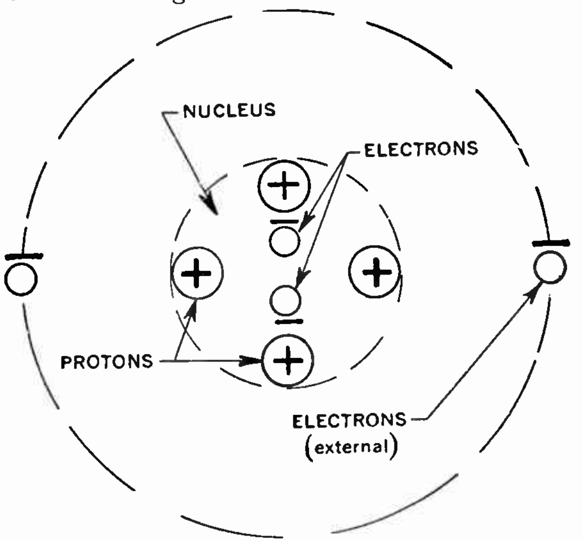


FIG. 2.—Structure and electronic orbit of a neutral helium atom.

The next atom in simplicity is that of helium, whose nucleus consists of four protons and two electrons bound together in a compact central core of great electrical stability. Revolving about this compact nucleus are two electrons. See fig. 2.

Atoms of other elements become increasingly more complex by the successive addition of one electron to those revolving about the nuclei, and with the progressive addition of protons, neutrons, positrons and electrons to the nuclei. In every case the normal atom has an exactly equal number of positive and negative elementary charges, so that the atom as a whole is neutral; that is, it behaves toward electrified bodies at some distance from it as though it had no charge at all.

Positively and Negatively Charged Substances.—With reference to the picture of the neutral atom, it will be easy to understand what takes place when a substance is electrically charged.

Assume that by some means one of the external electrons of the neutral helium atom is removed as shown in fig. 3, the result will be an unsatisfied atom in so far as the balance

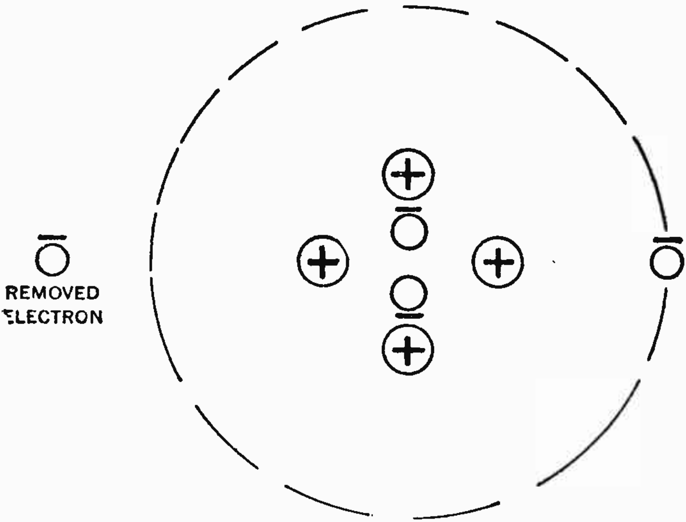


FIG. 3.—Structure and electronic orbit of a positive helium atom.

between the positive and the negative charges are concerned.

The excess of one proton in the nucleus gives the atom a positive charge, and if the previously removed electron is permitted to return to the atom, it will again become neutral as in fig. 2.

A positively charged body therefore is one which has been deprived of some of its electrons, whereas a negatively charged body is one which has a surplus (acquired more than its normal number) of electrons.

In its unbalanced state the atom will tend to attract any free electrons that may be in the vicinity. This is exactly what takes place when a stick of sealing wax or amber is rubbed with

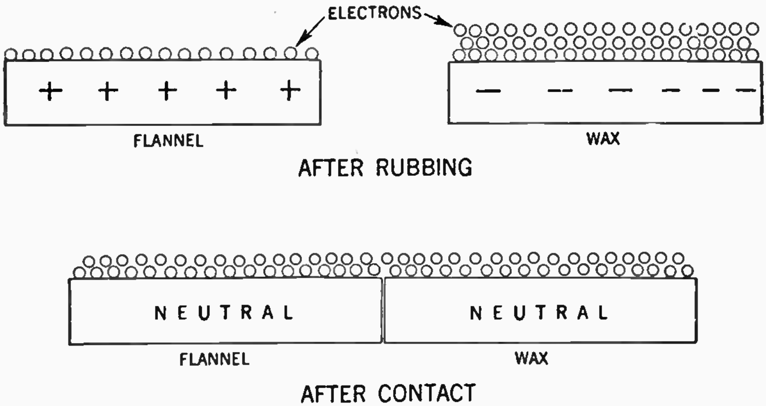


FIG. 4.—Illustrating how the rubbing process removes electrons from the flannel, and the re-distribution of electrons after contact of the two bodies.

a piece of flannel. The wax becomes negatively charged and the flannel positively charged.

During the rubbing process, the friction rubs off some of the electrons from the atoms composing the flannel and leaves them on the surface of the wax. Since the surface atoms or molecules of the flannel are left deficient in electrons and the surface atoms of the wax with a surplus, if the wax and the flannel are left together after being rubbed, there will be a readjustment of electrons, the excess on the wax returning to the deficient atoms of the flannel, as shown in fig. 4.

Most of the electrons in the universe exist as component parts of atoms as described, but it is possible for an electron to exist in the free state apart from the atom temporarily at least. Free electrons exist to some extent in gases, in liquids and in solids, but are much more plentiful in some substances than in others.

Conductors and Insulators of Electricity.—In metals for example, enormous quantities of free electrons exist while such substances as glass and rubber contain only small amounts.

It is the presence of free electrons in substances that enables us to account for the conduction of electricity. The more free electrons a substance contains, the better conductor of electricity is it, and it is on account of the great numbers of free electrons in metals, that metals are good conductors of electricity. Again, substances such as glass, rubber, mica, etc., with their comparatively few free electrons are poor conductors of electricity—good insulators.

Flow of Electric Current.—These free electrons are in a state of continual rapid motion, or thermal agitation. The situation is analogous to that in a gas where it is known that the molecules, according to the kinetic theory, are in a state of rapid motion with a random distribution of velocity.

If it were possible at a given instant to examine the individual molecules or electrons, it would be found that their velocities vary enormously and is a function of the temperature. The higher the temperature of a substance the higher the velocity of the atoms and electrons.

Now if by some means, the random motion of the molecules or electrons in a conductor be controlled and be made to flow in one direction, there results what is called a flow of electric current. Such means of controlling or directing the electron motion is provided by an electric battery or a generator. See fig. 5.

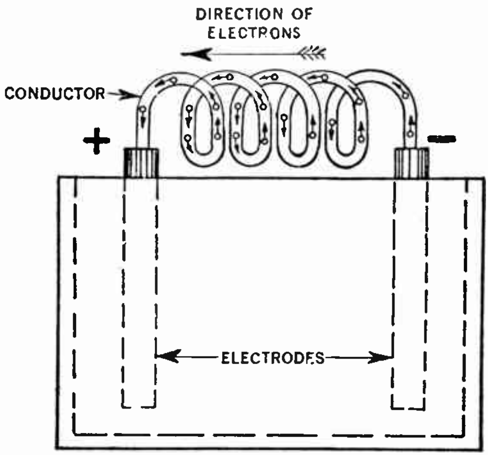


FIG. 5.—Illustrating the movement of electrons from the negative to the positive terminal of a battery. In practice it is customary to think of an electric current as flowing from the positive to the negative. The reason for this contradiction is due to the fact that the early electrical experimenters assumed the direction of current to be from the positive to the negative, which is now known to be opposite as far as analyzing a circuit is concerned. It causes considerable misunderstanding to those not duly informed.

Resistance to the Movement of Electrons.—The progressive motion of electrons in a conductor are retarded by the collisions of the atoms of the substance, and it is this hindrance to their movement which constitutes the electrical resistance in a conductor.

This resistance varies in different metals, and also with the temperature of the conductor. When the temperature increases, the higher will be the velocity of the atoms and electrons, which in turn causes more frequent collisions and as a result, there is a greater hindrance to their progress.

The frequency of collisions between the atoms and electrons is also increased when a greater number of electrons are present. It is on account of this fact that the heating in a current carrying conductor increases with the size of the current.

Electric Pressure.—It has been previously mentioned that the directed motion of free electrons in a conductor constitutes an electric current. To understand how a flow of current may be established, it is well to consider the analogy of, for example, a water pump in a hydraulic system. See fig. 6.

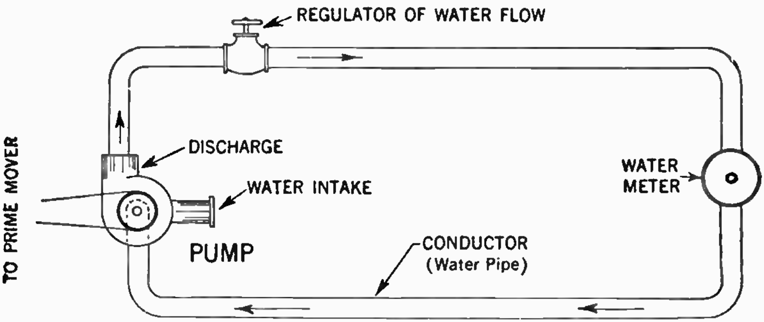


FIG. 6.—Water is forced through the conductor by means of the pump action causing a pressure difference between the conductor terminals.

In this case, by virtue of the pump piston the water enters the pump at the intake end at low pressure and leaves the discharge end at high pressure. The difference in pressure at the two ends of the pump causes water to flow through the pipe.

The action of the electrical system is similar. In any electrical circuit a generator or battery may be used to supply an electromotive force in a similar manner as the pump in the hydraulic system supplies mechanical force. Here the positive and the negative binding posts of the generator correspond to the discharge and the intake end of pump respectively. See fig. 7.

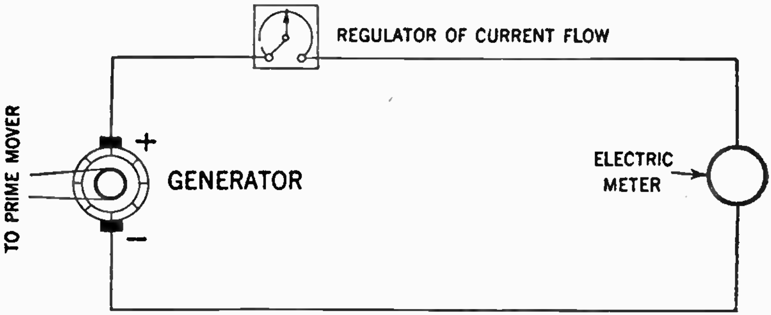


Fig. 7.—Note the similarity to the hydraulic circuit.

Similarly in case of the generator it is said that the pressure is higher at the positive end and lower at the negative, corresponding to the discharge and intake ends of the pump in the hydraulic system.

It is this difference in pressure between the generator terminals which causes an electric current to flow in the circuit, in much the same way as the water is forced through a pipe in the hydraulic system.

Electrical pressure variously called "difference in potential" and "electromotive force" is measured in terms of a unit called the volt.

Electric Current.—Again using the circuit (water pipes) in the hydraulic system, the rate at which water is flowing through the pipe may be measured in gallons per second. Similarly in the electric circuit the amount of current flowing is measured in a unit called "coulomb" which expresses the rate of flow.

When the current in a circuit flows at the rate of one coulomb per second the name of one ampere is used. This term facilitates the expression of current flow in that it makes it unnecessary to say "per second" each time, as second is already a part of the unit "*ampere.*"

Thus one coulomb per second is one ampere, and ten coulombs per second is ten amperes, etc.

The relation between coulombs and amperes may be expressed as follows:

$$I=\frac{Q}{t} \text{ or } Q=I\times t$$

where I is the current in amperes; Q is the amount of electricity in coulombs; and t is the time of flow in seconds.

Thus for example if a battery sends a current of 5 amperes through a circuit for one hour, the number of coulombs of electricity that will flow through the circuit will be $5\times60\times60=$ 18,000 coulombs.

Resistance to Current Flow.—All conductors of electricity oppose the flow of current through them, *i.e.*, they have electrical resistance. The unit of resistance is called the ohm. A conductor may be said to have one ohm's resistance if the ratio of the electrical pressure in volts to the current flowing through it, is unity.

Thus, for example, if the current flowing through a circuit is found to be 10 amperes, and the electrical pressure 10 volts the resistance of the circuit will be $\frac{10}{10}=1$ ohm.

Ohm's Law.—When considering the flow of electrons in a conductor it is evident that the greater the e.m.f. (electro-motive force) is, the more electrons will flow in the circuit, and also the greater the resistance of a conductor, the less number of electrons will flow through.

It has been found that there is a definite mathematical relationship between the e.m.f. applied to a circuit having a definite resistance, and the current flow. This relationship is known as the *ohm's law.* This law states that the current flowing through a resistance under a given e.m.f. is inversely proportional to the resistance and directly proportional to the voltage. Thus $I=\frac{E}{R}$ in which I, is the current in amperes; E, the e.m.f. in volts and R, the resistance in ohms.

Series Circuits.—If there be several resistances in series, as shown in fig. 8, the equation becomes

$$I=\frac{E}{R_1+R_2+R_3} \text{ or } E=I\ (R_1+R_2+R_3)$$

$$\text{or } E=I\times R_1+I\times R_2+I\times R_3$$

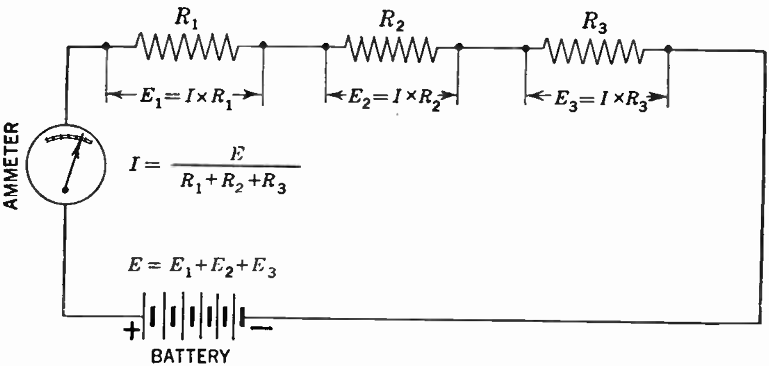


FIG. 8.—Simple circuit with three resistances connected in series.

The sum of the difference of potential across the various parts of the circuit is equal to the total voltage impressed on the circuit. Thus, $E=E_1+E_2+E_3$.

In a circuit as shown in fig. 8, the current I, is the same in each part of the circuit, but the voltage across each resistance depends directly upon the size of that resistance.

Example:—What voltage must be furnished by the battery in fig. 8, in order to force 0.25 ampere through the circuit if R_1, R_2 and R_3 are 5, 15 and 20 ohms respectively?

The total resistance $R=5+15+20=40$ ohms. The total voltage is $40\times0.25=10$ volts.

The voltage required for each part may be conveniently used as a check. Thus

$$E_1=0.25\times5=1.25 \text{ volts}$$

$$E_2=0.25\times15=3.75 \text{ volts}$$

$$E_3=0.25\times20=5 \text{ volts.}$$

Hence $1.25+3.75+5=10$ volts, as before.

Parallel Circuits.—In parallel circuits, see fig. 9, the voltage across the various resistances is the same and the current flowing through each resistance varies inversely with the value of it. The sum of all the currents, however, is equal to the main current leaving the battery. Thus

$$E=I_1\times R_1=I_2\times R_2=I_3\times R_3$$

and

$$I=I_1+I_2+I_3$$

When Ohm's law is applied to the individual resistances, the following is obtained:

$$I_1=\frac{E}{R_1},\ I_2=\frac{E}{R_2},\ \text{and}\ I_3=\frac{E}{R_3}$$

Hence $I = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3}$ or $I = E\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$;

and since $\frac{E}{I} = R$, the equivalent resistances of the several resistances connected in parallel is $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

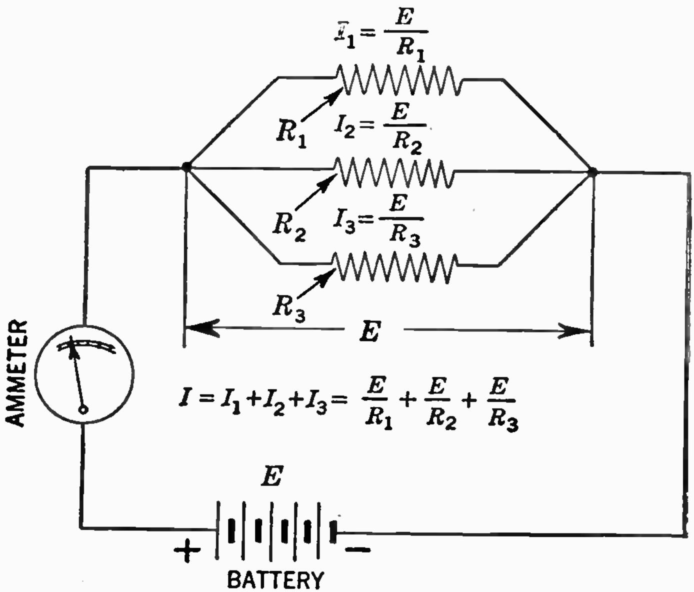


FIG. 9.—Simple circuit with three resistances connected in parallel.

Example:—If the resistances in previous example be connected in parallel as shown in fig. 9, what will be the total current and the current flowing through each resistance if the voltage remains unchanged or 10 volts?

The total resistance (R) for the combination will be found as follows:

$$\frac{1}{R}=\frac{1}{5}+\frac{1}{15}+\frac{1}{20}=\frac{19}{60} \quad \text{Then } R=\frac{60}{19}=3.16 \text{ ohm.}$$

The total current $=\frac{10}{3.16}=3.17$ amperes.

The current in the 5 ohms resistance is $\frac{10}{5}=2$ amperes.

" " " " 15 " " " $\frac{10}{15}=0.67$ "

" " " " 20 " " " $\frac{10}{20}=0.5$ "

The current through each resistance may conveniently be added as a check. Thus $2+0.67+0.5=3.17$ amperes as before.

Power in Electrical Circuits.—As previously stated, the electrons in their movement through a circuit do not have a clear path, but are in constant collision with atoms of the metals causing the metal to heat up. The heat so developed, varies with the number of collision and increases with the increase in current flow, due to a higher potential. It has been found that this developed heat or power loss varies directly as the resistance and as the square of the current, which relation may be written

$$W=I^2\times R=\frac{E^2}{R}=E\times I$$

in which W is the power in watts; E, I and R being the voltage current and resistances of the circuit. Thus to determine the power consumed in a device, multiply the voltage across it by the current flowing through it.

Example:—If certain heating elements take 25 amperes at a potential of 110 volt, what is the power consumption?

The power is $W=25\times 110=2{,}750$ watts $=2\frac{3}{4}$ k.w.

As the watt is a small unit of electrical power, the kilowatt (k.w.) which is a unit 1,000 times larger is more convenient, when it is desired to express larger amounts of power.

Therefore to change watts to kilowatts divide by 1,000 and to change kilowatts to watts multiply by 1,000.

One horse power (H.P.) is = 746 watts.

$$\text{Thus one kilowatt is } =\frac{1{,}000}{746} \text{ or } 1.34 \text{ horse power.}$$

To obtain the horse power consumption in the above heating elements $\text{H.P.}=\frac{2{,}750}{746}=3.7$ horse power.

Example.—*A certain carbon resistor is marked* 1 *watt and has* 3 *code colors as follows: yellow body, black tip and orange colored dot. What is the maximum current that may safely be sent through it?*

Solution.—In this case it is first necessary to find the resistance value in ohms. With reference to page 182 the Radio Manufacturer's Association's Code colors indicate that the resistor has a resistance of 40,000 ohms, which may be checked as follows: yellow body means (4); black tip means (0) and orange dot means (000) or 40,000. Now the value of power dissipation in watts is equal to (I^2R) from which it follows that

$$1=I^2\times 40{,}000 \text{ or } I^2=\frac{1}{40{,}000} \text{ hence}$$

$$I=\frac{1}{200} \text{ amperes or 5 milli-amperes.}$$

With an increase in current above the derived value, the heating of the resistor may become excessive and may even damage or change the accuracy of the resistance in question.

SERIES PARALLEL CIRCUITS.

The solution of circuit shown on opposite page is in reality very simple if it be kept in mind that any number of resistances connected in series may be replaced by a single resistor with a value equal to the arithmetical sum of the individual resistors, or that any number of resistors in parallel can be replaced by an equivalent whose value is equal to the reciprocal of the sum of the reciprocals of the individual units.

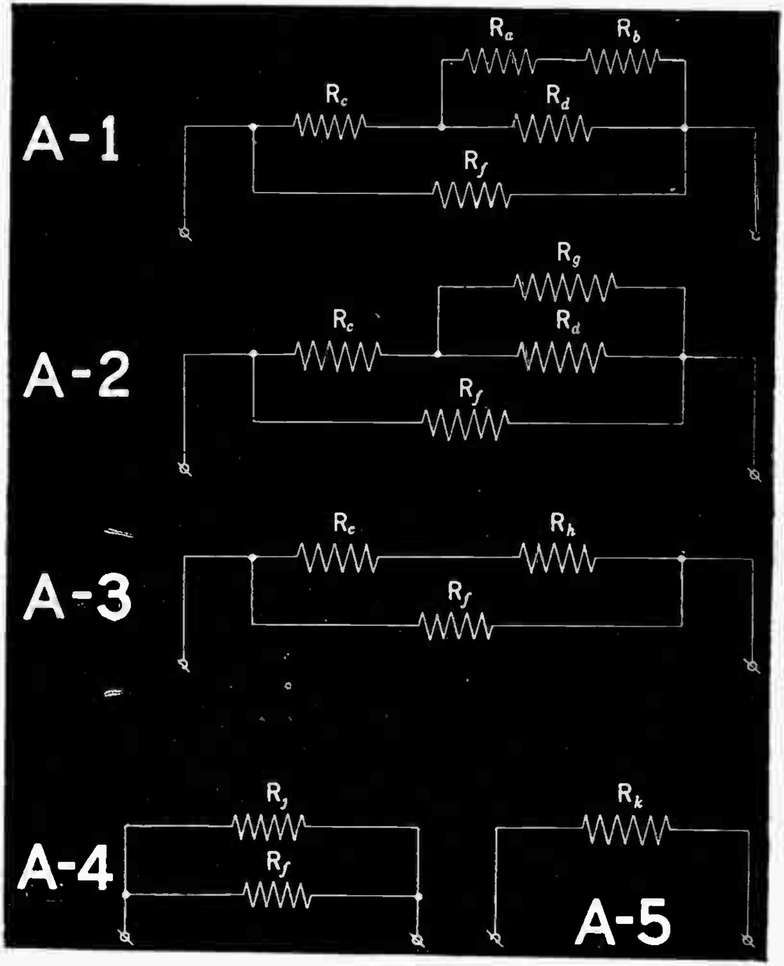
Circuit A-1 consists of resistors R_a and R_b in series, and the two also in parallel with R_d. This group is connected in series with R_c and the whole combination is again connected in parallel with R_f.

The simplest way to solve a resistance combination of this type is to remember the foregoing and to go through the problem step by step, combining each series and each parallel group and to replace them with their equivalent resistance.

Hence, to solve this circuit first replace R_a and R_b by their equivalent R_g.

The next step is to combine R_g and R_d replacing them by their equivalent R_h. By replacing R_c and R_h by their equivalent R_j, the original circuit now being reduced to the form as shown in fig. A-4.

In the manner similar to that already described R_j and R_f in parallel is replaced by a resistance R_k obtaining the result as shown in fig. A-5. Finally as a result of these calculations a resistance is obtained having the same current limiting effect as that shown in fig. A-1.



Method illustrating how a series parallel resistance combination of type shown in A-1 may be reduced to the simple form of that shown in fig. A-5.

Example.—*Assume a battery consisting of two dry cells connected in series, and that each cell has an* E.M.F. *of* 1.5 *volts and an internal resistance of* 0.3 *ohms. In this arrangement the battery then has a total* E.M.F. *of* 3 *volts and an internal resistance of* 0.6 *ohms. If a current of* 6 *amperes is required through a circuit of* 0.2 *ohms resistance, how many batteries should be used and how should they be arranged?*

Solution.—With one battery the current according to Ohm's law will be

$$I=\frac{3}{0.2+0.6}=3.75 \text{ amperes}$$

This is not sufficient current, and if two batteries be connected in series, we obtain

$$I=\frac{6}{0.2+1.2}=4.28 \text{ amperes}$$

This current is still too small and represents an increase in current of only about 14% although the voltage has been doubled; if, however, the two batteries be arranged in parallel, the current will be

$$I=\frac{3}{0.2+\frac{0.6}{2}}=6 \text{ amperes}$$

Example.—*In a certain galvanometer, the maximum deflection is obtained when the current is* 40 *milliampere. If the internal resistance is* 15 *ohms, what is the greatest voltage the instrument can be used to measure? If it is necessary to use the instrument for voltages up to* 10 *volts, what value of series resistance will be required?*

Solution.—By application of Ohm's law, the largest possible voltage that can be measured is given by the products of the largest current that can be sent through it (0.04 amperes) and the value of the internal resistance (15 ohms). Thus it may be written: $0.04 \times 15 = 0.6$ volts.

In order to measure larger voltages, however, it is necessary to insert a resistance in series with the instrument, after which the voltage to be measured is applied across the combination.

The additional voltage is now dissipated in the series resistance, and only the smaller voltage is applied to the galvanometer itself.

Since the same current obviously must flow in both the instrument and the series resistance, write as follows:

$$\frac{\text{Max. volt. drop across galvanometer}}{\text{Max. volt. drop across combination}} = \frac{\text{Galvanometer res.}}{\text{Galvanometer res.} + \text{ser. res.}}$$

In this equation the only unknown factor is the series resistance, hence by substituting known values, the following is obtained:

$$\frac{0.6}{10} = \frac{15}{15 + R_s}$$

where R_s denotes the unknown series resistance. Therefore,

$$150 = 0.6\ (15 + R_s) \text{ or } R_s = 235 \text{ ohms}$$

which is the value of the series resistance to be inserted in series with the galvanometer to give full scale deflection at a potential of 10 volts.

Alternating Current Series Circuits. (Inductive Reactance.) —In direct current circuits the current is exactly defined by the mathematical relations between voltage and resistance, whereas in the alternating current circuits this exact relationship no longer exists. For example in the case of direct current, the current through a piece of wire will be the same if the wire be coiled together or uncoiled. In the case of an alternating current the current will be less when the wire is in coiled than in straight form.

This is due to the inductive reactance (X_L) of the wire and is written

$$X_L = 2 \times \pi \times f \times L$$

in which X_L is the inductive reactance in ohms, f, the frequency of the alternating current source and L the co-efficient of self-induction in henrys.

Capacitive Reactance.—If a direct current be connected across a condenser there will be no current flow, but if the condenser be connected across an alternating current source of high frequency the current will pass through. This is due to the capacitive reactance (X_c) of the condenser and is written

$$X_c = \frac{1}{2 \times \pi \times f \times C}$$

in which X_c is the capacitive reactance in ohms, f, the frequency of the alternating current source, and C, the capacity of the circuit in farads.

Resistance and Inductance in Series.—When a circuit instead of containing resistance only or inductance only, contains both resistance and inductance as in the case of a coil, it is convenient to consider it as a resistance (R) connected in series with a pure inductive reactance (X_L). See fig. 10.

In this case it is necessary not only to know how to calculate inductive reactance but also how to combine R and X_L. (See impedance triangle fig. 11.)

The combined effect of total amount of resistance and inductive reactance in the circuit is called the impedance (Z). The mathematical relation between the impedance, the inductive reactance and the resistance is written

$$Z^2 = X_L{}^2 + R^2 \text{ or } Z = \sqrt{X_L{}^2 + R^2}$$

and since

$$X_L = 2 \times \pi \times f \times L$$

as previously shown, the equation may also be written

$$Z = \sqrt{(2 \times \pi \times f \times L)^2 + R^2}$$

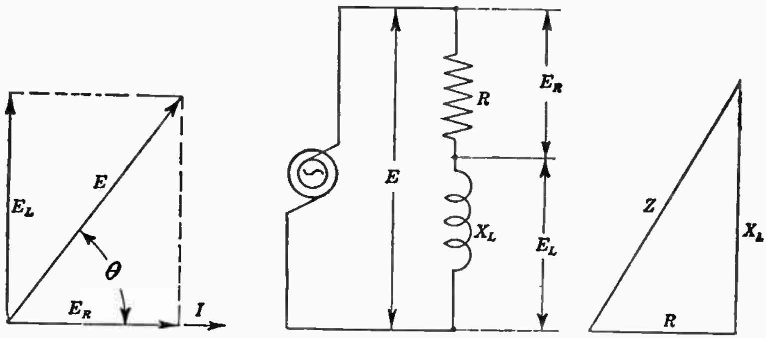


FIG. 10.—Combination of resistance (R) and inductive reactance (X_L).

Example:—A coil connected as shown in fig. 10 contains 5 ohms resistance and 0.04 henry inductance. The voltage and frequency of the source is 100 and 60 respectively.

Find (a) the impedance of the coil; (b) the current through the coil; (c) the voltage drop across the inductance; (d) the voltage drop across the resistance; (e) the power loss; (f) the power factor.

$$X_L = 2 \times \pi \times f \times L = 2 \times 3.14 \times 60 \times 0.04 = 15 \text{ ohms.}$$

(a) $Z = \sqrt{5^2 + 15^2} = \sqrt{250} = 15.8$ ohms

(b) $I = \frac{E}{Z} = \frac{100}{\sqrt{5^2 + 15^2}} = 6.3$ amperes

(c) $E_L = I \times X_L = 6.3 \times 15 = 94.5$ volts

(d) $E_R = I \times R = 6.3 \times 5 = 31.5$ volts

(e) $W = I^2 \times R = 6.3 \times 6.3 \times 5 = 198.45$ watts

(f) $\text{Cos}\theta = \frac{R}{Z} = \frac{5}{15.8} = 0.316$ or 32% approximately

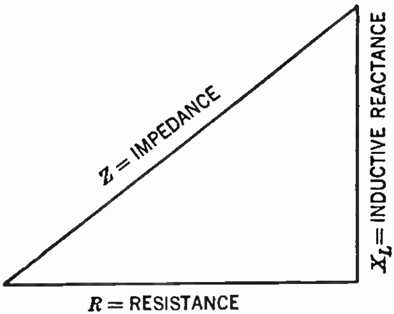


FIG. 11.—Illustrates vector relation between the inductive reactance and the resistance. To obtain the impedance: Resistance R (in ohms) is laid off horizontally; the inductive reactance X_L (also in ohms) is laid off to form the perpendicular. Measure the hypotenuse (in the same scale) which gives the impedance of the circuit in ohms. This triangle is variously referred to as the impedance triangle. vector diagram or impedance calculator.

Resistance and Capacitance in Series.—If a capacitance be connected in series with a resistance as shown in fig. 12 the impedance may be written $Z=\sqrt{R^2+X_c^2}$ and since

$$X_c=\frac{1}{2\times\pi\times f\times C}$$

it follows that

$$Z=\sqrt{R^2+\left(\frac{1}{2\times\pi\times f\times C}\right)^2}$$

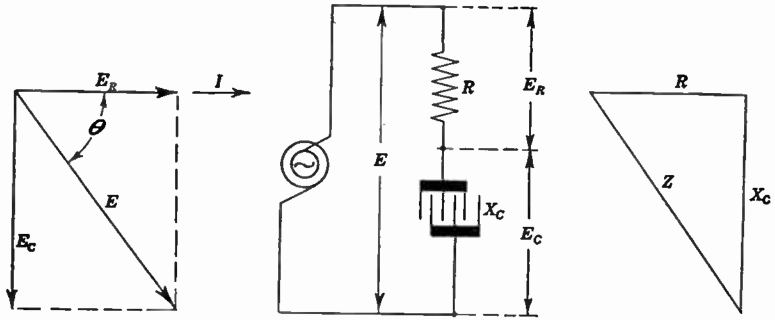


FIG. 12.—Combination of resistance (R) and capacitive reactance (X_C).

Example:—An alternating current circuit, connected as shown in fig. 12 contains 10 ohms resistance in series with a capacitance of 40 microfarads. The voltage and frequency of the source is 120 and 60 respectively.

Find (a) the current in the circuit; (b) the voltage drop across the resistance; (c) the voltage drop across the capacitance; (d) the power factor; (e) the power loss.

$$X_c=\frac{1}{2\pi\times f\times C}=\frac{1}{2\times 3.14\times 60\times 0.00004}=66.3 \text{ ohms}$$

$$Z=\sqrt{10^2+66.3^2}=67 \text{ ohms}$$

(a) $I=\frac{E}{Z}=\frac{120}{67}=1.8$ amperes

(b) $E_R=I\times R=1.8\times 10=18$ volts

(c) $E_c=I\times X_c=1.8\times 66.3=119.3$ volts

(d) $\text{Cos } \theta=\frac{R}{Z}=\frac{10}{67}=0.149$ or 14.9%

(e) $W=E\times I\times \text{Cos}\theta=120\times 1.8\times 0.149=32.18$ watts

Resistance Inductance and Capacitance in Series.—In a circuit which contains resistance (R) inductance (X_L) and capacitance (X_c) the reactance (X) is equal to the arithmetical difference between the inductive reactance (X_L) and the capacitive reactance (X_c) which may be written thus

$$X=X_L-X_c,$$

but as previously shown

$$Z=\sqrt{R^2+X^2}=\sqrt{R^2+(X_L-X_c)^2}$$

but since

$$X_L=2\times\pi\times f\times L \text{ and } X_c=\frac{1}{2\times\pi\times f\times C}$$

it follows that

$$Z=\sqrt{R^2+\left(2\times\pi\times f\times L-\frac{1}{2\times\pi\times f\times C}\right)^2} \text{ ohms}$$

also the current flowing in this circuit

$$I=\frac{E}{\sqrt{R^2+\left(2\times\pi\times f\times L-\frac{1}{2\times\pi\times f\times C}\right)^2}}$$

The equations just derived are of the utmost importance in all alternating current calculations and are generally referred to as *the Ohm's law* for alternating current.

Alternating Current Parallel Circuits.—In the previous analysis of direct current parallel circuits, it was found that across each branch of the parallel circuit the voltage was equal, and that the current in each branch varied inversely as the resistance of that branch. The arithmetical sum of the current in each branch circuit was also equal to the main current.

When considering a parallel circuit as shown in fig. 13 through which an alternating current flows, the voltage across each branch (as in the case of the d.c. circuit) is equal.

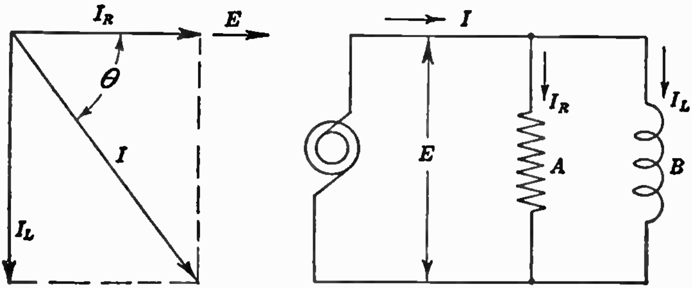


FIG. 13.—Parallel connection of resistance (R) and inductive reactance (X_L).

The total current, however, can not be obtained (as in direct current circuits) by arithmetical addition of the branch circuit currents, but each branch circuit current must be added vectorially which can best be shown by the following example:

A parallel connection consists of two branches A and B See fig. 13. A, has a resistance of 40 ohms and B, has an inductive reactance of 30 ohms. If the impressed voltage is 120, determine: (a) the current through branch A; (b) the current through branch B; (c) the line current; (d) the power factor of the circuit.

(a) $I_R = \frac{120}{40} = 3$ amperes

(b) $I_L = \frac{120}{30} = 4$ amperes

(c) $I = \sqrt{3^2 + 4^2} = \sqrt{25} = 5$ amperes

(d) $\text{Cos}\,\theta = \frac{3}{5} = 0.6$ (or power factor = 60 per cent)

Resonance.—When in a series circuit the inductive reactance becomes equal to the capacitive resistance, the circuit is said to be in *resonance*. The only opposition to the current flow then is the ohmic resistance (R).

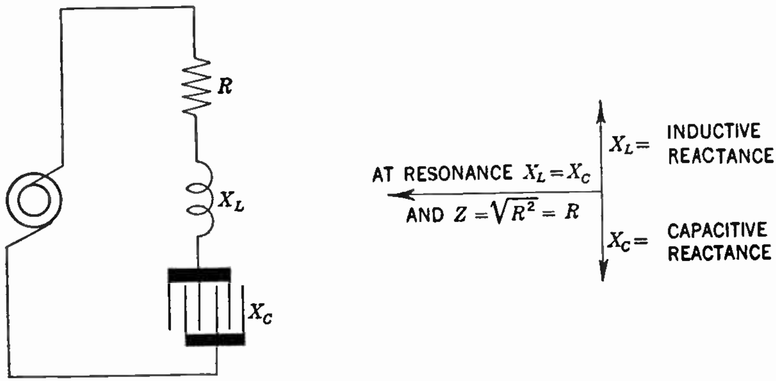


FIG. 14.—Illustrates connection diagram and resonance effect in a series circuit.

Referring to fig. 14 this condition may be written $X_L = X_c$ but since $X_L = 2 \times \pi \times f \times L$ and

$$X_c = \frac{1}{2 \times \pi \times f \times C}$$

it follows that

$$2 \times \pi \times f \times L = \frac{1}{2 \times \pi \times f \times C}.$$

If it be desired to find the resonant frequency (f) for the circuit, the equation may be written

$$f^2 = \frac{1}{4\pi^2 LC};\ f = \frac{1}{2\pi\sqrt{L \times C}}$$

This equation is of importance in all kinds of radio work and is used exclusively in calculations for wavemeters, filters, circuit tuning, etc. If C, be expressed in microfarads and L, in microhenries the equation may be written

$$f = \frac{159{,}000}{\sqrt{C(\text{microfarads}) \times L(\text{microhenries})}}$$

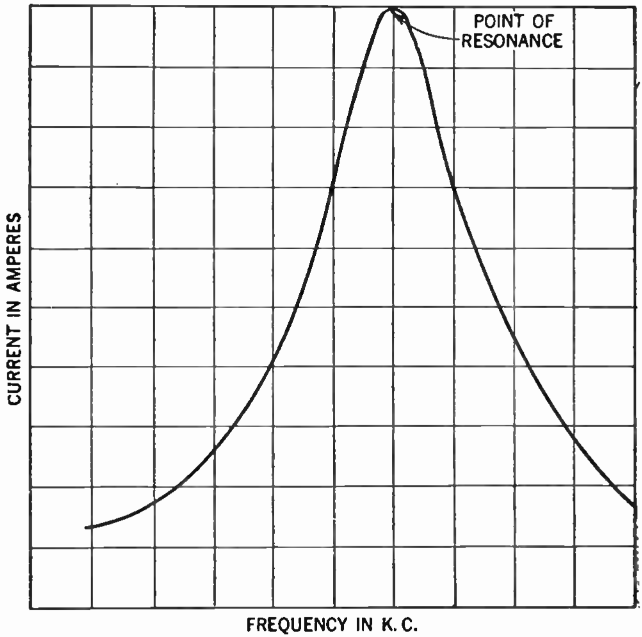


FIG. 15.—Illustrating how the current varies for increasing frequency in a resonance circuit.

Example.—*Considering the circuit shown in fig.* 16A-1 *in which a resistance of R_1 ohms is connected in parallel with an inductive coil whose resistance is R_2 ohms and whose reactance is X_2 ohms at the working frequency. If $R_1 = 15$ ohms, $R_2 = 12$ ohms and $X_2 =$ 16 ohms what will be the impedance of the circuit between A and B?*

Solution.—The simplest way to find the impedance is to determine the total current taken when a particular voltage is applied to the ends, the impedance then being given by dividing the voltage by the current obtained. Since the circuit is a parallel one, 10 volts will be applied to each branch, and the voltage vector is thus first drawn as the reference vector, preferably in the horizontal position as shown by *O-E* in fig. 16A-2.

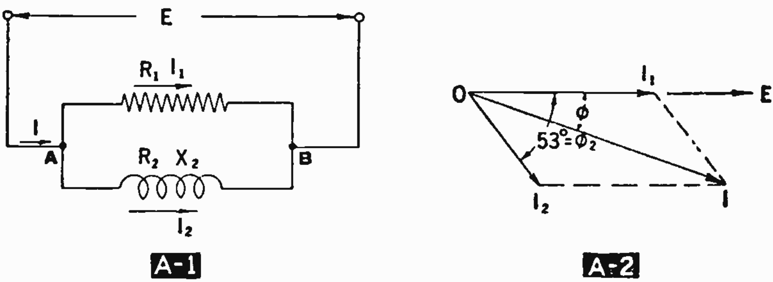


FIG. 16.—Resistance and inductive reactance in parallel combination.

The current I_1 in the upper branch of the circuit will be calculated from Ohm's law, being $I_1 = \frac{E}{R} = \frac{10}{15} = 0.667$ amperes, and this is exactly in phase with the voltage. The corresponding current vector $O\text{-}I_1$, is thus drawn over the top of the voltage vector as shown, and its length could conveniently be made 6.67 inches. The lower branch has an impedance of

$$Z_2 = \sqrt{R_2^2 + X_2^2} = \sqrt{12^2 + 16^2} = 20 \text{ ohms},$$

and the current in it is therefore

$$I_2 = \frac{E}{Z_2} = \frac{10}{20} = 0.5 \text{ amperes}$$

but as this is an inductive branch the current lags to some extent behind the voltage.

If ϕ_2 is the angle of lag $\cos \phi_2 = \frac{R_2}{Z_2} = \frac{12}{20} = 0.6$ and from a table of cosines, it is found that $\phi_2 = 53°$ approx. Thus in a vector diagram of fig. 16A-2 the current vector O-I_2 is drawn at an angle of 53° to the voltage vector O-E, to the right since the current lags by this angle. Using the same scale, its length would be made 5 inches. The total current is then found by completing the parallelogram and measuring the length of the diagonal O-I. This will be found to be approximately 10.5 inches corresponding to a current of 1.05 amperes, and then the impedance of the whole circuit is $Z = \frac{E}{I} = \frac{10}{1.05} = 9.52$ ohms. The combined current I lags behind the applied voltage by the angle ϕ which if measured off by a protractor will be found to be 22.9°.

The circuit values just being arrived at by a combined measurement and calculation method may of course be calculated directly. If this be done, the procedure will be as follows:

(1) current through the upper branch, being $I_1 = \frac{10}{15}$ or 0.667 amperes

(2) current through the lower branch, $I_2 = \frac{10}{\sqrt{12^2+16^2}} = \frac{10}{20}$ or 0.5 amperes

(3) $\cos \theta_2 = \frac{12}{20} = 0.6$ and the angle of lag between voltage and I_2 is 53° as before.

(4) Total current $I=\sqrt{(I_1+I_2\times\cos 53°)^2+(I_2\times\sin 53)^2}$ and after substituting numerical values

$$I=\sqrt{(0.667+0.5\times0.6)^2+(0.5\times0.8)^2}$$

from which $I=1.05$ amperes approximately.
Angle of lag between voltage and I is similarly found, thus

$$\cos\theta=\frac{I_1+I_2\times\cos 53°}{1.05}=\frac{0.967}{1.05}=0.92$$

and $\theta=22.9°$ approximately.

In a similar manner most alternating current problems of like nature may readily be solved. The important thing to remember is that currents and potentials must be computed geometrically and not arithmetically as each value is represented by a vector of definite size and direction.

Application to an Inter-stage Coupling.—In a low frequency amplifier where resistance, capacitance or choke capacity coupling is employed between the tubes, it is necessary to guard against excessive drop of voltage across the coupling condenser at the lowest frequency and the determination of the fraction of the total available voltage passed on to the grid of the second tube is a matter which is easily analyzed by the aid of vectors, which also give the phase angle of this voltage.

Fig. 17 (a) depicts an ordinary resistance capacity coupling. Assuming that the alternating component of the voltage developed across the anode resistance is E volts, this potential difference is set up between the ends of the coupling circuit CR as shown. Suppose that the grid leak R has a resistance of 0.5 megohms, and that the capacity of the coupling condenser is 0.01 microfarad. Assuming that 50 cycles per second represent the lowest frequency to be dealt with, the reactance of the condenser at this frequency is $\frac{1}{2\pi fc}=\frac{10^6}{2\pi50\times0.01}=318{,}000$ ohms or 0.318 megohms.

Now since R and C are in series, there is only one current and so the current vector of fig. 17 (b) is drawn in position first, this being denoted by O-I of arbitrary length.

In the circuit diagram the voltage required to drive the current through the condenser is denoted by E_c and through the grid leak by E_g. What is required to find is the ratio of E_g to E.

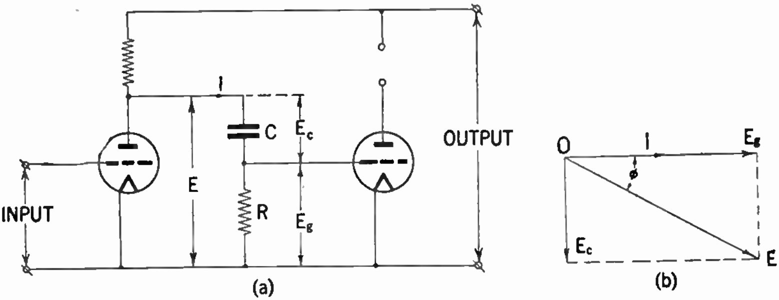


FIG. 17.—Showing interstage coupling and efficiency components with vector diagram.

By Ohm's law $E_g = IR$ volts in phase with I. Its numerical value cannot be found yet because I is not known, but the vector O-E_g can be drawn parallel to O-I and its length made proportional to the resistance R. Since R is 0.5 mehogms O-E_g could conveniently be made 5 inches long.

The current taken by the condenser leads the voltage across it by a quarter of a cycle, and the voltage E_c will therefore lag behind the current by this amount. Hence the vector O-E_c is drawn at right angles to OI in the position shown in fig. 17 (b) and its length is made proportional to the reactance of the condenser to the same scale as O-E_g.

Since the condenser reactance at 50 cycles is 0.318 megohm, O-E_c will have to be 3.18 inches using the same scale as before. Now the total voltage E, across the coupling circuit must be equal to the vector sum of E_c and E_g. If the rectangle

OE_c EE_g be completed as shown OE will represent the total available voltage to the same scale.

The length of OE will clearly be

$$\sqrt{OE_g^2+OE_c^2}=\sqrt{5^2+3.18^2}=5.92 \text{ inches.}$$

Thus the ratio of E_g to E, is $\frac{5}{5.92}=0.844$ so that 84.4% of the available signal voltage is passed to the succeeding tube at 50 cycles, which represents quite a high efficiency.

Incidentally the actual value of the voltage E would be $0.592\ I\times10^{-6}$ volts so that the impedance of the coupling circuit is 0.592×10^{-6} ohms or 0.592 megohms. It can be shown that the efficiency of the coupling is equal to its power factor.

Example.—*In a certain two tube receiver the negative grid bias is obtained by means of insertion of a* 600 *ohms resistor between the high potential and low potential leads. With a tube of* 6,500 *ohms a.c. resistance, the grid bias is* 7 *volt negative. With another tube of* 8,000 *ohms a.c. resistance it is only* 4.5 *volt negative. If the H.P. supply is* 120 *volts, what is the steady anode current in each case?*

Solution.—When filament current is provided by a battery it is customary to measure the grid bias voltage from the negative end of the filament, which is thus assumed to have zero potential. Fig. 18 shows the essential of the grid biasing arrangement adopted, in which the steady part of the anode current, provided by the *H.P.* battery flows through the biasing resistance of 600 ohms, while the speech component follows the low impedance path of the shunting condenser. The filament end of the resistance *F*, has evidently a more positive potential than the grid end *G*, which is connected directly to the negative end of the battery. *G*, is thus biased negatively with regard to *F*, and since this last has zero potential, *G* may be properly regarded as being so many volts negative with respect to *F*.

By Ohm's law the steady current I, in amperes, is given by the quotient $\frac{E}{R}$ where E is the potential drop or bias voltage and R the resistance in ohms. In the case of the first tube, therefore,

$$I = \frac{7}{600} = 0.0117 \text{ amperes} = 11.7 \text{ milliamperes}$$

with the second tube

$$I = \frac{4.5}{600} = 0.0075 \text{ amperes} = 7.5 \text{ milliamperes}$$

In neither case has the *a.c.* anode resistance anything to do with the problem.

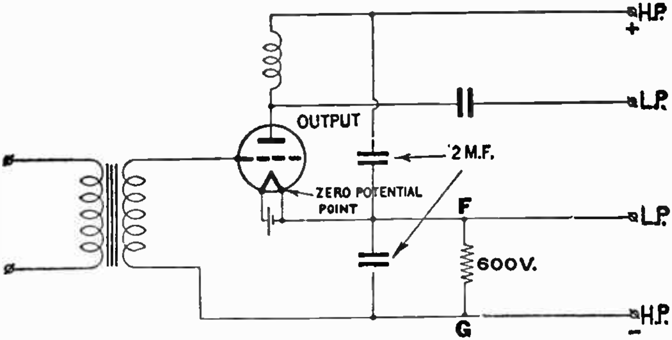


FIG. 18.—Schematic arrangement of components.

Problem.—*In order to measure the resistance of a grid leak, a 200-volt meter of 980 ohms per volt resistance is employed in conjunction with a dry battery. The direct voltage reading of the battery is 144 volts, but if the grid leak be included in the circuit, the reading drops to 24 volts. What is the value of the leak?*

Solution.—This is quite a good method of ascertaining the approximate value of the grid leak or similar large resistance if a reliable high resistance voltmeter be available. The meter resistance in ohms per volt is usually quoted by the manufacturer, but if not, it can readily be calculated by the simple expedient of measuring the current taken by it in order to produce a given deflection and applying ohms law.

In this case, since the meter is scaled for 200 volts, its resistance will be 200×980 or 196,000 ohms. First let us denote the unknown value of the grid leak by (R) ohms. Then, when the voltmeter is connected to a battery through R, the circuit will appear as shown in fig. 19. Now since the battery resistance

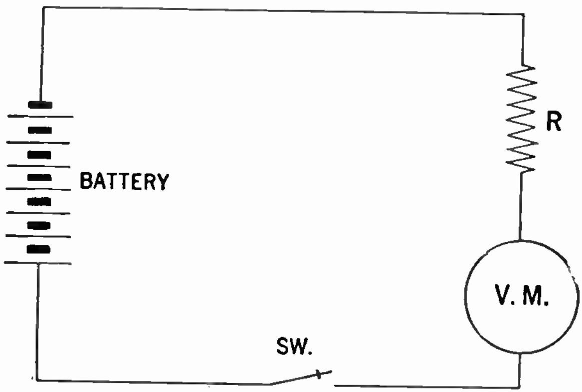


FIG. 19.—Circuit arrangement for approximate determination of grid leak values.

may be assumed negligible in comparison with the other resistance in the circuit, we may regard the voltage drop of the battery when measured directly by the meter as equivalent to the *e.m.f.* in the circuit illustrated. The current flowing will therefore be:

$$I = \frac{E}{\text{total res.}} = \frac{144}{196{,}000 + R} \text{ amperes}$$

Now it is known that this current flowing through the voltmeter causes it to register a deflection of 24 volts, which is the IR drop across its terminals, but this IR drop is also given by the product of the current flowing and the meter resistance, so it may be written:

$$\left(\frac{144}{196{,}000+R}\right)196{,}000=24$$

Solving this equation for R, we may write

$$24(196{,}000+R)=144\times196{,}000$$

from which follows that

$$24R=120\times196{,}000 \text{ or}$$
$$R=980{,}000 \text{ ohms}$$

Example.—*Assuming that the galvanometer on page 40 is to be used as an ammeter reading currents up to 2 amperes, how should it be connected?*

Solution.—Without any changes the instrument is a direct reading milli-ammeter with full scale reading when 40 milliamperes passes through it. To measure higher currents, this extra current is simply passed through a resistance inserted in parallel with the meter. This resistance must be of such value that when 2 amperes flows in the main circuit, only 0.04 amperes flows through the galvanometer. If R_g, I_g, R_s, I_s represent the resistance and current in the galvanometer and parallel resistance respectively, then, since the potential drop across both the galvanometer and the parallel resistance are the same, it is obtained as follows:

$R_g\times I_g=R_s\times I_s$ and since R_s is the only unknown, by substitution

$$R_s=\frac{R_g\times I_g}{I_s}=\frac{15\times0.04}{2-0.04} \text{ or } 0.306 \text{ ohms,}$$

which is the value of the resistance to be shunted across the instrument to enable measurements of currents up to 2 amperes.

Example.—*What is the maximum direct current that may be sent through a* 50,000 *ohms resistance rated at* 20 *watts, without over-heating?*

Solution.—The power loss in watts when a direct current of I amperes passes through a resistance of R, ohms is given by the formula I^2R, with regard to the above example in which R is 50,000 ohms and the power loss is 20 watts, it follows that

$$20 = I^2 \times 50{,}000 \text{ or } I^2 = \frac{1}{2{,}500}$$

hence

$$I = \frac{1}{50} \text{ ampere or 20 milli-amperes.}$$

Example.—*If in an alternating current circuit the following readings are obtained, watts* 10, *current* 125 *MA, and voltage* 100, *what is the power factor and the angle between the current and voltage?*

Solution.—In an alternating current of pure sine wave form the power in watts will be equal to voltage times current times cos θ or in equation form $W = E \times I \times \cos\theta$ in which

W is the power in watts, E the pressure in volts.

I the current in amperes and θ the angle of lag or lead between the current and voltage, or in the above example $10 = 100 \times 0.125 \times \cos\theta$

from which $\cos\theta = \frac{10}{12.5} = 0.8$ from this it follows that the angle between the current and the voltage is 60°.

CHAPTER 4

Magnetism and Motors

Early experimenters dating back to the "dawn of history" applied the word "magnet" to certain hard black stones which possess the property of attracting small pieces of iron, and as discovered later, to have still the more remarkable property of pointing "North" and "South" when freely suspended on a piece of string. At this time the magnet received the name of *lodestone* or "leading stone."

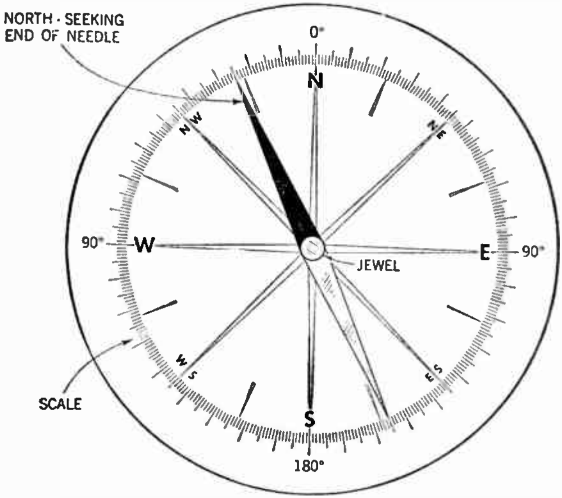


FIG. 1—Illustrating typical compass card. A compass consists essentially of a magnetic needle resting on a steel pivot, and protected by a brass case covered with glass and a graduated circle marked with the letters N,E,S and W, to indicate the cardinal points.

Kinds of Magnetism.—Magnets have two opposite kinds of magnetism or magnetic poles, which attract or repel each other in much the same way as the electrons generated by the rubbing of a stick of sealing wax with a piece of flannel, as described in an earlier chapter.

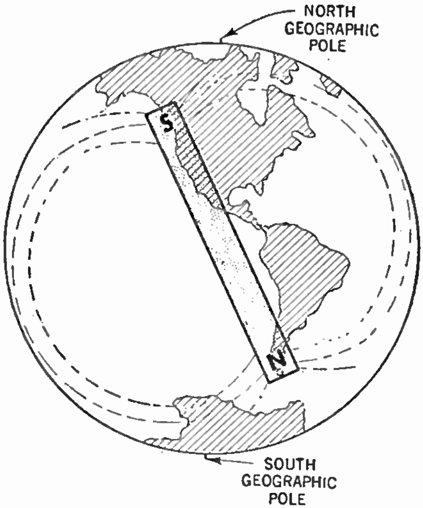


FIG. 2—Illustrating the magnetic properties of the earth. To comprehend the magnetic properties of the earth, the earth may be visualized as a gigantic sphere with its magnetic north and south poles being located several hundred miles distant from its geographic poles.

In our early school days, we learned that the earth is a huge, permanent magnet with its *North* magnetic pole somewhere in the Hudson Bay region and that the compass needle points toward the magnetic pole; that is, the point of the compass needle is a South Pole, magnetically speaking. The compass is thus an indication of magnetism.

One of the two spots on the magnet points North and the other South; they are called *poles;* one is called the *North-seeking* pole (*N*) and the other the *South-seeking* pole (*S*).

Experiments with Magnets.—If we bring the South-seeking or S-pole of a magnet near the *S-pole* of a suspended magnet, as in fig. 3, we find that the poles repel each other. If we bring

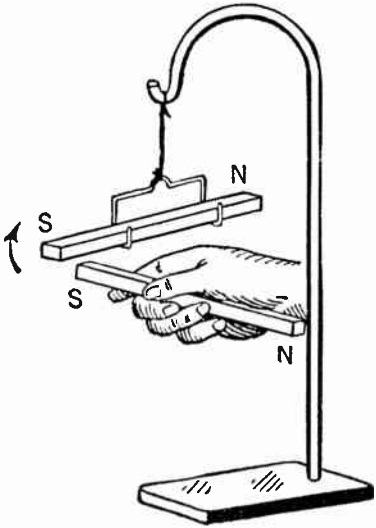


FIG. 3—Showing repulsion between like magnetic poles.

two *N-poles* together, they also repel each other, but if we bring an *N-pole* towards the *S-pole* of the moving magnet, or an *S-pole* toward the *N-pole*, they attract each other; that is, *like poles repel each other and unlike poles attract each other.*

It can also be shown by further experiments, that these attractive or repulsive forces between magnetic poles vary inversely as the square of the distance between the poles.

It will also be found that if a magnetic substance like iron filings be placed in a test tube and the latter stroked from end to end with a permanent magnet, that the filings themselves become a magnet. The acquired magnetism of the filings, however, will disappear as soon as the filings are shaken up.

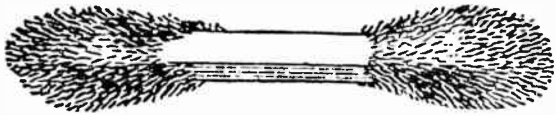


FIG. 4—Showing the effects of a magnet on iron filings. If a bar magnet be plunged into iron filings, and then lifted a mass of iron filings will adhere themselves to the ends of the magnet poles.

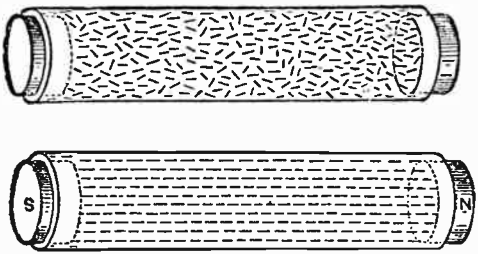


FIG. 5—Illustrating behavior of iron filings in a glass tube when tube be stroked with a permanent magnet. In this experiment it will be found that the iron filings which at first had no definite arrangement, will rearrange themselves under the influence of magnetic force, and assume symmetrical positions, each one lying in line with or parallel to its neighbor as shown in the lower figure.

For example, if a magnetized knitting needle is heated sufficiently it will be found to have lost its magnetism completely. Again, if such a needle be jarred, hammered or twisted, the strength of its poles as measured by their ability to pick up tacks or iron filings will be found to be greatly diminished.

Again, if a magnetized needle be broken, each part will be found to be a complete magnet, that is, two new poles will appear at the breakage point, a new *N-pole* on the part which has the original *S-pole*, and a new *S-pole* on the part which has the original *N-pole*. This subdivision of the needle may be continued indefinitely, but always with the same result as indicated in fig. 6. Thus it will be noted that no single magnetic pole can exist by itself, but will always appear as a North and a South pole, irrespective of the size involved.

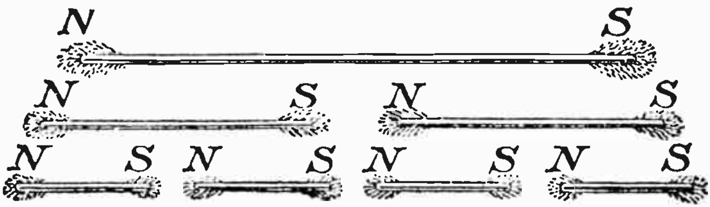
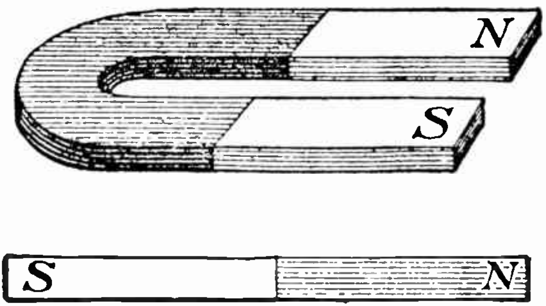


FIG. 6—Showing the effects of breaking a magnet into several parts. If a magnetized needle be broken, each part will be found to be a new magnet having an N and *S* pole. The sub-division may be continued indefinitely but always with the same result as indicated in the figure.

The foregoing facts also point to the conclusion that in any unmagnetized piece of iron, the atoms in it are not lined up in any particular order, that is, the electrons circling the nuclei of the iron atoms produce magnetic effects, but these effects cancel out each other.

On the other hand, when the iron is magnetized and becomes a magnet, the iron atoms are forced into a more definite alignment. Also the more strongly a piece of iron is magnetized, the more atoms are brought into alignment.

The fact that a piece of iron cannot be magnetized beyond a certain limit irrespective of the magnetizing force, is because there is a definite limit to the number of atoms that can be made to stay in alignment, and when this limit is approached, the iron is said to be *fully magnetized* or *saturated*.



FIGS. 7 and 8—Showing a horseshoe magnet and bar magnet respectively.

Magnetic Materials.—Iron and steel are the only substances which exhibit magnetic properties to any marked degree. Nickel and cobalt are also attracted appreciably by strong magnets. Bismuth, antimony, and a number of other substances are actually repelled instead of attracted, but the effect is very small. For practical purposes *iron* and *steel* may be considered as the only magnetic materials.

The Magnetic Field.—It can easily be shown that when a straight bar magnet is held under a piece of cardboard upon which iron filings are sprinkled, the filings will arrange themselves in curved lines radiating from the poles.

If a horse shoe magnet be held at right angles to the plane of the cardboard the filings will arrange themselves in curved lines as shown in fig. 9. These lines are called *magnetic lines of force* or simple *lines of force;* they show that the medium surrounding a magnet is in a state of stress, the space so affected is called the *magnetic field*, and the lines of force are collectively referred to as *magnetic flux.*

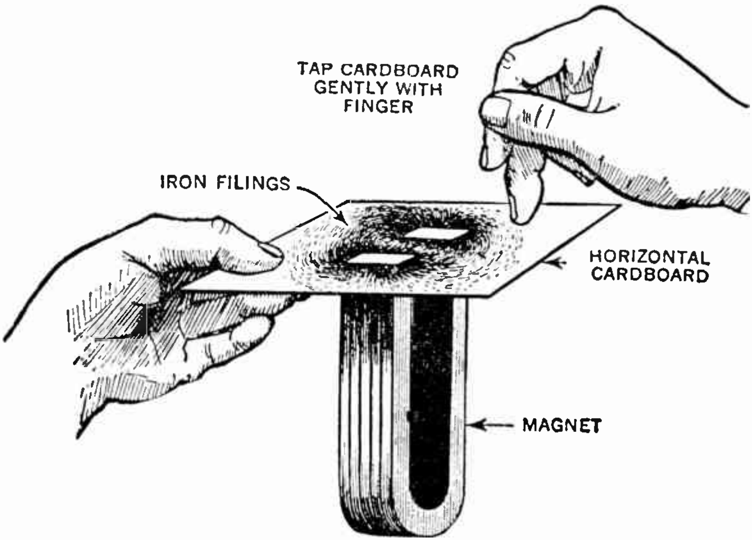


FIG. 9—Showing magnetic effect of a horseshoe magnet. The region about a magnet in which its magnetic forces can be detected is called the magnetic field. This can readily be presented graphically by placing a piece of cardboard over the magnet, sprinkling iron filings on the paper, gently tapping it at the same time. Each filing then becomes a temporary magnet by induction, and sets itself, like the compass needle, in the direction of the lines of force of the magnetic field.

Characteristics of the Magnetic Field.—The foregoing discussion of magnets and iron filings indicates certain characteristics common to all magnets, in that they produce *lines of force* and that these lines arrange themselves in certain geometrical patterns stretching from one pole to the other of the magnet.

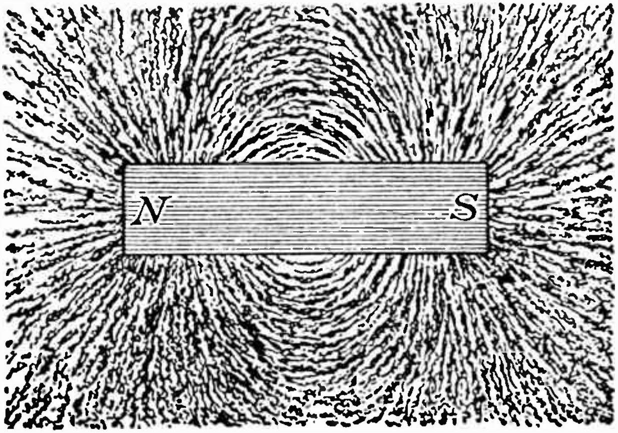


FIG. 10—Photographic illustration showing the magnetic lines of force as exerted by a bar magnet on iron filings.

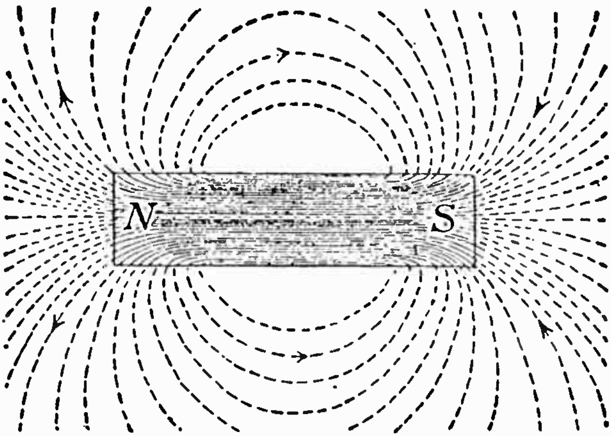


FIG. 11—Showing theoretical concepts of lines of force surrounding the poles of a bar magnet.

It would be incorrect, however, to think of these as actual lines extending through the space surrounding the magnet. The lines are only imaginary, and the idea of referring to magnetism in terms of *lines of force* has been adopted merely as a convenient means of expression when experimenting with magnets.

A better way of expressing this behavior would be perhaps to think of the lines of force as lines of stress, and that the magnet is in some way able to produce a strain in the medium about it, that this strain has a definite direction at every point, and consists of a tension in the direction of the lines of stress, and a repulsion at right angles to that direction.

Permanent and Temporary Magnets.—Certain substances like steel retain their magnetism after the magnetic field used to magnetize them has been removed, and are, therefore, called *permanent magnets.*

Other substanses, like soft iron, remain magnets only when they are in the field of another permanent magnet and become demagnetized after removal. Such magnets are called *temporary magnets.*

Analogy between Electric and Magnetic Circuits.—The total number of magnetic lines of force, or magnetic flux, produced in any magnetic circuit will depend upon the magnetomotive force (*m.m.f.*) acting on the circuit, just as the current in the electrical circuit depends upon the electromotive force and the resistance of the circuit.

The similarity between the electric and the magnetic circuit will readily be noted if Ohm's Law be applied to both. Thus, according to Ohm's Law:

$$\text{electric current} = \frac{\text{electromotive force}}{\text{resistance}}$$

$$\text{expressed in units, amperes} = \frac{\text{volts}}{\text{ohms}}$$

The resistance, as already explained, depends upon the materials of which the circuit is composed, and their geometrical shape and size.

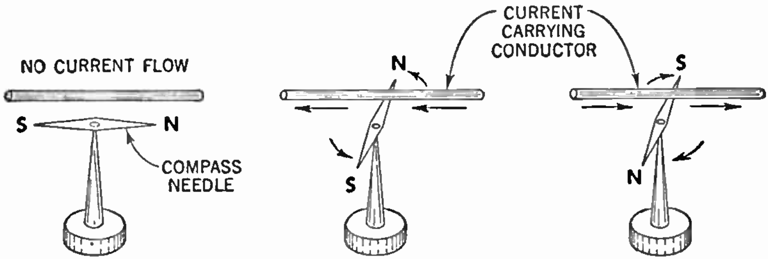
Similarly, in the magnetic circuit, the total number of magnetic lines produced by a given magnetizing solenoid depends upon the magnetomotive force, the material composing the circuit, and its shape and size. That is,

$$\text{magnetic flux} = \frac{\text{magnetomotive force}}{\text{reluctance}}$$

$$\text{expressed in units, maxwells} = \frac{\text{gilberts}}{\text{oersteds}}$$

It should be noted that in the electric circuit, resistance causes heat to be generated, resulting in waste of energy; but in the magnetic circuit, reluctance does not involve any similar waste of energy.

Electromagnetism.—Back in the early part of the eighteenth century, a Danish physicist, Hans Christian Oersted discovered the effects of an electric current upon the magnetic needle. Oersted found while experimenting with the voltaic battery that when joining the wires from a battery above a suspended magnetic needle, that the compass needle instantly turned on its axis, and set itself at right angles to the wire. When the current was reversed the compass needle turned in the opposite direction.



FIGS. 12 to 14—Showing deflection of a compass needle held near a conductor through which an electric current flows.

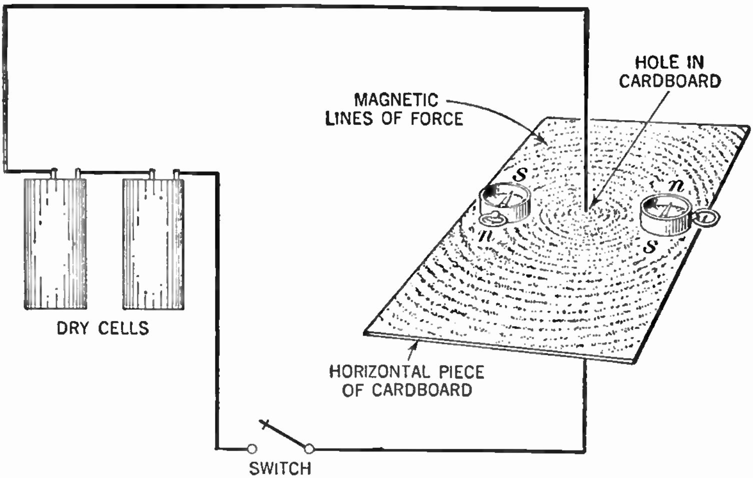


FIG. 15—Experiment showing direction of lines of force in the magnetic field surrounding a conductor carrying an electric current. A piece of copper wire is pierced through the center of a sheet of cardboard and carried vertically for two or three feet and then bent around to the terminals of a battery or other source of current. If iron filings be sprinkled over the card while the current is flowing, they will arrange themselves in circles around the wire, thus indicating the form of the magnetic field surrounding the conductor.

The magnetic effect of an electric current was further demonstrated by sending an electric current through a vertical wire which passes through a horizontal piece of cardboard filled with iron filings as shown in fig. 15.

By gently tapping the cardboard it will be found that the iron filings arrange themselves in concentric rings about the wire. An examination of the filings will show that each magnetic line forms a complete circle by itself. By placing small compasses at various positions on the cardboard it will be observed that the

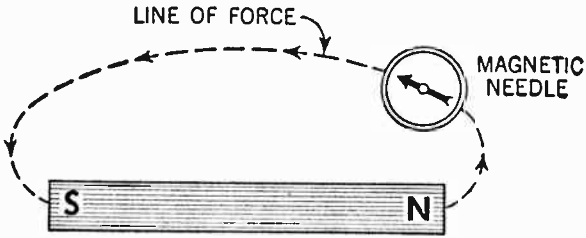


FIG. 16—Showing how lines of force may be traced by a magnetic needle. If a small magnetic needle be suspended by a thread and held near the magnet it will point in some fixed direction, depending on the proximity of the poles of the magnet. The direction taken by the magnet is called the direction of force at that point, and if the suspended needle be moved forward in the direction of the pole, it will trace a curved line which will start at one pole and end at the other. Any number of such lines can be traced. The space filled by these lines are called the magnetic field.

needles always point in a direction parallel to the circular magnetic lines. When the current flows through the wire as indicated, the needles will point in a counter-clockwise direction and if the current be reversed the needles will also reverse themselves, that is, they will point in a clockwise direction.

With these great discoveries it was conclusively shown that an electric current possesses magnetic properties, in that it can move a magnet and that a relationship exists between electricity and magnetism. It is perhaps true to say that these observations more than any other started a chain of events that has helped to shape our industrial civilization.

From the foregoing it is also clearly evident that a wire carrying an electric current acts like a temporary magnet and that magnetic lines of force in the form of concentric circles surround the wire and lie in planes perpendicular to the wire.

It was soon discovered that when several turns of wire were formed into a coil and current passed through it, that each turn added its magnetic field to the others, resulting in added magnetic strength. Such a magnet is called an *electromagnet.* Electromagnets are essential parts of electrical machinery, meters and instruments.

Ampere Turns.—In the construction of electromagnets, it is customary to wind the coil upon a soft iron core. When the coil is wound around the core several times, its magnetizing power is proportional both to the strength of the current and the number of turns in the coil. *The product of the current passing through the coil multiplied by the number of turns composing the coil is called the ampere turns.*

By experiments it has been established that the magnetomotive force in such a coil is

$$m.m.f. = 0.4\,\pi\, IN = 1.257\, IN, \text{ gilberts}$$

where I is the current in amperes and N the number of turns in the coil.

From the foregoing expression it follows that the strength of an electromagnet depends upon the product (IN) or ampere turns. Thus, for example, an electromagnet of 50 turns with one ampere flowing through it, has the same strength as an electromagnet of only 10 turns with 5 amperes flowing through it.

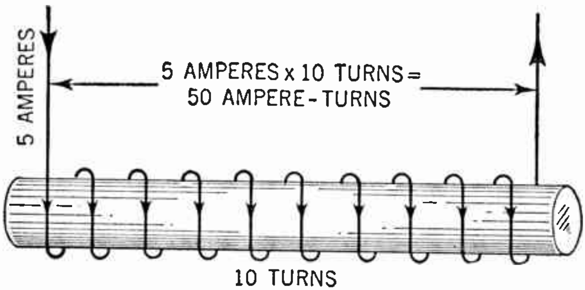


FIG. 17—Showing method of determining ampere-turns in a coil or electromagnet. Thus by measuring the current flow in amperes and multiplying with the number of turns in the coil, the product so obtained is called the ampere-turns of that coil.

Determination of Polarity.—There are several methods used to determine polarity of electromagnets. The simplest possible method is of course the employment of a permanent magnet such as a compass needle or any other magnet of known polarity. Thus if the North pole of a compass needle, for example, be brought into close proximity to one of the poles of an electromagnet of unknown polarity the action of the compass needle will immediately classify the pole as North or South depending upon whether the needle be repelled or attracted.

The Left-Hand Rule.—Another method for determining the polarity of an electromagnet is by means of the so-called *left-hand rule.* This simple rule consists in grasping the coil in the left hand with the fingers pointing in the direction of the current flow (assuming the current flowing from negative to positive) then the thumb points toward the North pole of the coil.

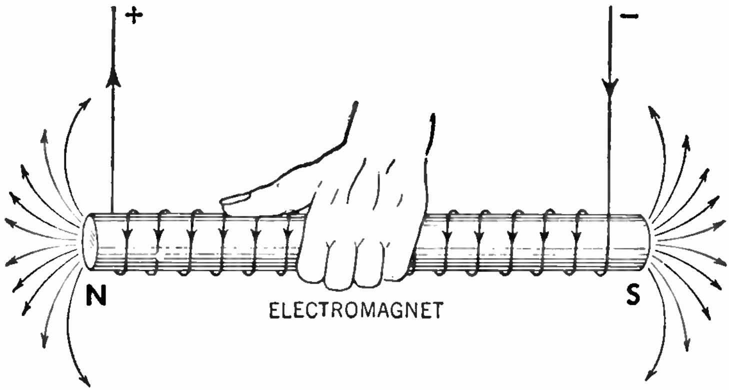


FIG. 18—Showing method of finding the polarity of a coil by means of the left-hand rule.

Relationship between Current Flow and Magnetic Lines of Force.—The direction of current flow versus the direction of lines of force may be found by encircling the conductor with the left hand, and with the thumb in direction of the current (assuming the direction of current from negative to positive), then the curled-up fingers will point in the direction that the lines of force are assumed to be taking in circling the conductor.

Horseshoe Magnets.—To facilitate the employment of magnets in practical devices such as in instruments, meters and the like, it is customary to bend the magnet in the form of a horseshoe. In this manner the North and South poles will be brought adjacent to one another, thus projecting the magnetic lines of force in a direction perpendicular to the surface of the magnet as illustrated in fig. 7.

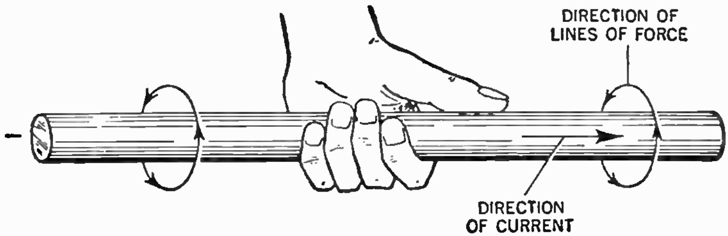


FIG. 19—Illustrating how the left hand rule may be used to determine direction in which lines of force encircle a current-carrying conductor.

Electromagnetic Induction

Early experimenters with electricity noted that if a closed circuit conductor such as a coil was moved in the vicinity of a magnet a current would flow in the circuit.

It was also found that a varying current in one conductor would cause a current to flow in a second conductor, provided the second conductor was brought close enough to the first one and a continuous path provided for the current flow. Such currents are said to be generated by *induction* and are termed *induced currents.* The combined action of induction and current flow is called *electromagnetic induction.*

It is the ability of an electromagnet to produce a current in a conductor which is responsible for the operation of motors and generators. Electromagnetic induction is also employed in the transfer of electric energy from one circuit to another such as in transformers, used in the supply of power and light for homes and industry.

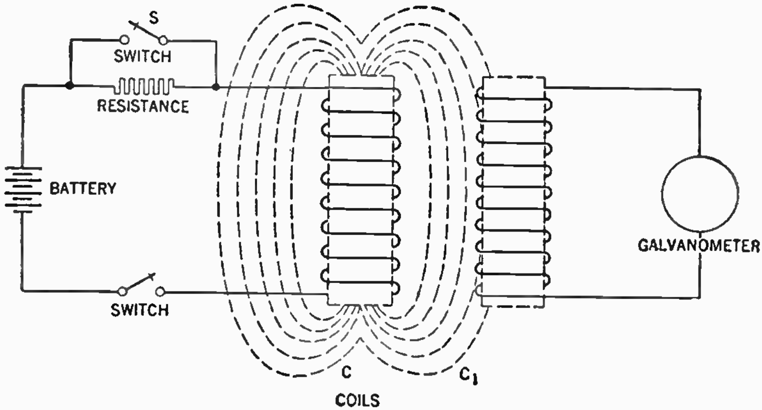


FIG. 20—Circuit showing how the effect of mutual induction may be measured by a galvanometer. If two coils *C* and C_1, be placed in axial relationship to one another as illustrated, and the current through coil *C* be varied by means of switch *S*, the induced current through coil C_1 will also be varied as indicated by the deflection of the galvanometer.

Direction of an Induced Current.—Various experiments have been made resulting in several rules or laws for determination of the direction of an induced current flow.

Laws of Induction.—These simple rules state (1) that *when an e.m.f. is induced in a closed circuit by a conductor cutting a field, or vice versa, the amount of current flow is proportional to the rate of cutting and the number of linkages.*

2. *The induced e.m.f. sets up a current the direction of which tends to prevent a change in the number of linkages.*

The foregoing statements have been combined and summarized into a law which may be stated as follows:

3. *An induced current has such a direction that its magnetic action tends to resist the motion by which it is produced. This is known as Lenz's Law.*

Measurement of Magnetism.—As previously noted, the magnetic lines of force are characterized by a closed loop, in which the path of the lines runs from the North to the South poles of the magnet and complete their circuit in the magnet itself. The space through which the lines of force act is called the *magnetic field.*

In connection with a study of magnetizm there are several units which are related to one another and which must be clearly understood. They are:

1. *The magnetic flux* (ϕ) is equal to total number of lines of force in a magnetic circuit and corresponds to the current in the electric circuit. The unit of flux is one line of force and is called *the maxwell.*

2. *The magnetomotive force* (*m.m.f.*) tends to drive the flux through the magnetic circuit and is similar to the electromotive force (*e.m.f.*) in the electric circuit. The unit of magnetomotive force is *the gilbert.*

3. *Reluctance* ($\mathcal{R}$) is the resistance offered by a substance to the passage of magnetic flux and corresponds to resistance in an electric circuit. The unit of reluctance is the *oersted.*

4. *Permanence* ($\mathcal{P}$) is the opposite of reluctance, and may be defined as the property of a substance which permits the passage of magnetic flux. It is the reciprocal of reluctance and corresponds to conductance of the electric circuit.

5. *Permeability* (μ) may be defined as the ratio of the flux existing in a certain substance to the flux which would exist if that material were replaced by air; the magnetomotive force acting upon this portion of the magnetic circuit remaining unchanged.

The permeability of air is therefore taken as unity or 1 (one). The permeability of certain types of iron is often more than 5,000 times that of air, varying with quality of the iron. It should also be noted that *the permeability of any substance increases with the increase of its cross-section and decreases with its length.*

Magnetization Curves.—These are frequently used to determine the number of ampere-turns required in an electromagnetic circuit when the magnetic material composing the circuit and other factors are known.

Thus to determine the ampere-turns required per inch of a magnetic circuit it is only necessary to know the flux density and permeability. If a curve, or curves be plotted, giving the direct relation between flux density B and ampere-turns required per inch H, of various magnetic materials, they will have the shape as noted in fig. 21.

Hysterisis.—The term hysterisis has been given to the action of lag of magnetic effect behind their source. Hysterisis thus means to "lag behind", hence its application to denote the lagging of magnetism in a magnetic material, behind the magnetic flux which produces it.

Hysterisis is caused by the friction between the molecules in a magnetic material which require an expenditure of energy to align their position. This change of position or alignment takes place both in the magnetization and demagnetization process.

The amount of energy expended in the magnetization process and manifest by heat may be found by the use of a mathematical formula and is called the *hysterisis loss.*

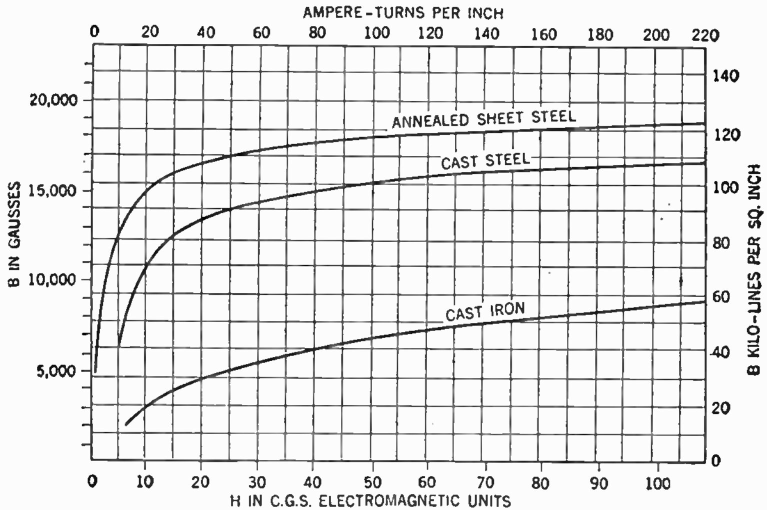


FIG. 21—Typical magnetization curves for cast iron, cast steel and annealed sheet steel.

This may best be understood by referring to the hysteresis loop or magnetic cycle shown in fig. 22, which shows how *B* changes when *H* is periodically varied. In the figure *H*, equals the number of lines of force per *sq. cm.* and *B*, equals number of lines of induction per *sq. cm.*

If now *H* be gradually diminished to zero it is found that the value of *B*, for any given value of *H*, is considerably greater when that value of H, was reached by decreasing H from a higher value, than when the same value was reached by increasing H, from a lower value; that is to say, the curve AC when H is decreased, is very different from the curve OA, when it is increased.

Take for instance, the value of $H = 20$. When this is reached by increasing H from 0 to 20, the corresponding value of B is 5,100 but when it is reached by decreasing H from 94 to 20, the value of B is 12,200.

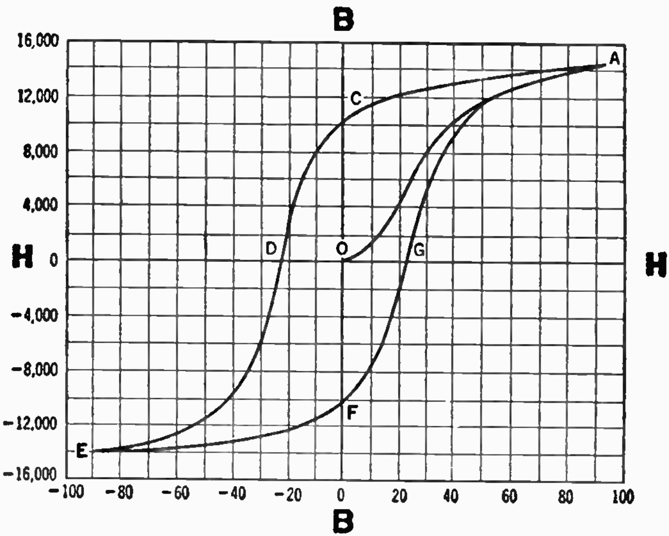


FIG. 22—A typical hysteresis loop.

It may be noted also that when H is reduced to zero, B, still has a value OC of 10,300 which is nearly three quarters the value it had when H, was 94. This induction is known as residual magnetism.

In soft iron it will nearly all disappear on tapping, but without this it can also be removed by reversing the current in the magnetization coil, so as to demagnetize the iron. The curve fig. 22 shows that a demagnetizing force of $H = 23$, is required to make B zero at point D. This force is called *coercive force* of the iron, and is a measurement of the tenacity with which it holds the residual magnetism.

As the magnetizing force is still further increased in the reverse direction, the curve passes from D to E, where the iron becomes saturated negatively. On gradually returning H to zero, the curve passes from E to F, along a similar but opposite path to AC, OF, because of the residual magnetism. The magnetizing force has now completed the cycle from O to a positive value, back to O, to a negative value and again back to O, and if this cycle be repeated several times, the B-H curve becomes a loop $FGACDE$, which loop is symmetrical about the center O.

The Electric Motor

Although electromagnets have found employment in a great variety of electrical devices, one of its most important uses is in the electric motor.

The electric motor principles can best be demonstrated by means of (1) a source of current such as a battery; (2) a horseshoe magnet and (3) a suspended coil of light copper wire arranged as shown in fig. 23.

If a current be sent through the coil it will commence to rotate through a right angle, and sets its faces opposite the poles of the magnet, but it will be found that it does not stop at the instant it reaches that position, but is carried beyond it.

The magnetic force and the torsional elasticity of the suspended cord, however, stops it and brings it back. After a few oscillations it settles into the position just mentioned, in which its line of force coincides with those of the magnet.

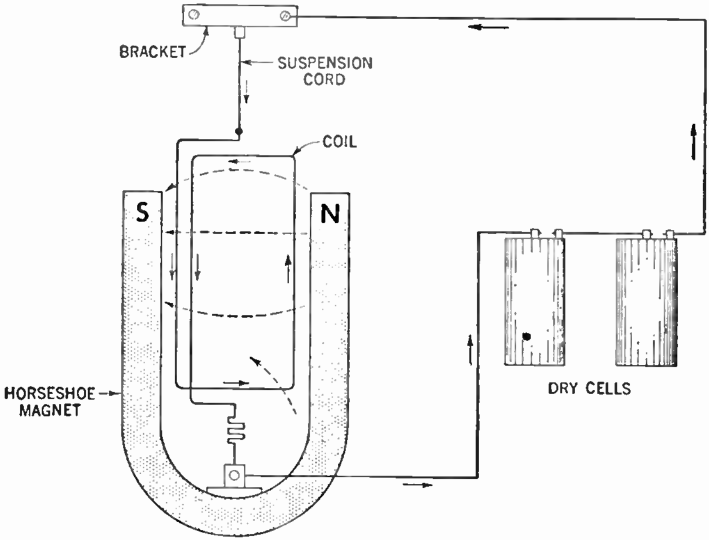


FIG. 23—Experimental circuit arrangement showing motor action of a suspended coil.

If we could manage to reverse the current just as it passes this position and if we also could free the coil from the torsion of the suspended cord, then instead of oscillating and settling in the position mentioned, it would go through half a revolution more. On account of its inertia, however, it cannot stop itself; and if we again reverse the current at the right instant, it will continue to rotate another half turn. From the foregoing it becomes evident that if the current be reversed exactly at the end of each half turn, and the twisting force of suspension be eliminated a continuous rotation would be obtained.

To obtain continuous rotation therefore some means must be found to mechanically reverse the direction of the current at exactly the correct time, and also to free the coil so that it may rotate continuously without the hindrance of the suspension cord.

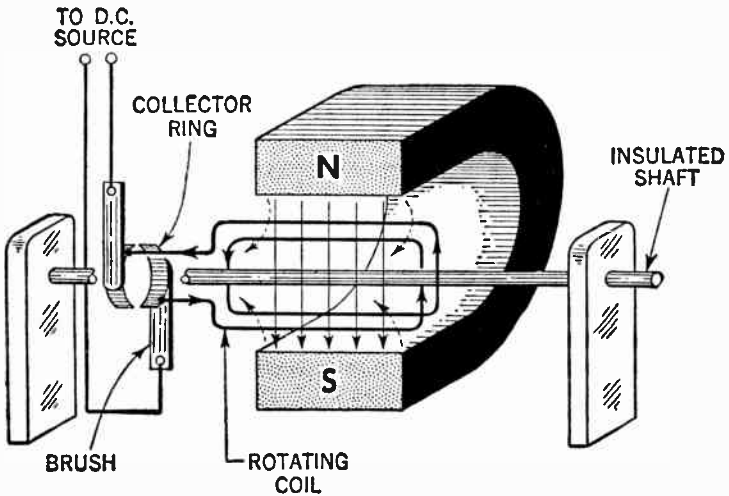


FIG. 24—Showing greatly simplified circuit arrangement where a coil may be made to rotate in a magnetic field.

This may easily be accomplished by mounting our copper wire coil, which may be called the armature on a horizontal steel axis or shaft whose ends are allowed to turn freely in suitable bearings. On this shaft and insulated from it, is mounted a metal ring that has been split and slightly separated in the middle as illustrated in fig. 24.

It will be noted that in order to complete our circuit it will be necessary to attach the two ends of the coil, one to each ring segment, and also to provide a connection to the current source. The latter will be accomplished by providing a couple of light metal springs each of which will be allowed to ride freely on diametrically opposite points of the split ring. The ends of the metal springs are finally attached to the current source.

Our apparatus is now completed and the coil rotates with its ring segments, and if the current be of sufficient strength the rotation will continue indefinitely. The early experimenters with electricity discovered the principle of the *direct current motor* in the foregoing manner.

In practical machines, the rotating coil is called *armature,* the ring segments *commutator,* the metal springs *brushes* and the permanent magnet is substituted for two or more *field coils.*

In summing up it will be noted that as the commutator rotates with the armature and when the armature is in one position, the electrons (or current) flows in through the negative brush to one half of the commutator, thence through the armature coil to the other half of the commutator and then out by means of the positive brush. However, as the armature makes another half turn, or revolution, so does each half of the commutator, which thereupon comes in contact with the opposite brush. The electrons now flow into the opposite half of the commutator and thus through the coil in the opposite direction. This reverses the poles of the armature and it continues its rotation.

Practical Direct Current Motors.—Although in the foregoing experiment the principles of the motor have been found, our miniature motor is very weak and inefficient being barely able to run itself to say nothing of driving machinery.

In construction of a practical motor therefore, we may improve upon construction principles involved in the following manner:

1. Since the turning force acting upon our coil depends upon the two magnets, we may increase this force by making these magnets stronger.

2. Our knowledge of the permeability of soft iron suggests the application of a soft iron core upon which to wind or form our rotating coil.

3. We know that an electromagnet will provide a stronger magnetic field; so we can further increase the strength of the field by substituting electromagnets for the steel magnet.

4. The strength and efficiency of our magnet may be further improved if they be made shorter and thicker, with large pole pieces, shaped so as to embrace the coil as closely as possible without interfering with its rotation. This fills the air-gaps as nearly as possible with soft iron, and gathers in the lines of force, so that more of them pass through the armature.

5. The effectiveness of the armature may be greatly increased by winding on the iron core another coil at right angles to the first, so that when one coil is turning into the least effective position, the other is turning into the most effective position. The number of coils may be increased to four, six, eight and so on as illustrated in fig. 25, until all the available space on the core is filled. The commutator must also be constructed in such a way that each coil is

connected to its own segment. Increasing the number of coils not only increases the magnitude of the magnetic force, but also makes it approximately uniform in intensity.

This then, constitutes a direct current motor in modern form, and although improvements in materials, designs and efficiency are constantly sought, the motor in its present form leaves little to be desired in the matter of service in the multitude of tasks assigned to it.

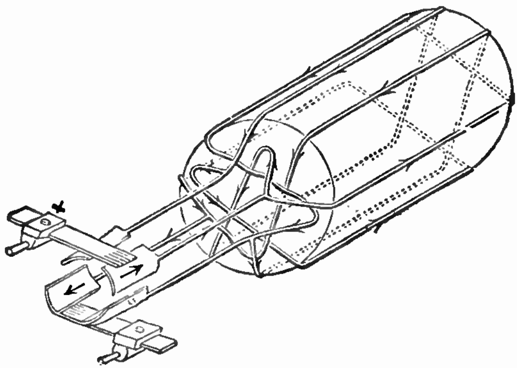
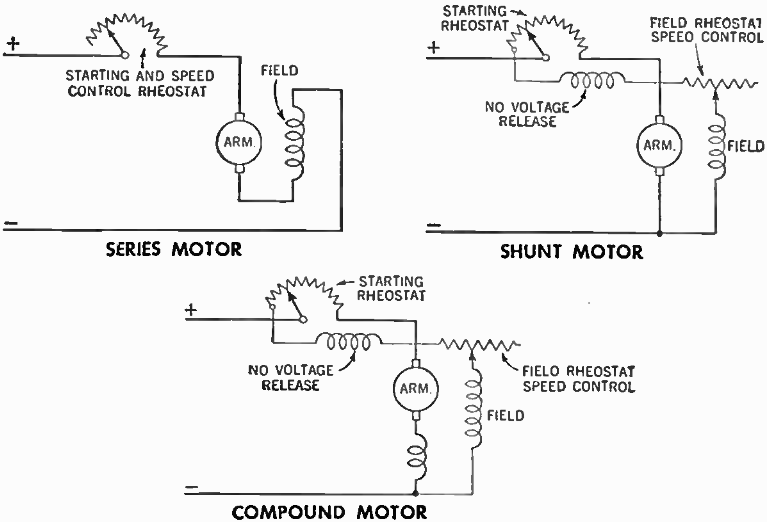


FIG. 25—Elementary four coil drum winding, showing the connections with the commutator segments and direction of currents in the several coils.

Direct Current Motor Connections.—Depending upon the connections between the field coils and armature, direct current motors are divided into three groups, and are classified as *series, shunt and compound wound.*

Thus, the *series motor* has derived its name from the fact that its *field* and *armature* are connected in *series* with one another. In a *shunt motor*, on the other hand, the *field* coils are connected in *shunt* or across the armature.

The compound motor, as the name implies, is actually connected as a combination of the series and shunt wound type and has two windings on its field poles, one having a relatively small cross-sectional area, connected across the armature in the manner of a shunt motor and the other winding connected in series with the armature.



FIGS. 26 to 28—Typical wiring diagrams showing internal connections of series, shunt and compound wound motors respectively.

Commutating Poles.—As an aid to commutation, and to prevent excessive sparking at the brushes, it is customary to provide larger motors with commutating or interpoles. These are located between the main field poles, the commutating field winding being connected in series with the armature. The *m.m.f.* of the commutating pole flux is opposite that of armature reaction. Thus the commutating pole flux induces a voltage in the armature coils undergoing commutation in such a direction as to aid in reversing the current in those coils. Without this effect it would be difficult to obtain good commutation particularly in the larger machines.

Application of Direct Current Motors.—Since direct current is not usually available in most localities, *d.c.* motors are most commonly used in special applications, such as in certain types of hoisting machinery, on electrically or Diesel operated railroads, on electric motor drives requiring very close speed control, etc.

The trend towards the universal use of alternating current machinery is mainly one of economy since the cost of direct current motors is presently 150 to 300 per cent higher than those of squirrel cage induction motors of the same horsepower ratings. To this must also be added the cost of conversion from one type of current to another, which is usually accomplished by rectification of *a.c.* current, by synchronous converters or by motor generator sets.

Alternating Current

In our previous discussion of the direct current motor it was noted that the proper functioning of the motor was obtained chiefly because of the construction of the commutator, that is, the commutator ring had to be split into two equal segments in order to establish a reversal of the current.

If, however, a device be designed in the manner illustrated in fig. 29, with two metal rings, and with each end of the coil terminated as shown, we will note that if the terminal be connected to a direct current source, no motion of our armature will take place. Connecting the device to an alternating current, on the other hand, will result in rotation of the armature coil. Our device may therefore be called an *alternating current motor*.

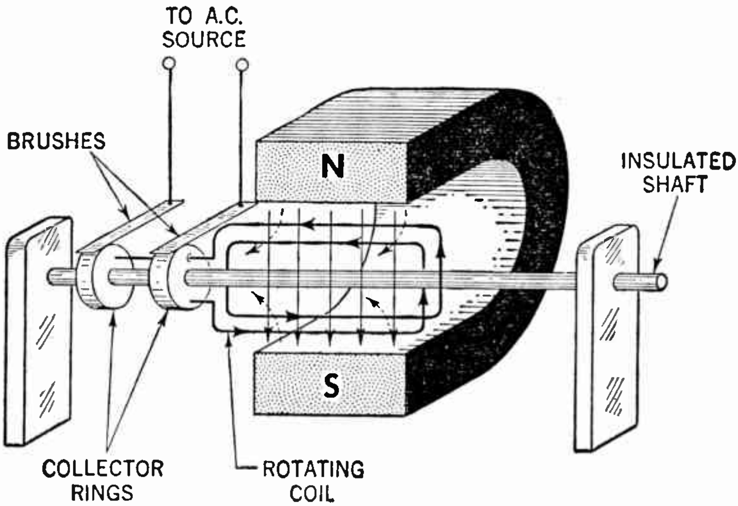


FIG. 29—Simplified circuit showing basic principles of an alternating current motor.

Motors and Generators.—Motors are classified as *direct or alternating current machines*, and as *series, shunt or compound.* A direct current motor and a direct current generator are interchangeable and an alternating current motor and an alternating current generator are also inter-changeable.

When a machine is operated by mechanical power and the rotor is revolved it will deliver power in the form of electric current. Such a machine is termed a *generator*. When, on the other hand, the machine is driven by electromagnetic force supplied by electric current, it will deliver energy in the form of mechanical power, which can be utilized to turn a shaft, drive machinery by means of a belt or do other useful mechanical work. A machine of this type is termed a *motor*.

In practice, however, certain minor changes are necessary in order to reverse the machines. Thus, for example, if a self-excited shunt wound direct current generator be connected at the brushes to a source of electric power, this current will pass through both the field winding and the armature. The direction of current through the external circuit will now be opposite to that when the machine was used as a generator; in other words, that which formerly was the positive output brush is now the positive input brush.

It should also be noted that generators of electric power are commonly manufactured in large sizes for reason of economy, whereas motors are tailored to suit individual load requirements which may vary from a fraction of horsepower up to several thousand.

The A.C. Generator.—An alternating current may be defined as *a current which continually changes in magnitude and periodically reverses in direction.* Generators of alternating current are usually known as alternators and are theoretically the simplest types of electrical machines. Basically an alternator consists of an electromagnet and a moving conductor, an electromagnetic force being induced in the conductor by its movements through the magnetic field.

A simple illustration of the alternating current principle is shown in fig. 30, in which a conducting coil *ABCD* is arranged in a position so that it can be rotated on its horizontal axis in the space between the two poles of a permanent magnet *N* and *S*. The coil terminals are joined to two slip rings and brushes

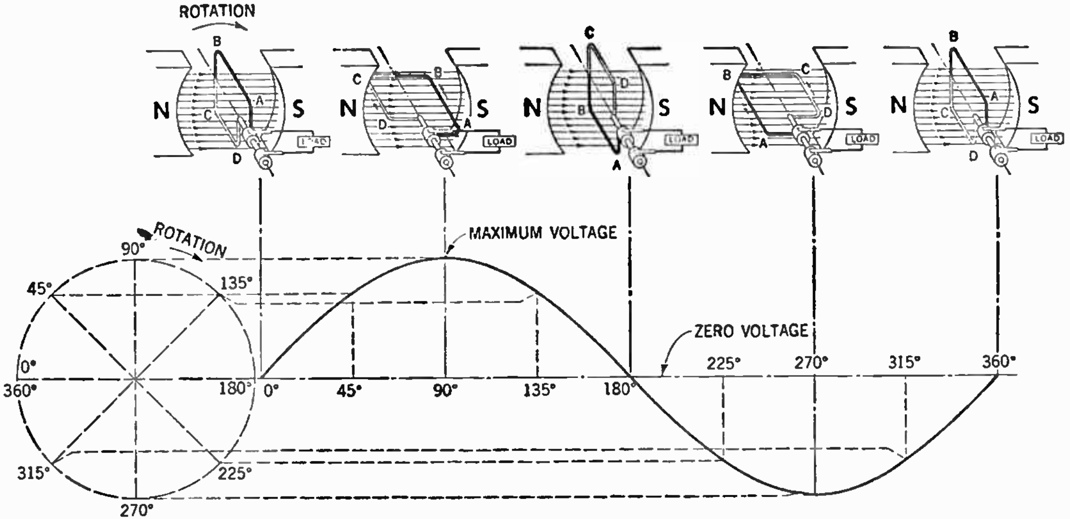


FIG. 30—Simple illustration showing generation of a sine curve during an alternating current cycle. Here the progressive generation of the sine curve is shown with a view of the armature for each 90° of a complete revolution. To facilitate sine curve construction, it is often convenient to sub-divide the circle periphery in eight or more equal parts.

which are insulated from each other and from the shaft on which they are fastened. The wires leading from the brushes are used as a means of conducting the generated current to a load or measuring instruments.

In following the action of our conducting coil, it will be noted that the current delivered to the load or external circuit for one-quarter revolution of the coil will rise to maximum amplitude and then falls to zero as the coil reaches the different angles of the circle which place it in a corresponding relation to the magnetic field.

When the coil continues the other half of the revolution, the process is repeated, only this time on account of each side of the loop cutting the magnetic field in a direction opposite to the way it cut them during the first half, the current flows in the reverse direction.

Thus with one complete revolution of our loop an alternating current has been generated. The geometrical figure represented by plotting the current generated by the coil during one complete revolution is known as a *sine curve.*

Cycle and Frequency.—From the foregoing observation of the current it is evident that during the complete revolution of the loop two alternations of current have taken place. These two alternations of current constitute one *cycle* of alternating current, and the number of cycles per second is termed the *frequency* of the current. In practical machines the number of cycles per second is usually 60. The number of poles may vary and depends upon the speed in revolutions per minute of the machine in question.

The rule for the frequency or the number of cycles per second generated by a machine is:

$$\text{Frequency} = \frac{\text{Number of field poles} \times \text{revolutions per second}}{2}$$

$$\text{or } f = \frac{P \times N}{2 \times 60}$$

Where f = frequency in cycles per second.
P = number of poles in the machine.
N = revolutions per minute of the machine.

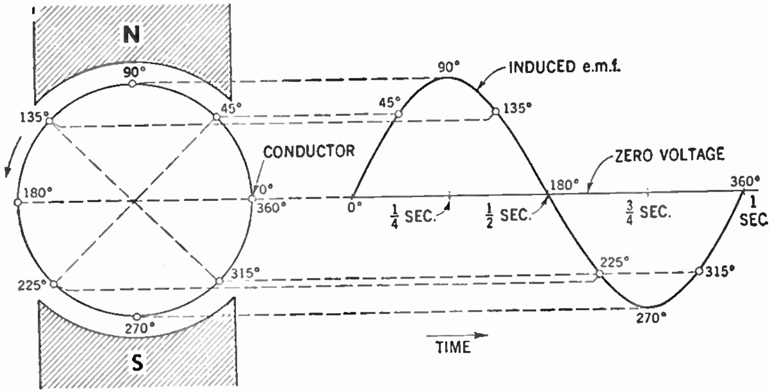


FIG. 31—Curve showing relationship between time and induced voltage in an alternating current circuit. It will be noted that during a complete revolution of the conductor there will be two positions at which there is no induced voltage and hence no current in the external circuit, and also two positions where the induced voltage has a maximum value. If the conductor were rotated 60 times per second, the induced electromotive force would go through one cycle in 1/60 second. The frequency would then be 60 cycles per second, which is the commercial frequency of the alternating current.

Example.—*A certain alternating current generator equipped with eight field poles is required to furnish a* 60 *cycle current. At what speed should the generator be run?*

Solution.—The speed or *r.p.m.* of our generator may conveniently be found by solving our previously derived equation with respect to N and substitution of values. We have,

$$N = \frac{f \times 120}{P} \quad \text{or} \quad N = \frac{60 \times 120}{8} = 900 \ r.p.m.$$

Average Values of Voltage and Currents.—In our construction of the sine curve, or sine wave, it will be noted that the true average voltage and current in an alternating current circuit is always changing during a complete cycle from a positive peak or maximum value to a negative peak of the exact opposite value. Therefore, when considering a complete cycle the true average value is zero.

When we consider the average values of current and voltages in *a.c.* circuits, we do not refer to the averages of the full cycle, but to the average of each half cycle only.

To obtain the average value of each half cycle, therefore, it is merely necessary to add the instantaneous values of one half cycle as plotted on a curve and divided by the number of such values used.

If this be done, the results will show that the average value of voltage or currents is 0.636 times the maximum or peak value. This is usually written:

$$\text{Average voltage} = 0.636 \times \text{maximum voltage}$$
$$\text{and Average current} = 0.636 \times \text{maximum current}$$
$$\text{or } E_{av} = 0.636\ E_{max}$$
$$\text{and } I_{av} = 0.636\ I_{max}$$

Effective Values of Voltage and Currents.—In practical calculations, however, the instantaneous or average values of voltage and currents are seldom used but the *effective values* are.

Because of the fact that voltage and current in an *a.c.* current system is actually of different instantaneous values throughout

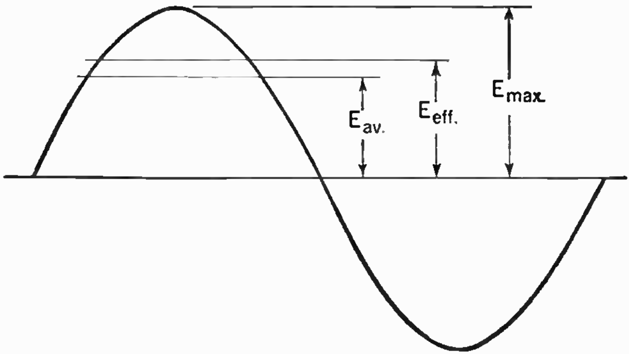


FIG. 32—Graphic representation of relations between average, effective (r.m.s.) and maximum currents and voltage during a half cycle.

the time periods of an alternating cycle, and since the cycles follow one another in rapid sequence per second of time, the actual effective voltage or current can only be determined by comparing the alternating current heating effect with that of a direct current.

This is known as the *effective or root-mean-square* (abbreviated *r.m.s.*) value of an alternating current or voltage because, if the instantaneous values of this current during a cycle be taken, the results squared and an average value obtained, and the square root of this value derived, the heating effect will be the same as in a direct current circuit, namely proportional to the square of the current.

From the foregoing it follows that the amplitude or peak factor of an alternating voltage or current must be the ratio of its maximum value to its effective or *r.m.s.* value, or $\sqrt{2}$, but since this value is approximately 1.414 and its reciprocal value 0.707, we may write:

$$E_{eff} = E_{rms} = E_{max} \times 0.707 = \frac{E_{max}}{1.414}$$

$$\text{Similarly } E_{max} = E_{eff} \times 1.414 = \frac{E_{eff}}{0.707}$$

When an alternating current be considered, we may similarly write:

$$I_{eff} = I_{rms} = I_{max} \times 0.707 = \frac{I_{max}}{1.414}$$

$$\text{or } I_{max} = I_{eff} \times 1.414 = \frac{I_{eff}}{0.707}$$

It should be noted that whenever an alternating current or electromotive force is mentioned without specific reference as to *instantaneous*, *maximum* or *average* values, *the effective value* is always assumed, because it is this current or voltage which are measured by their respective instruments.

If a maximum or peak value of the current or voltage be desired, it may readily be obtained by multiplying the instrument or meter reading by 1.414.

The Sine Curve.—Since the generation of an alternating current or potential is always represented by means of a sine curve, certain factors concerning its construction will be considered; and although the sine of an angle is a trigonometric figure, it may be represented by the aid of one or more right angle triangles as shown in fig. 33.

By definition a sine of an angle (A) such as is shown in fig. 33 is equal to the opposite side of the triangle divided by the hypotenuse. This may be written sine $A = \frac{\text{opposite side}}{\text{hypotenuse}}$

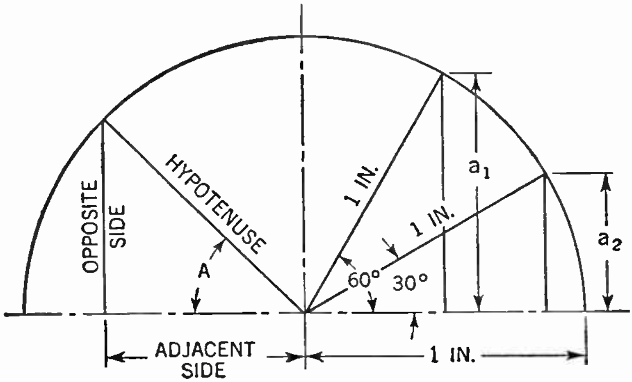


FIG. 33—Diagram illustrating what is meant by the sine of an angle.

It may easily be proved with the aid of simple mathematical relations that the sine values for angles such as 30°, 45° and 60° (degrees) are $\frac{1}{2}$, $\frac{1}{2}\sqrt{2}$ and $\frac{1}{2}\sqrt{3}$, respectively. Approximate sine values for various angles may easily be obtained from triangles inscribed in a circle of unity length radius as illustrated in fig. 33. Thus, if the radius of our circle be one inch, for example, the hypotenuse will also be one inch in length. Similarly, we have the sine for an angle of 30° $= a_2/1$ or a_2, which may be found by direct measurement to be 0.5. The sine for a 60 degree angle will in a like manner be found to be approximately 0.87, or 0.8660 from table.

A further study of our sine function will show that the sine for angles of say 120° and 150° are equal to the sines for 60° and 30° respectively. By using the foregoing values on a co-ordinate axes system as illustrated in fig. 34, with the sines

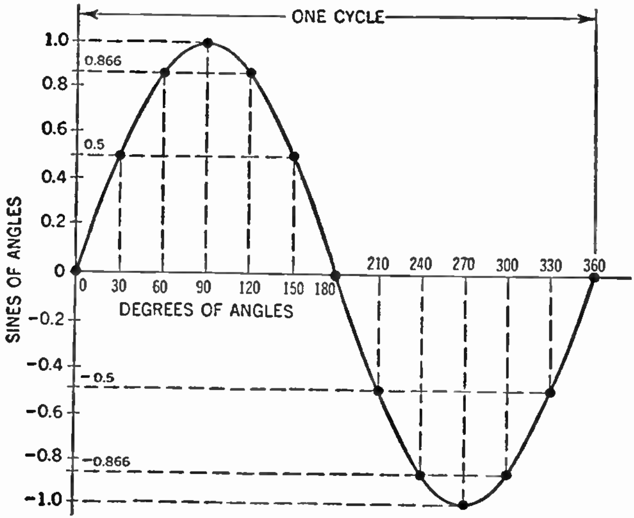


FIG. 34—Curve showing relationship between angles in 30° steps and their respective sine. The complete curve covering angles from 0° to 360° represents one complete cycle of an alternating current.

plotted on the vertical axis (ordinate) and the number of degrees from 0° to 360° on the horizontal axis (abscissa) it will be found that the projecting intersections when properly joined together represent a true sine curve.

Vector Representation of Voltage or Currents.—The periodic change which occurs in the value of an alternating voltage or current during a cycle need not be represented by a curve plotted as illustrated in fig. 35, but may more easily be represented by vectors as shown in fig. 37.

In order to show how vectors may be applied to study of an alternating current, reference is made to fig. 35. Here two sine curves R and S are drawn on the same base, having a phase difference of $\phi°$. The curves indicate the various instantaneous values throughout the complete cycle. At θ degrees from the starting point, for example, the value R is $O'A'$, while that of S is $O'B'$.

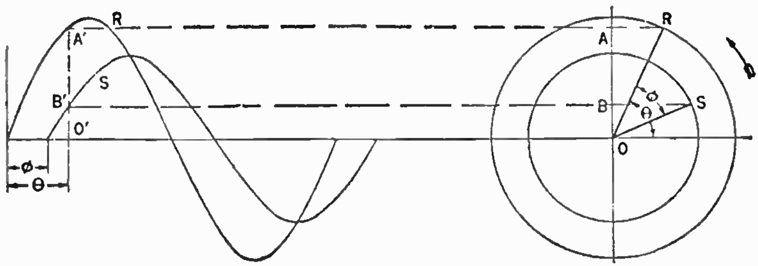
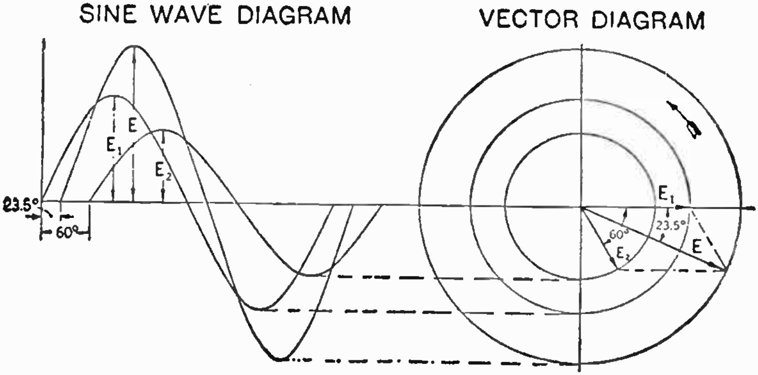


FIG. 35—Vectorial representation of two alternating current sine curves.

In the other part of the diagram two circles are drawn, their radii being equal to the maximum value of the two sine curves. The lines OR and OS are assumed to rotate about O as center and in a counter-clockwise direction. At an angle $\theta°$ from the start OR and OS have reached the position shown.

The vertical projection of these two lines are OA and OB respectively and these lines represent the instantaneous values under consideration.

Now since both OR and OS are assumed to rotate at the same speed corresponding to the same frequency, it follows that the angle $ROS = \phi$ remains constant throughout the cycle. The projection OA and OB on the vertical axis varies according to a sine law since the points A and B perform a simple harmonic motion about the point O.



FIGS. 36 and 37—Addition of two alternating current voltages.

Diagrams of this type are often made to represent alternating current or voltage values since they lend themselves more readily to exact mathematical treatment.

Addition of Alternating Current Voltages.—In the study of alternating currents, vector representation is always used since this method greatly facilitates representation of all the factors involved.

Assume, for example, that it be desired to add two voltages E_1 and E_2 as illustrated in fig. 37, with effective values of 75 and 50 volts respectively. Assume further that E_2 is lagging E_1 by an angle of 60°. These voltages will have maximum voltages of $75\sqrt{2} = 106$ and $50\sqrt{2} = 70.7$ volts respectively.

The addition may be performed by plotting the two sine curves as shown in fig. 36, and adding at equally spaced distances their instantaneous value which will give a new sine curve *E*. This new sine curve will be found to have a maximum value of 154 volts and an effective value of 109 volts and will lag E_1 by 23.5°. Thus the sum of the two voltages with effective voltages of 75 and 50 volts and differing in phase by an angle of 60° is 109 volts.

A considerable amount of time saving will be obtained if instead of plotting the three sine curves they be added vertically as previously considered. The method used is shown in fig. 37, where the two vectors E_1 and E_2 are geometrically added by completing the parallelogram and drawing the diagonal. This diagonal represents the resultant vector *E*.

It should be pointed out, however, that since effective values are 0.707 times the maximum values, then, if maximum values be used in laying out of the vectors, the resultant vector should be divided by 1.414 to obtain the effective value.

The geometrical addition of the vectors E_1 and E_2 may be performed mathematically as follows:

$$\mathbf{E} = \sqrt{(75 + 50 \times \cos 60°)^2 + (0 + 50 \times \sin 60°)^2}$$

$$= \sqrt{100^2 + 43.3^2} = 109 \text{ volts}$$

$$\text{and } \mathbf{E}_{max} = 109\sqrt{2} = 154 \text{ volts}$$

The angle can readily be verified, since

$$tg\ \phi = \frac{43.3}{100} = 0.433 \text{ and } \phi = 23.5°$$

CHAPTER 5

Radio Batteries

Early in the eighteenth century, an Italian scientist Alessandro Volta, discovered that if two dissimilar substances, such as zinc and carbon were placed in an acid solution, the chemical

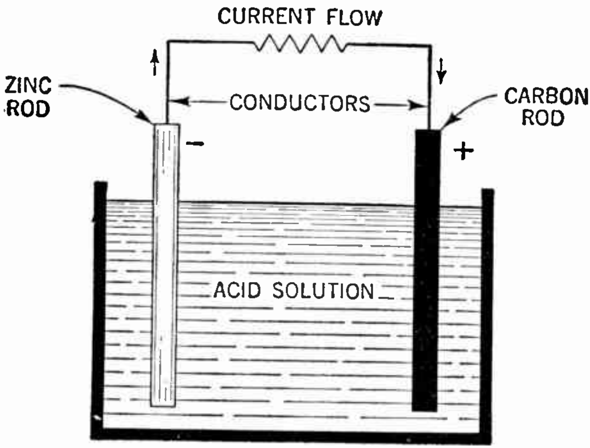


FIG. 1—Illustrating construction principles of the Voltaic cell.

action would accumulate electrons on the zinc rod making it negative with respect to the carbon, which does not react with the acid.

Volta also noted that if a wire joined the ends of the zinc and carbon electrodes, outside of the liquid, a current flowed continuously in the circuit from the zinc to the carbon. Such a device is called a Voltaic Cell in honor of its inventor.

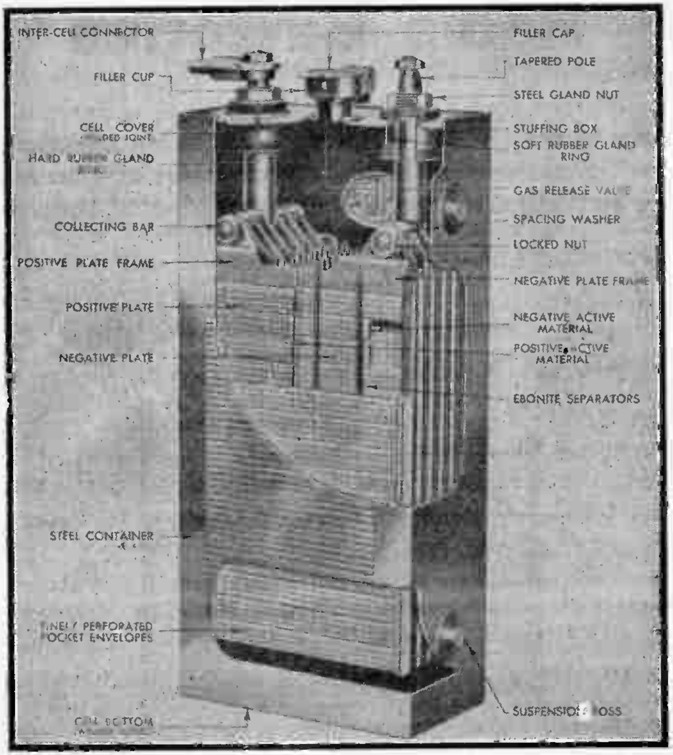


FIG. 2—Showing construction principles of a nickel cadmium storage battery. In a battery of this type nickel and cadmium function as the active materials while potassium hydroxide in solution serves as the electrolyte. (Courtesy NIFE Incorporated.)

While seeking still further to increase the capacity of his discovery, Volta found that by joining a large number of such cells in series or parallel in the form of a battery, a considerable amount of power could be obtained.

In dealing with batteries, certain distinctions should be made with respect to the terms used:

A primary cell consists of a vessel containing a liquid in which two dissimilar metal plates are immersed.

A battery consists of two or more cells joined together (in series or parallel) so as to form a single unit.

The fluid or acid solution used in a cell is termed the *electrolyte* or *exciting* fluid.

A dry cell is one in which the electrolyte has been substituted for a paste of certain chemicals in combination with ammonium chloride.

A storage battery consists of a connected group of electrochemical cells for the generation of electrical energy in which the cells after being discharged may be restored to a charged condition by passing a current through them in a direction opposite to the flow of current during the discharge period.

The Dry Cell.—The dry cell or battery is used in radio receivers of the portable type to supply "A" and "B" power. In England the filament lighting battery is known as the low-tension battery usually abbreviated *L.T.*; whereas the plate battery is termed *H.T.*, for high-tension. In the United States the term "A" and "B" battery has found acceptance, the *A* battery being that used for energizing the filaments, and the *B* battery that used for energizing the plate circuit.

The dry cell is being used in applications where considerable jarring or motion is involved and its use in portable radios is only one of its numerous duties.

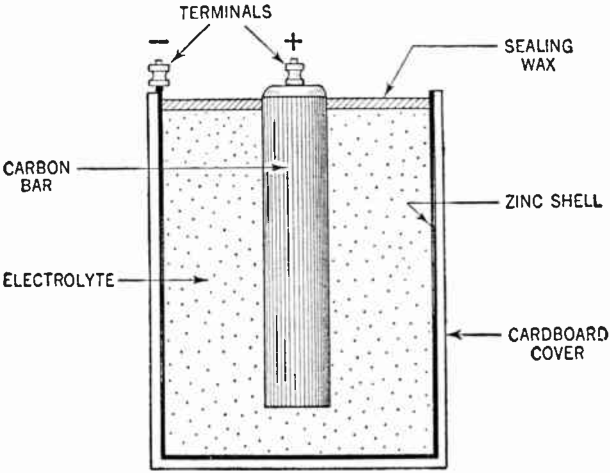


FIG. 3—Cross-section of typical dry cell showing construction. The electrolyte commonly used consists of a paste made up of ammonium chloride, manganese dioxide, sawdust and graphite.

How a Dry Cell Works.—There is nothing mysterious about a dry cell or the manner in which it works. In its usual form a dry cell consists of a zinc can into which are packed certain active chemical materials which combine with the zinc to produce an electrical pressure or voltage. The voltage thus produced is the result of the chemicals used and is always the same regardless of the size of the dry cell. A new dry cell has a pressure of about 1.5 volts, and this is true whether the dry cell be a very small one like a flashlight battery or a large 6 in. dry cell.

A dry cell is simply a package of electricity done up in convenient form. When you purchase a dry cell, the commodity actually bought is stored up electricity and the dry cell which gives you the most electricity for a given price is the cell you want to use.

The unit of quantity of electricity is commonly known as the ampere hour. It is the amount of electricity which will flow from a battery that is delivering one ampere for a period of one hour or one-half an ampere for a period of two hours, etc. If the number of ampere hours in a dry cell be known and also the rate at which this electricity was extracted from the cell, it would be a simple matter to find out how long the dry cell would last. To determine this, divide the ampere hour capacity of the dry cell by the current which it is delivering in amperes, and the result is the number of hours that the cell will last.

In practice it is almost impossible to apply this simple calculation to dry cells because it is very difficult to predict just how many ampere hours a dry cell will deliver.

The amount of electricity which is actually in a dry cell and the amount which can be obtained from it are two different things, and sometimes the difference is surprisingly large.

Battery Connections.—There are three methods of connecting cells to form a battery. They may be connected:

1. In series
2. In parallel
3. In series-parallel.

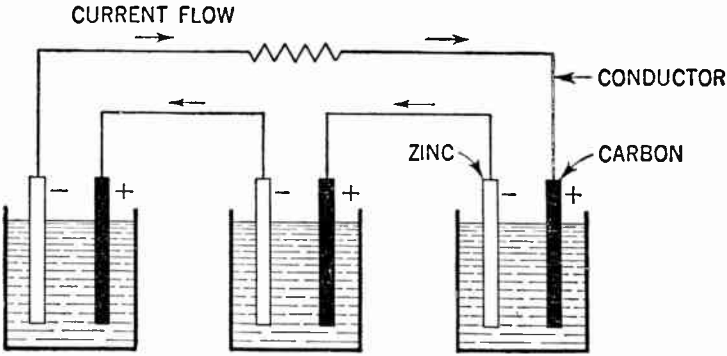


FIG. 4—Showing three series connected Voltaic cells. To obtain a series connected circuit the plus pole of one cell must be joined with the negative pole of the next cell as illustrated.

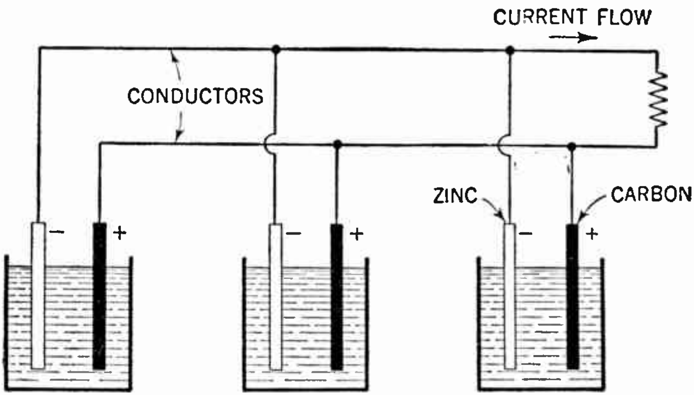


FIG. 5—Three Voltaic cells connected in parallel. To obtain a parallel connected circuit, the plus poles are joined together to form one part of the circuit and the negative poles are joined together to form the other.

A series connection consists in joining the positive pole of one cell to the negative pole of the other to form a circuit. A series connection adds the voltage of each cell; that is, the voltage of the battery will equal the sum of the voltage of each cell.

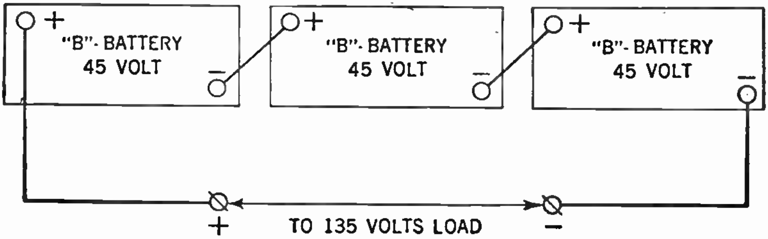


FIG. 6—Showing three series connected "B" batteries, each battery delivering a potential of 45 volts. A single battery or a series connected group of batteries such as illustrated are commonly used to supply the plate voltage on small portable type radio receivers.

A parallel or multiple connection consists in connecting the positive terminal of one cell with the positive terminal of another cell and the negative terminal of the first cell with the negative terminal of the second cell. A parallel connection adds the amperage of each cell, that is, the amperage of the battery will equal the sum of the amperage of each cell.

A series-parallel connection consists of two series sets of cells connected in parallel. The voltage of a series parallel connection is equal to the voltage of one cell multiplied by the number of cells in one battery, and the amperage is equal to the amperage of one cell multiplied by the number of batteries.

Thus, to obtain 6 volts from four dry cells, each of which has a potential of 1½ volts, a series connection will be necessary. If, on the other hand, only 1½ volts be required, but it is desired to obtain a current flow of four times that furnished by each cell, a parallel connection should be made.

CHAPTER 6

Electrical Measuring Instruments

Galvanometers.—Instruments designed for measuring small amounts of electricity may be called galvanometers, although a galvanometer is generally employed as an electro-dynamic instrument used to indicate current.

There are numerous kinds of galvanometers designed to meet various requirements such as the *astatic*, *tangent*, *differential*, *ballastic* and *D'Arsonval types*, which according to their design may have either a movable magnet and stationary coil or a stationary magnet and movable coil. The above types may be designed with a short or long coil, and the indications or deflections are given in several ways, depending upon the various uses.

The Tangent Galvanometer.—In the tangent galvanometer the sensitivity is directly proportional to the number of turns in the coil, and inversely proportional to its diameter. The strength of the current may be calculated in c.g.s. units when the dimension of the instrument is known, by the use of the following formula:

$$I = \frac{r \times H}{2\pi} \times tg\,\theta$$

in which H is the galvanometer constant representing the horizontal force of the earth's magnetism for the place where the galvanometer is used; r, the radius of the coil in centimeter; θ, the angle of the needle deflection in degrees; and I, the current in c.g.s. units.

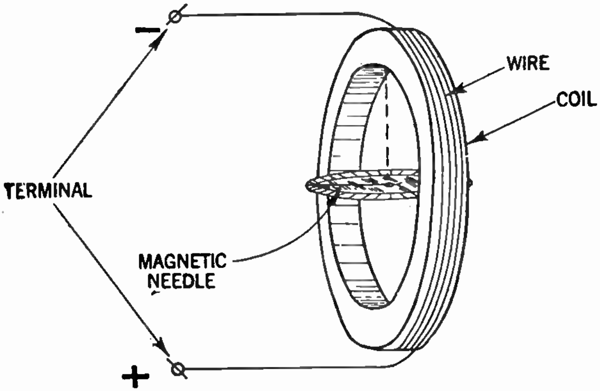


FIG. 1—The tangent galvanometer consists essentially of a short magnetic needle suspended at the center of a coil of large diameter and small cross-section. In practice the diameter of the coil is approximately 17 times the length of the needle. If the instrument be so placed, that when there is no current in the coil, the suspended magnet lies in the plane of the coil, that is, if the plane of the coil be set in the magnetic meridian, then the current passing through the coil is proportional to the tangent of the angle by which the magnet is deflected from the plan of the coil or zero position, hence the name: "Tangent galvanometer."

When the tangent galvanometer has more than one turn the factor 2π should be multiplied by the number of turns (N) on the coil.

Example.—*Find the current in a tangent galvanometer having a coil of* 25 *centimeter radius, when the needle deflects an angle of* 10 *degrees. Assume* $H = 0.2066$

Solution.—$I = \frac{r \times H}{2\pi} \times tg\,\theta = \frac{25 \times 0.2066}{2 \times 3.1416} \times 0.1763$ from which $I = 0.145$ *c.g.s.* units or 1.45 amperes.

If it be desired to determine the tangent galvanometer constant for a certain location, the current through the galvanometer may be measured by inserting an instrument of known accuracy in the circuit.

With the circuit of known value the galvanometer constant can be computed from the following formula as follows:

$$H = \frac{2 \times \pi \times I}{r \times tg\theta}$$

This type of galvanometer however, has a number of disadvantages of which the following are the most prominent.

1. The coil being much larger than the needle, and hence far away from it, reduces to a considerable extent its sensitiveness.

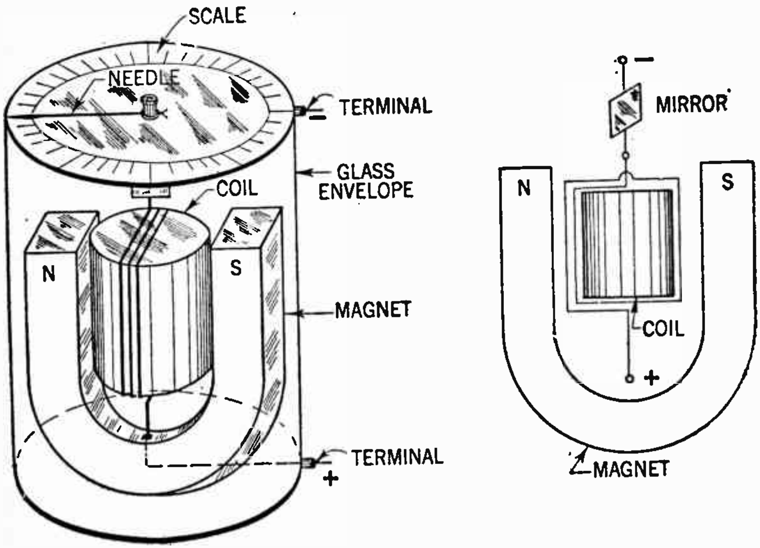
2. The readings are effected by an external magnetic field which may exist in the neighborhood of the instrument.

3. Accuracy of readings may be lessened by changes in the earth's magnetic field, which changes may be of considerable proportions especially during magnetic storms.

D'Arsonval Galvanometer.—In this type of galvanometer the aforementioned disadvantages are largely eliminated.

The principal design is shown in figs. 2 and 3. In this instrument the indicating needle is attached to a coil of wire, through which the current flows, and inside of which is an iron core.

The coil is free to turn with the core which is held in place with a pin, and suspended between the poles of a horseshoe magnet. When the current to be measured flows through the coil, a magnetic field is set up in and around it, causing the coil to turn.



FIGS. 2 and 3—Drawing showing essential features of construction and principle of operation of D'Arsonval type galvanometer.

This rotating tendency is prevented by the twisting of the wire which suspends the loop. By planning the weight of the wire used, the number of turns in the coil and the amount of resistance used, this galvanometer can be used for determining small amounts of currents. It is on this principle that many commercial types of current measuring devices is based.

The readings of the galvanometer may be facilitated by means of a mirror which is usually attached to the coil in such a way that a beam of light from a light source directed to the coil by a lense system, will be reflected back on to a semi-circular graduated scale placed at a suitable distance from the mirror as shown in fig. 4.

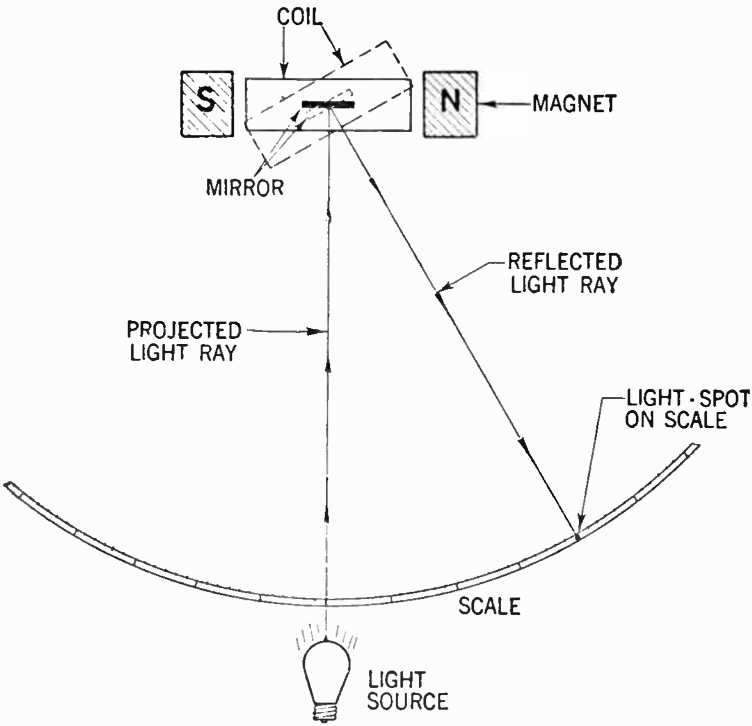


FIG. 4—Arrangement to obtain enlarged view of mirror movement.

In this way a small deflection of the coil and mirror will produce an enlarged amplification of the beam of light on the scale, which reading may be accurately accomplished by means of a telescope.

Electrochemical Current Measurements.—Another method of current determination is by utilizing the amount of the chemical decomposition the current causes in passing through the electroylete in a cell.

FIG. 4a—Weston model 440 movable coil galvanometer.

If a constant current of (I) amperes is passed through the electrolyte during (t) seconds, the weight increase on the cathode in milligram (M) is direct proportional to the amount of current multiplied by the electrochemical equivalent of the metal (C) and the time of current flow.

$$M = C \times I \times t$$

For $I = 1$ ampere and $t = 1$ second; $M = C$.

Among the various apparatus based on the electrochemical effect of an electric current are:

The weight voltameter

The gas voltameter.

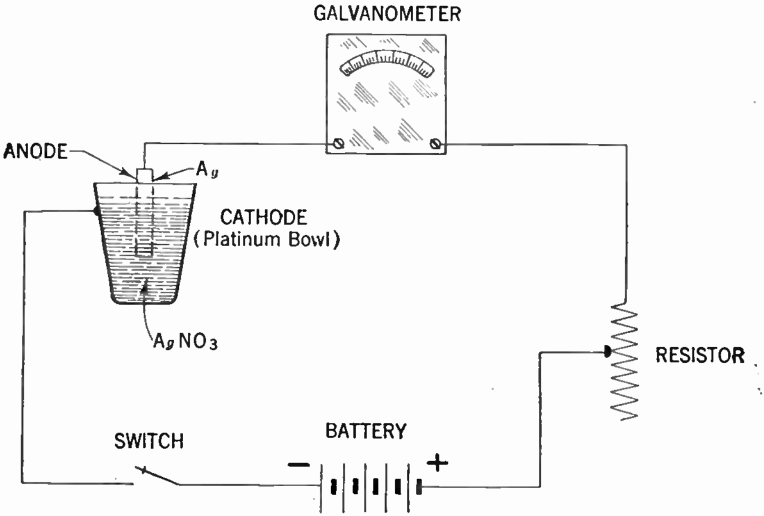


FIG. 5—Diagram of connection to obtain current strength by use of a silver-voltameter. *Example:* What is the current strength in amperes when after 20 minutes the silver deposit on the cathode is found to be 1.34 gram.

Solution: $M = C \times I \times t$ **or** $I = \frac{M}{Ct} = \frac{1{,}340}{1.118 \times 20 \times 60} = 1$ **ampere**

A typical silver voltameter is depicted in fig. 5 and functions principally as follows: The cathode on which the silver is deposited consists of a platinum bowl not less than 10 centimeters in diameter and from 4 to 5 centimeters in depth.

The anode consists of a disc or plate of pure silver, some 30 square centimeters in area and 2 to 3 centimeters in thickness, which is horizontally supported in the electrolyte near the top by a silver rod rivited through its center.

To prevent the disintegrated silver which is formed on the anode falling upon the cathode, the anode should be wrapped around with pure filter paper, secured at the back by suitable folding.

The liquid consists of a neutral solution of pure silver nitrate ($Ag\ NO_3$) containing approximately 15 parts by weight of the nitrate to 85 parts of water.

Direct Current Meters.—Most electrical measuring devices are fundamentally current measuring devices, being either voltmeters, milliammeters or microammeters.

Construction.—Such a meter consists of a horseshoe magnet between the two poles of which is suspended an armature to which is attached a pointer and a spring arrangement to hold the pointer to its zero position when no current is being passed through the meter coil.

How the Current is Measured.—When a current be passed through the armature coil, it becomes an electromagnet, with two poles of opposite polarity, and the reaction between the energized coil and the permanent magnet causes the coil to rotate on its axis so as to facilitate the attraction of the unlike poles and the repulsion of the like poles of the two magnets.

The amount of movement is determined by the balance attained between the resiliency of the spring mechanism and the strength of the magnetic field set up around the coil, and since the strength of the magnetic field set up around the coil is determined by the amount of current flowing through it, the movement may be calibrated in unit of currents, or in any other unit such as volts, ohms or microfarads, all of which possess a definite relationship to the unit of current.

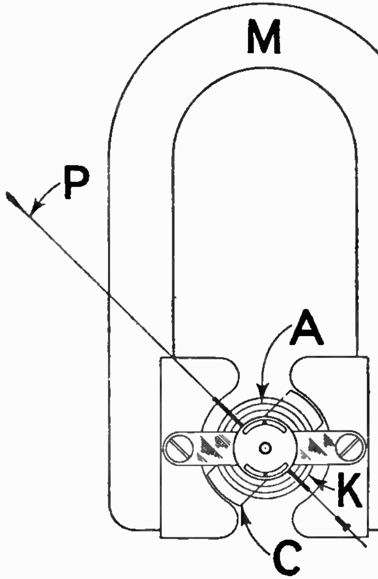


FIG. 6—The essential parts of the instrument are: *A*, spiral spring; *C*, coil; *K*, soft iron core; *M*, permanent magnet and *P*, pointer. Current passing through the coil causes the moving system to turn against the restraining force due to the influence of the permanent magnet.

Connection of Meters.—A meter calibrated for current measurement in terms of amperes or fraction thereof, usually has a comparatively low resistance and is connected in *series* with the circuit in which the current is to be measured, whereas a potential pressure measuring meter or voltmeter is of comparatively high resistance and is connected *across* the circuit, across which a potential pressure is to be measured.

Direct Current Ammeters.—The ammeter as already described is an instrument of low resistance, and is *always connected in series with the current it is desired to measure.* It is for this reason that the series resistance usually found in voltmeters are omitted.

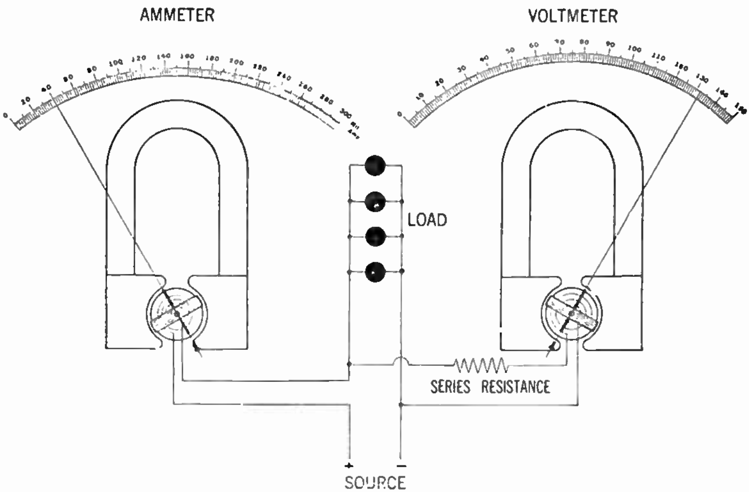


FIG. 7—Indicating method of connecting for determination of current flow and pressure in a circuit.

Ammeters are employed for current measurement in all branches of electrical work and may be designed for measurement of from a few milliamperes up to thousands of amperes.

A milli-ammeter therefore is an ammeter which measures divisions of currents in $\frac{1}{1,000}$ of an ampere, whereas an ammeter employed in measurements of larger amounts of current measures amperes in units of 1 to 100 or more.

Using a Milliammeter as a Voltmeter.—As previously pointed out the only difference between a voltmeter and a milliammeter is that a voltmeter has a high resistance connected in series with the moving coil.

Hence by connecting accurately fixed resistances in series with the milliammeter, it is possible to make a very useful voltmeter that may be employed to read filament voltages, plate voltages, *C* voltages, the output voltage of *B*-power units, etc.

Of course it is self evident that the accuracy of such a converted meter depends upon the accuracy of the milliammeter, and the fixed resistance used.

The table shown gives the value of resistances required with different milliammeters to read voltages from 1 to 1,000 volts.

VOLTAGE MULTIPLIER FOR MILLIAMMETERS

Milli-Amperes	1,000 Ohms	10,000 Ohms	100,000 Ohms	1,000,000 Ohms
1.	1. volt	10 volts	100 volts	1000 volts
1.5	1.5 "	15 "	150 "	
2.	2. "	20 "	200 "	
3.	3. "	30 "	300 "	
5.	5. "	50 "		
8.	8. "			
10.	10 "			

Example.—*If a* 5 *milliampere meter is to be employed to read voltages up to* 50 *volts, what resistance should be used?*

Solution.—From table, the resistance required is 10,000 ohms. According to Ohm's law, $E=IR$ or $R=\frac{E}{I}=\frac{50}{0.005}$ from which $R=10{,}000$ as already obtained from table.

Likewise, if a 1-milliampere meter is to be used to read voltages up to 1,000 volts, then a 1-megohm resistance is placed in series with it.

If the values of resistance required to read voltages is not found in the table, the resistance may be obtained by calculation in the same manner as that already shown.

Resistors with a wattage rating of one watt will be satisfactory for all those values given in the table, however, it is advisable to use resistors with a rating of approximately 5 watts so that there will be little possibility of the value of the resistance changing due to the heating effect (I^2R).

Also, resistors with a 5 watts rating operating considerably below their rated dissipation, will be likely to hold their calibration a longer time then resistors of lower wattage.

The Direct Current Voltmeter.—Since the current through a meter is proportional to the voltage impressed at its terminal, any ammeter as previously described may be used as a voltmeter.

In this case however, a resistor of high value must be connected in series with the movable coil, because if an ammeter were connected directly across the line, it would immediately burn out due to the low resistance in its coil.

The high fixed resistance connected in series with the moving coil is considered as part of the meter.

Assume that the moving coil milliammeter, as used in the previous example, is to be utilized for a voltage measurement of 110 volts at full scale deflection, the allowable current drain to be 1 milliampere, what will be the value of the series resistance?

It is evident that the resistance unit must be of such a value that when the voltage across the terminal is 110 volts, exactly 1 milliampere will flow through the resistance and meter coil at full scale deflection of the pointer.

By Ohm's law is obtained:

$$R = \frac{110}{0.001} = 110{,}000 \text{ ohms}$$

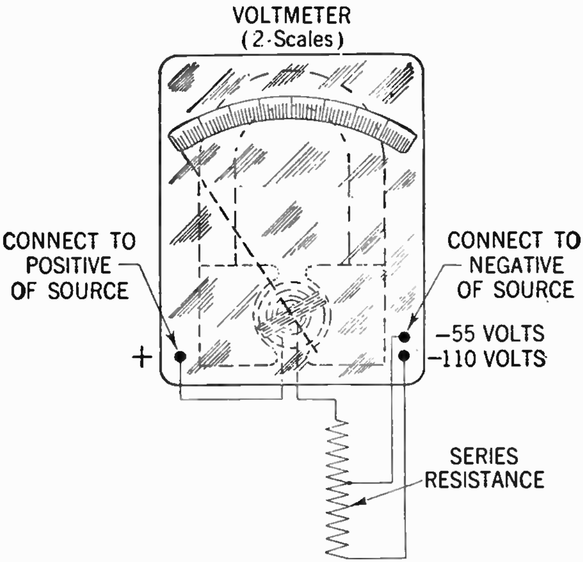


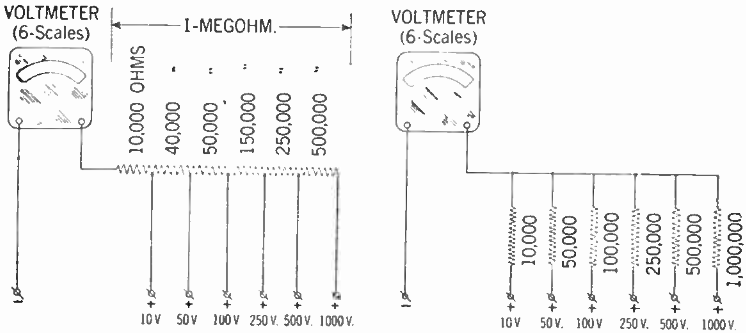
FIG. 8—Connection of multiplier resistance to 2-range voltmeter.

As the moving coil resistance is very small compared with the series resistance, it may readily be omitted for most practical problems.

The series resistance or *multiplier resistance* may be tapped at various places to obtain more than one voltage range, and is usually placed inside the voltmeter case and connected in series with the coil. See fig. 8.

If the voltmeter with the 110,000 ohms series resistance be tapped at its center, the voltage range for the same current drain would be $E=0.001\times55,000=55$ volts.

In order to obtain proper needle deflection the binding posts of the meters are marked + (plus) and − (minus). The post marked + should always be connected to the positive of the line and either of the other binding posts to the negative side.



FIGS. 9 and 10—Two methods of connecting multipliers to a voltmeter. In fig. 9, one resistor is tapped at the various points to obtain the proper multiplier values for each scale as shown. This arrangement obviously is economical in that only one resistor need to be used. However, the disadvantage being that if an opening occur for example to the left of the 10 volt tap, the voltmeter will be rendered useless until the fault is being repaired, whereas if an opening occur within a resistance when connected as shown in fig. 10, only that particular scale will be effected.

How to Arrange Resistors for a Multi-Range Voltmeter.—Resistors for multi-range voltmeters may be arranged in various ways as shown in figs. 9 and 10. Each resistor will give a certain definite voltage drop, and should be of the so-called precision type, unaffected by nominal temperature changes.

Voltmeters suitable for radio work usually have a resistance of 1,000 ohms per volt.

Inspecting the resistance arrangement in fig. 10 it is found that when using the 0-100 volt the circuit resistance is 100,000 ohms and when using the 0-250 volt scale, 250,000 ohms, etc.

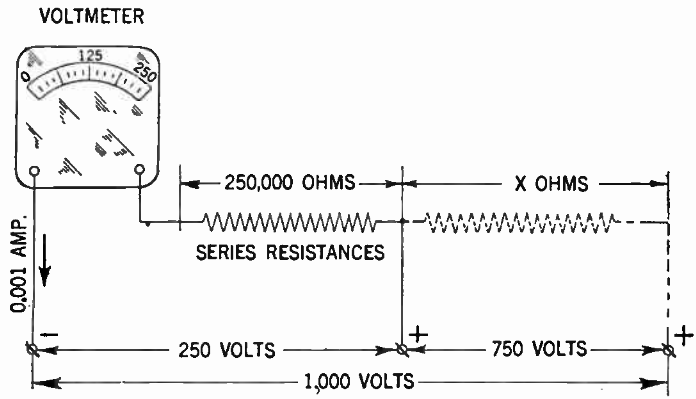


FIG. 11—Illustrating how to increase voltmeter range by adding series resistance.

To compute the resistance to be inserted to obtain a certain voltage range, no difficult mathematical formulas need to be employed.

According to Ohm's law $E=I\times R$; hence to obtain a voltage drop of 100 volts for example, with a current drain of 1 milliampere, a resistance of $\frac{100}{0.001}$ or 100,000 ohms should be inserted.

Example.—*Assume that the voltmeter shown in fig.* 11 *which has a range of* 250 *volts and a resistance of* 250,000 *ohms must be changed so as to enable it to be used on* 1,000 *volts, what value must a resistance connected in series with the existing multiplier have?*

Solution.—The multiplying factor $=\frac{1000}{250}=4$

using Ohm's law $E=IR$; $1{,}000=0.001\ (250{,}000+X)$

or $1{,}000=250+0.001X$; from which $X=\frac{750}{0.001}=750{,}000$ ohms.

The resistor to be inserted should have a value of 750,000 ohms and each reading taken after insertion of this new resistance should be multiplied by 4 to obtain the true voltage.

A Combination Volt-Ammeter.—Since the construction of a voltmeter and ammeter is the same, the difference being that in an ammeter resistors are placed parallel to the moving coil, while in the voltmeter resistors are placed in series with the moving coil, it is possible that by employing a proper switching arrangement, to use a single instrument for measurement of both volts and currents. A typical arrangement of this kind is shown in fig. 12 and 12a.

Other meters of this type may have in addition to the voltage and current scale, a resistance or ohmmeter scale, which makes it convenient to check the value of a certain resistor. It is to be observed that an ohmmeter is simply a low current *d.c.* voltmeter, provided with a source of voltage usually consisting of dry cells, which are connected in series with the unknown resistance.

An instrument of this sort is shown in fig. 13 and it may readily be seen that the instrument is rather complicated with its various scales, switches and terminals.

When using this type of instrument great care should be observed so as to minimize contact resistance. Hence the ordinary selector switches should be substituted for toggle switches if possible.

Before the use of a multi-purpose meter a precautionary examination should be taken to make sure that the respective

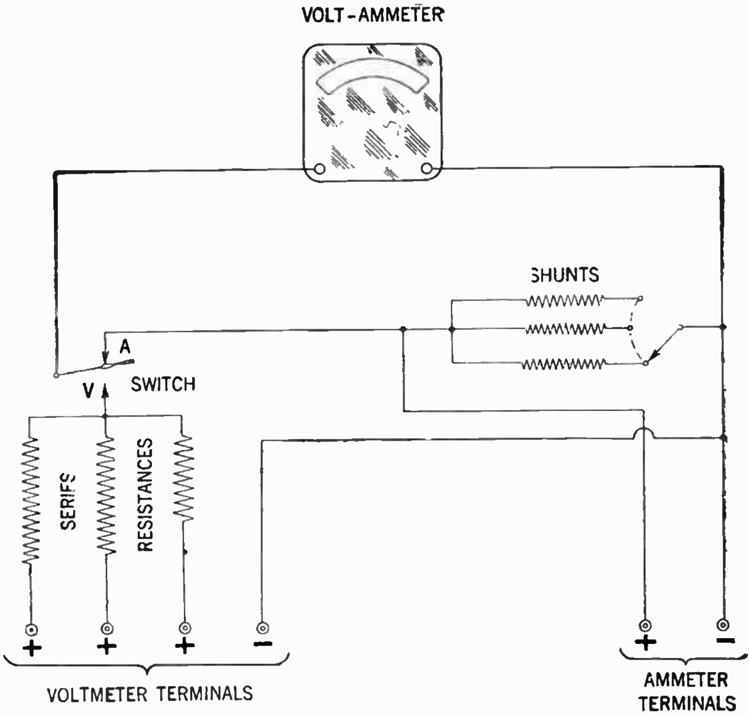


FIG. 12—Schematic or simplified diagram showing principal method of circuit hook-up and switching arrangement when using a volt-ammeter instrument. *Current measurement:* When it be desired to employ the meter for current measurement, the current voltage selector switch is closed towards *A*, after the proper shunt has been selected. *Voltage measurement:* For voltage measurement the meter is connected across the load after selection of proper resistor, and the current voltage selector switch is closed towards *V*.

controls are properly adjusted, to prevent the instrument from serious damage.

When measuring unknown values of currents, it is an excellent idea to begin with the highest range, and thus identify the proper range for most accurate measurement.

When using the instrument as an ohmmeter the instrument should never be connected across a circuit in which current is flowing, i.e. the receiver power should be turned off when resistance measurements are obtained.

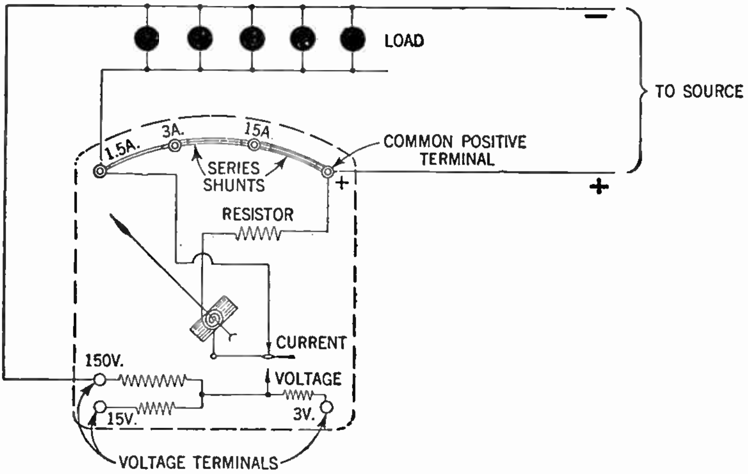


FIG. 12a—Outline of principal construction details of a combination volt-ammeter.

Shunts and Their Use.—All ammeters for use in direct current measurements may be designated to pass a similar amount of amperes, although the actual amount of current in the circuit may differ greatly.

The main difference between the various ammeters is in the type of shunts employed. The function of a shunt is to pass a certain definite amount of the circuit current through the meter.

If the full amount of current were allowed to pass through the ammeter, the ammeter coil would of necessity have to be of heavier wire and thereby increase the size and cost, and also cut down the sensitivity of the entire moving element.

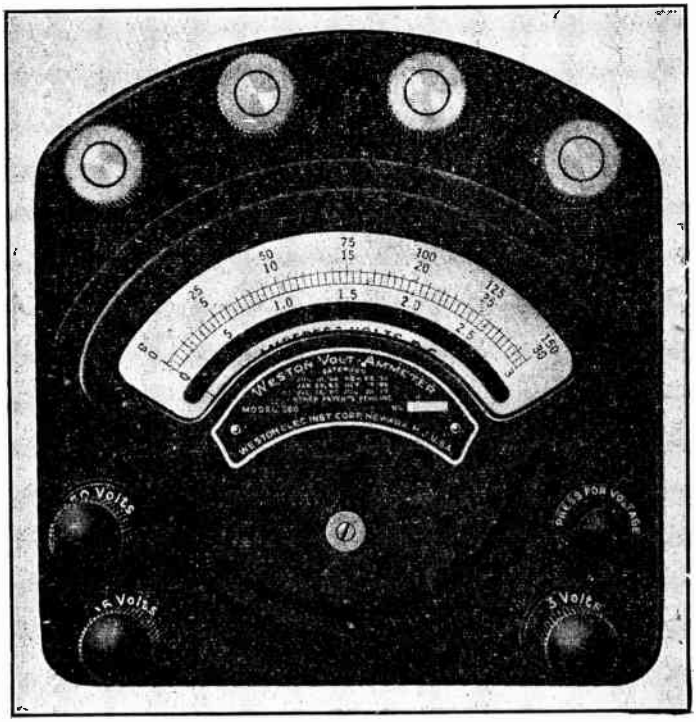


FIG. 12b—Front view of typical combination type volt-ammeter. (Courtesy Weston Electrical Instrument Corp.)

A shunt will carry a certain ratio of the total current depending upon the ratio of its resistance to the resistauce of the ammeter coil; this makes it possible to use the same sensitive ammeter for different current carrying ranges by merely shunting or by-passing a portion of the current.

The size of the shunts required are designed from a knowledge of the proportional current to be measured, and of the existing resistance of the ammeter coil.

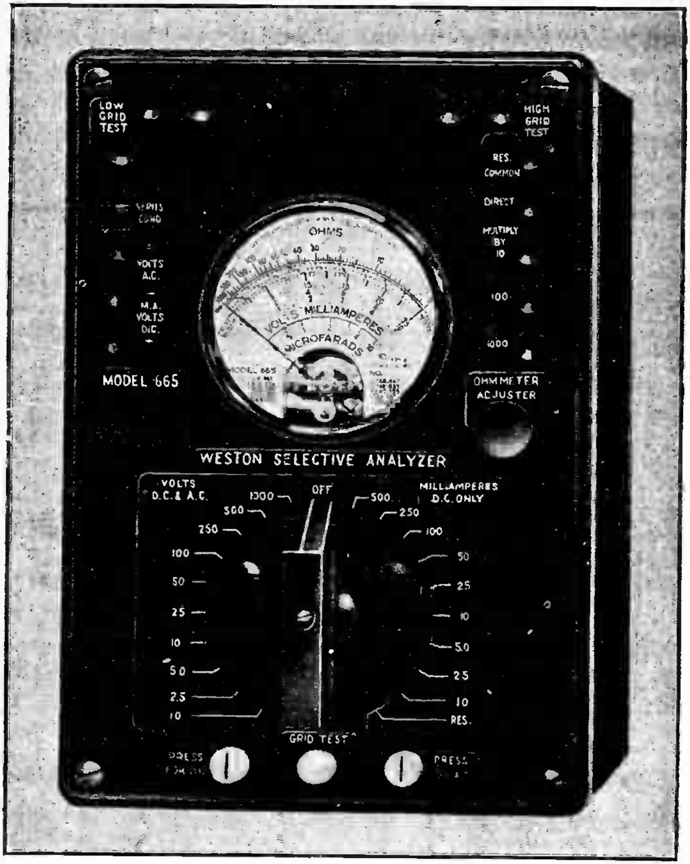


FIG. 13—Typical volt-milliamp-ohmmeter. (Courtesy Weston Electrical Instrument Corp.)

Example.—*If a milli-ammeter giving full scale deflection on* 500 *milliamperes* $\left(\frac{500}{1,000}\right)$ *of an ampere is required to be changed so* *as to enable the measurement of currents up to 5 amperes, what size of shunt should be used?*

Solution.—The increase in current for full scale deflection is then $\frac{5}{\frac{1}{2}}$ or 10 times; hence each scale reading would have to be multiplied by 10 for each actual current indication.

The resistance therefore, of the coil and shunt combined, in order to permit 10 times the current to flow through, would have to be such that the coil would carry $\frac{1}{10}$ of the current and the shunt the remaining $\frac{9}{10}$ of the total current. By formula: The shunt resistance is equal to the meter resistance divided by the multiplication factor less one or $R = \frac{r}{n-1}$ in which:

R is the resistance of the shunt;

n is the multiplication factor or the number indicating how many times the meter range is to be extended or multiplied;

r is the internal resistance of the meter.

From the above it follows that the shunt resistance would have to be $\frac{1}{10}$ of the coil resistance.

If the meter coil has a resistance of $\frac{2}{10}$ of an ohm the shunt resistance would have to be

$$R = \frac{0.2}{10-1} = \frac{2}{90} \text{ or } 0.0022 \text{ ohms approximately.}$$

Hence a shunt having a resistance of 0.0022 ohms must be connected across the meter. This resistance should be of a size sufficient to carry the current without overheating.

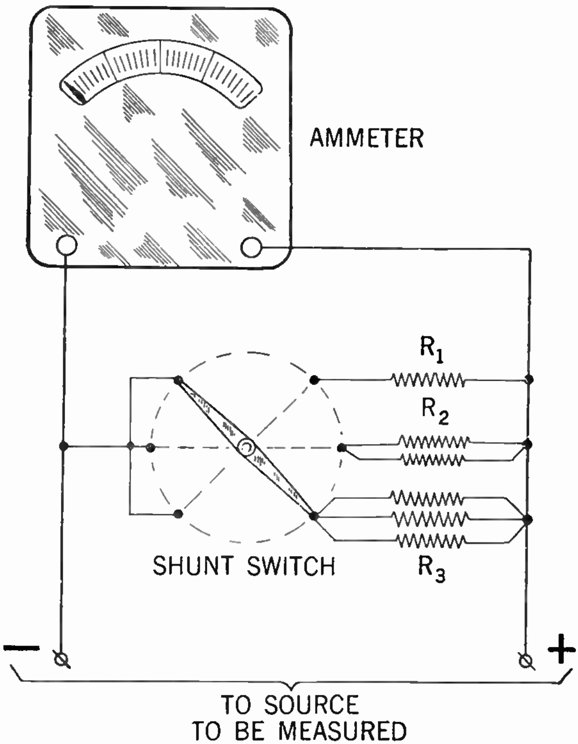


FIG. 14—Arrangement in which shunts R_1, R_2 and R_3 may be utilized for various size current measurements. In the case where the meter has only one scale, current indication shown on meter should be multiplied by the value of the multiplication factor given for each shunt.

Hot Wire Instruments.—The action of this meter depends upon the heating of a conductor by the current flowing through it, causing an expansion which in turn sets in motion an index needle or pointer, the movements of which by calibration are made to correspond to the amount of the actuating currents.

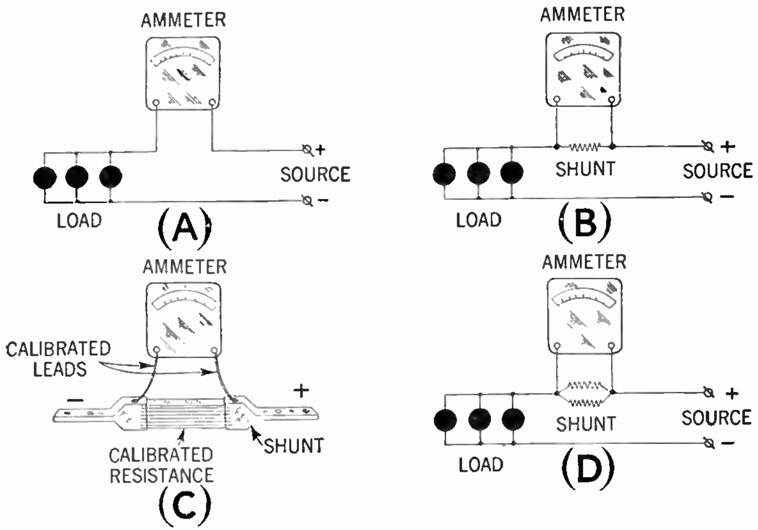


FIG. 15—Various ammeter connections and method of showing connections. As connected in (*A*) it is obvious the ammeter coil must carry the total current in the circuit. If this current is greater than the meter coil is permitted to carry, then part of the current should be allowed to pass through the shunt as shown in (*B*), (*C*) or (*D*). A shunt as shown at (*C*) consists of one or more sheets of a special alloy, fitted at each end into grooves of two copper blocks, which are provided with means for connecting the shunt into the circuit with the main conductor and with the meter.

This type of meter is frequently employed in radio work on account of its ability to measure either direct or alternating current.

The principal defects of this type however, are:

1. Scale divisions will not be uniformly spaced, since the heating effect and movement of the pointer depends upon the square of the current (I^2R) flowing through it.

2. They are somewhat erratic in the readings near the zero point.

3. They are sluggish in operation and their readings are effected by changes in room temperature.

4. The actuating wire has a tendency to expand when not in use, hence it is necessary to set the pointer back to zero before sending a current through it.

5. They are uneconomical, i.e. the current consumption is considerably in excess of that in other types.

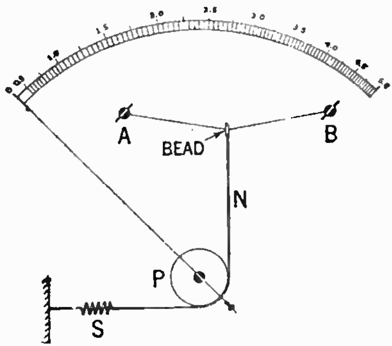


FIG. 16—Simplified diagram illustrating the construction of a hot wire instrument. *N*, represents a silk thread connected to spring *S*, wound around pully *P*, and attached to a bead threaded on wire *AB*. Wire *AB*, made of platinum alloy, is connected in the circuit whose current is tc be measured. This wire lengthens, due to the heating effect (I^2R) when a current flows through it. The slack is taken up by spring *S*, causing pulley to turn and move the pointer over the scale.

Thermocouple Instruments.—In this type of instrument the direct or alternating current to be measured is sent through heater (*H*) fig. 17, which heats the junction of two dissimilar metals.

When two dissimilar metals are joined together and their junction heated, a voltage is generated which is proportional to the temperature difference between the heated junction and the open end of the thermocouple.

A sensitive milliammeter is connected to the open ends and is generally calibrated to indicate the current through the heater. For measurements of very small values, the heater and the thermocouple are enclosed in an evacuated glass bulb to prevent oxidation.

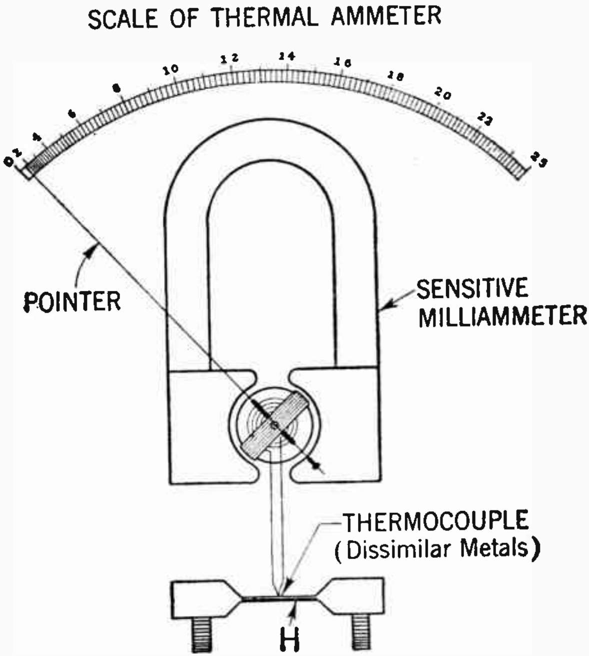


FIG. 17—Schematic thermocouple arrangement and connection to sensitive milliammeter. ***Note:*** **Unequal division of instrument scale.**

This vacuum tube thermocouple is usually mounted under the sub-base of the meter. The thermocouple instrument may be used on either alternating or direct current and is extensively used in radio and general high frequency work.

An instrument of this type however has certain disadvantages compared with various other instruments, as follows:

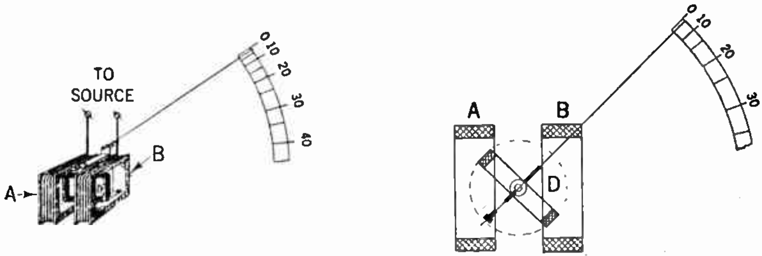
1. The motion of the pointer along the scale will increase approximately in proportion to the square of the *r.f.* current sent through the thermocouple. Hence the instrument scale will not have equal divisions.

FIG. 17a—Weston Model 622 Thermo A.C.-D.C. Milliammeter.

2. The thermocouple is sensitive to overloads and may burn out if excessive amounts of current be sent through it, in which case the thermocouple will have to be replaced and the instrument recalibrated.

Electrodynamometer Type Instrument.—This type of instrument can be employed on either alternating or direct current.

Figs. 18 and 19 show a typical instrument which consists of two stationary coils (*A*) and (*B*) and a movable coil (*D*) to which the indicating pointer is attached. The three coils are connected in series through the two spiral springs, which also hold the movable coil in position as indicated.



FIGS. 18 and 19—Principal construction method of an electro-dynamometer type of instrument.

When a current is sent through the coils, coil (*D*) tends to turn in a clockwise direction because its flux tends to line up with the flux of coils (*A*) and (*B*).

If a current be sent through the coils in the reverse direction, the torque developed remains the same, hence the instrument can be used on alternating as well as on direct current.

However, the scale as shown cannot be graded uniformly as in the moving coil type, because the torque developed varies as the square of the current (I^2), similarly to that of the direct current motor.

One of the detrimental factors in this type of instrument is that the current requirement is approximately 5 times that of a movable iron type instrument. Hence it is somewhat sluggish, and on account of the large current consumption uneconomical.

The Wattmeter.—In direct current circuits the product of voltage and current is a measurement of the amount of power dissipated in the circuit in question and is measured in watts.

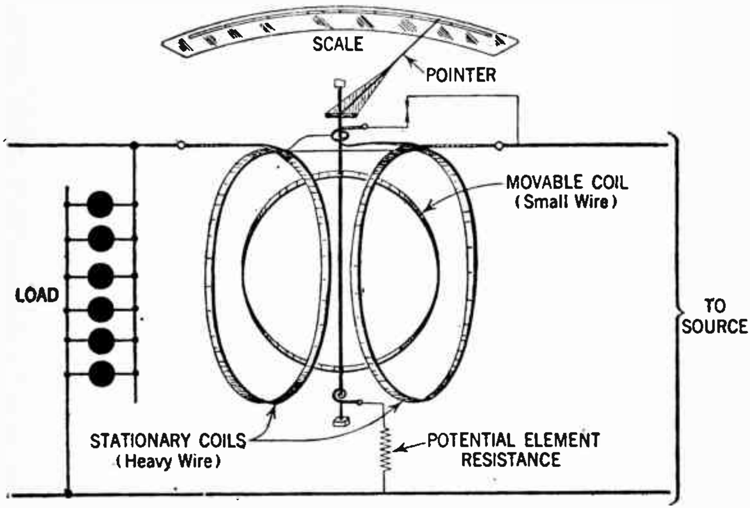


FIG. 20—Construction method of an electro-dynamometer as arranged to read watts.

The number of watts dissipated may be obtained by measuring the voltage across and the current through the circuit.

Thus in a circuit through which a current of 2 amperes flow at a pressure of 110 volts, the power in watts (W) will equal 2×110 or 220 watts or $W = I \times E = 2 \times 110 = 220$ watts.

If in an alternating current circuit it be desired to measure the power, this relationship holds true only when the connected load consists of pure ohmic resistance; and when the circuit in addition to the ohmic resistance also contains inductive or capacitive resistance, the power in watts will be equal to $E \times I \times \cos \theta$ or $W = E \times I \times \cos \theta$ in which

W is the power in watts

E, the pressure in volts

I, the current in ampere and θ the angle of lag or lead between the current and voltage.

A meter used for the purpose of obtaining the power consumption in an electric circuit is called wattmeter or dynamometer.

The wattmeter may be employed to record directly either the *a.c.* or *d.c.* power at any instant, giving the three values as indicated by the aforementioned formulas.

A typical instrument is shown in fig. 20. Its operation depends on reaction between the coils when current is passed through them. Two coils are fixed and the other is movable.

The fixed coils are composed of a number of turns of heavy wire and fastened to a vertical support and is surrounded by a movable coil composed of a few turns of very fine wire.

In the operation of a wattmeter, when current is passed through the coils, the movable coil is deflected against one of the stop pins, then the tortion head is turned to oppose the movement until the deflection has been overcome and the coil brought back to its original position.

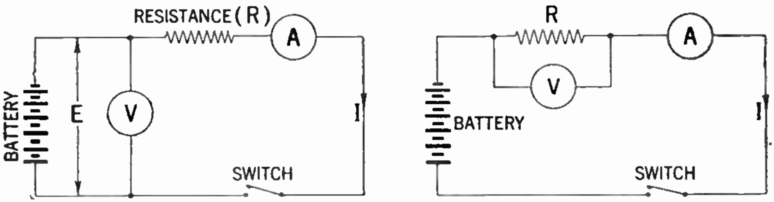
When connecting the meter, care should be taken to prevent damage, i.e. the heavy wire coil (current element) should be connected in series with the load and the small wire and coil, potential element, should be connected across the load to be measured.

Resistance Measurement.—(Ammeter-Voltmeter Method).—This is one of the simplest methods of measuring resistance, and is convenient because of the fact that the instruments used consist of only an ammeter, voltmeter, battery and switch, the connection of which is shown in fig. 21. In making the test the ammeter and voltmeter readings are taken simultaneously and the unknown resistance calculated from Ohm's law.

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

Example.—*If in fig.* 21 *the readings obtained are* 150 *volts and* 4 *amperes, how many ohms is the unknown resistance?*

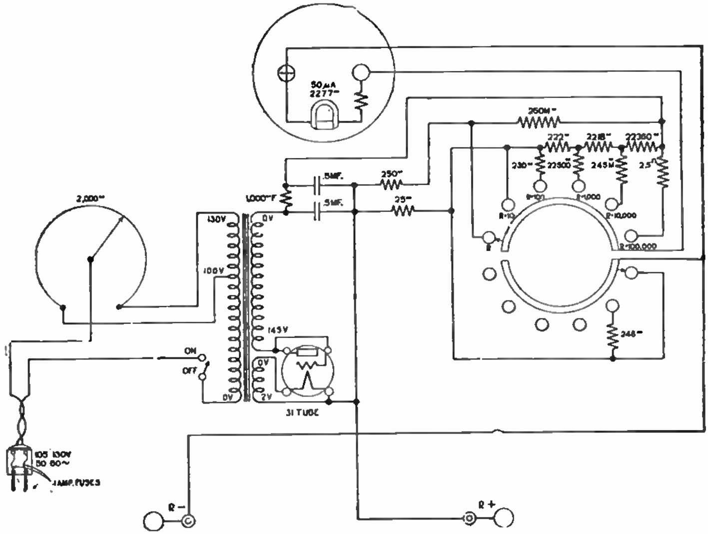
$$R = \frac{E}{I} = \frac{150}{4} = 37.5 \text{ ohms}$$

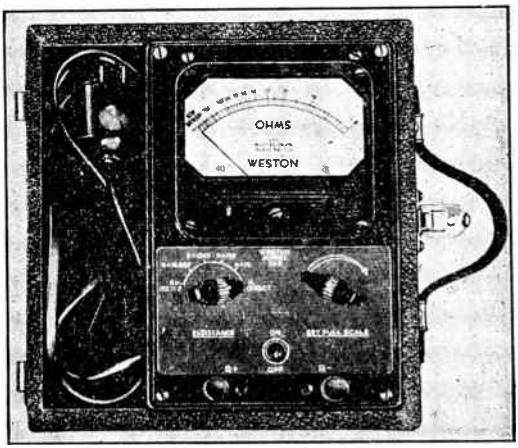


FIGS. 21 and 22—Illustrating two methods of connections to obtain resistance values.

Ohmmeter Method.—By using the ohmmeter previously described the value of an unknown resistance may be read directly on the instrument scale without calculation. This type of instrument is shown in fig. 24 and its circuit in fig. 23. On an instrument of this type resistance values up to 300 megohms may readily be obtained.

Wheatstone Bridge Method.—The Wheatstone bridge, fig. 25 consists of several resistances so arranged that an unknown resistance may be calculated in terms of known resistances.





FIGS. 23 and 24—Schematic circuit arrangement and front view of typical ohmmeter.

The so called "Wheatstone" bridge was invented by Christie, and improperly credited to Wheatstone, who simply applied Christie's invention to the measurement of resistances.

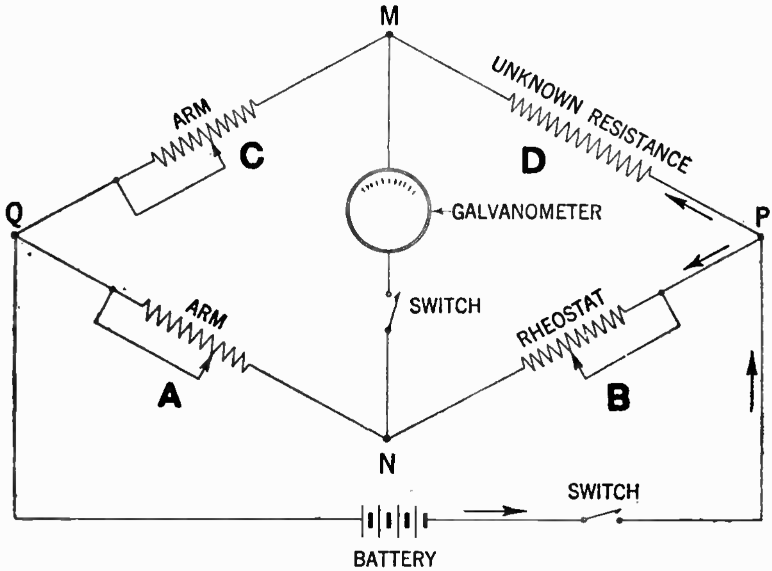


FIG. 25—Schematic diagram of Wheatstone bridge showing resistances and method of connecting galvanometer, battery and unknown resistance.

As shown in fig. 25 the circuit of a constant battery is made to branch at *P*, into two parts, which re-unit at *Q*, so that part of the current flows through the point *M*, the other part through the pont *N*. The four conductors, *A*,*B*,*C*,*D*, are spoken of as the arms of the balance or bridge.

It is by the proportion existing between the resistances of these arms that the resistance of one of them can be calculated when the resistances of the other three are known.

When the current which starts from the battery arrives at *P*, the pressure will have fallen to a certain value. The pressure in the upper branch falls again to *M*, and continues to fall to *Q*. The pressure of the lower branch falls to *N*, and again falls till it reaches the value at *Q*.

Now if *N*, be the same proportionate distance along the resistances between *P* and *Q*, as *M*, is along the resistances of the upper line between *P* and *Q*, the pressure will have fallen at *N*, to the same value as it has fallen to at *M*; or, in other words, if the ratio of the resistance *C*, to the resistance *D*, be equal to the ratio between the resistance *A*, and the resistance *B*, then *M* and *N*, will be at equal pressures. To find out if this condition obtain, a sensitive galvanometer is placed in a branch wire between *M* and *N*, which will show no deflection when *M* and *N*, are at equal pressure or when the four resistances of the arms "balance" one another by being in proportion, thus:

$$A{:}C = B{:}D \qquad \text{.................... (1)}$$

If then, the value of *A*, *B*, and *C*, be known, *D*, can be calculated. The proportion (1) is reduced to the following equation before substituting.

$$D = \frac{BC}{A}$$

For instance, if *A* and *C*, be, as in fig. 25, 10 ohms and 100 ohms respectively, and *B* be 15 ohms, *D* will be

$$(15 \times 100) \div 10 = 150 \text{ ohms.}$$

Example.—*It is desired to use a milli-ammeter whose maximum reading is* 5 *M.A. to measure current up to* 100 *M.A. If the meter resistance is* 50 *ohms, what value of external resistance will it be necessary to use, and how should it be connected?*

Solution.—At full scale deflection the meter passes 5 M.A. or 0.005 amperes, hence the voltage drop across the instrument at maximum deflection will be IR or 0.005×50 volts, i.e. 0.25 volts. Now, since the meter can take no more current without danger, it follows that the extra current must be shunted away from the instrument through a resistance placed in parallel with it.

In this case, it is desired to pass 100 M.A. through the combination of meter and resistance in parallel so that at the same time the meter will show its full scale reading. Since it does this at 5 M.A. the balance of 95 M.A. must obviously be passed through the parallel resistance.

Now the potential drop across the meter was previously found to be 0.25 volts and this must also be the drop across the resistance since they are both in parallel. There is then a means of finding the value of the resistance, since from Ohm's law—

$$R = \frac{E}{I} \text{ its value is thus } \frac{0.25}{0.095} = 2.63 \text{ ohms.}$$

Example.—*What resistance should be placed in parallel with a milliammeter of 5 ohms resistance in order that the total resistance of the combination may be 0.5 ohm?*

Solution.—If X denote the value of the required resistance, by the known formula for resistance in parallel the following may be obtained:

$$\frac{1}{X} + \frac{1}{5} = \frac{1}{0.5} \text{ that is } \frac{1}{X} + 0.2 = 2$$

hence $\frac{1}{X} = 1.8$ or $X = \frac{1}{1.8} = 0.555$ ohms (approximately).

Example.—*A 2-volt battery is used to supply filament current to a multiple receiver. An ammeter is inserted in one of the battery* *leads and shows that a current of* 0.8 *ampere is being taken. What is the total resistance of the filament circuit?*

Solution.—According to Ohm's law, it is known that $I=\frac{E}{R}$ for any circuit in which direct current flows through a resistance. The current I, is measured in amperes, and the resistance R, in ohms. Since $E=2$ volts and $I=0.8$ amperes, therefore

$$R=\frac{E}{I}=\frac{2}{0.8}=2.5 \text{ ohms.}$$

Example.—*After the battery in the previous example had been fully charged, it was noted that the current reading had increased to* 1 *ampere. What difference does this indicated in* (*a*) *the circuit resistance*; (*b*) *the E.M.F. of the battery?*

Solution.—Of course the fact of the increased current is due solely to the greater E.M.F. of the battery, the circuit resistance being entirely independent of this and remaining quite unchanged. The new E.M.F. is obtained by the formula $E=IR$ in this case 1×2.5 or 2.5 volts. This condition is of course only temporary and after a very little time, the battery E.M.F. will have fallen to its normal working value of 2 volts.

Example.—*What power is consumed by the filaments when the E.M.F. of a battery is* 2 *volts and the filament current is* 0.8 *amperes?*

Solution.—In *d.c.* circuits, the power consumed in any resistance when measured in watts is given by the product of the number of amperes passing through the resistance and the number of volts across it or $W=I\times E$ here $I=0.8$ and $E=2.0$ hence the power consumed $W=2\times0.8=1.6$ watts.

Example.—*An electric lamp is marked* 40 *watt,* 220 *volt. What current will it take from a* 220 *volt d.c. source and what resistance will it have at that voltage? What further specification* *would be required before employing such a lamp in a d.c. current receiver?*

Solution.—It is now fairly common in *d.c.* sets to employ electric light "bulbs" to obtain the necessary voltage drop suitable for the filament supply. Unfortunately, however, the question of selection is complicated by the fact that when so used, the full voltage supply is not effective across the lamp. The result is that a considerably smaller current may flow than would be the case if the lamp was used simply for its normal lighting purpose.

The present example refers to the current and resistance of the lamps at 220 volts; there is therefore no question of employing it as a "voltage reducer." The fundamental formulae relating the power taken by a given resistance to the *d.c.* voltage across is $W = \frac{E^2}{R}$ where W is in watts and E and R in volts and ohms respectively. For the lamp in question, $W = 40$ and $E = 220$, therefore it may be written—

$$R = \frac{E^2}{W} \text{ or } R = \frac{220^2}{40} = 1{,}210 \text{ ohms}$$

The current taken by the lamp obviously is $\frac{220}{1210} = 0.182$ amps.

Before the lamp could be employed as a voltage reducing resistance for a *d.c.* receiver it is first necessary to know the voltage and current necessary to operate the tube filaments—usually connected in series. The actual voltage across the lamp would be the difference between the filament voltage and that of the supply. Finally, it is required to know the current actually taken by the lamp at this reduced voltage. If this current were approximately the same as that taken by the filaments, the lamp would be suitable; otherwise another type would have to be employed.

CHAPTER 7

Power Supply Units

Receiver power supplies generally may be classified as follows:

1. The *a.c.* supply group which operate from alternating current only.

2. The *d.c.* supply group which operate from direct current only.

3. The *a.c.* and *d.c.* supply group which furnish power to "A" and "B" batteries from either alternating or direct current.

A.C. Supply Systems.—The power supply in this group generally consist of a power transformer, rectifier tubes and filter units which consist of capacity condensers and choke coils.

The Power Transformer.—The purpose of the power transformer is to supply a high voltage to the rectifier tube for rectification of the *a.c.* current and to supply the filament or heaters with the required current and voltage.

Power transformers generally contain a primary winding and several secondary windings, on a laminated steel core. That part of the secondary winding which furnishes power to the rectifier tube contains more turns than the winding which is used for heater or filament supply.

The method of using only one transformer for the various requirements, makes a compact arrangement, facilitates the

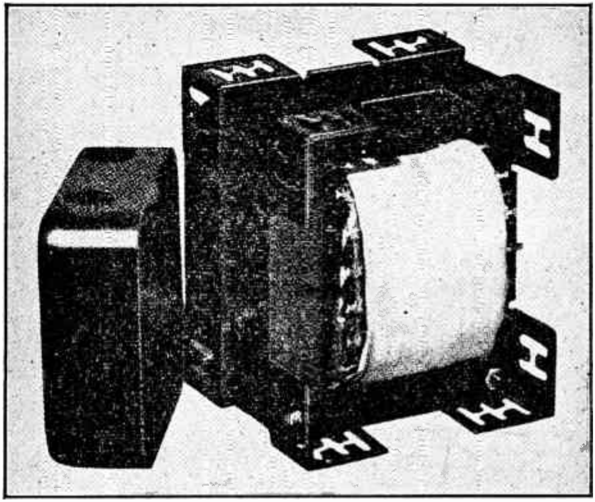


FIG. 1—Exterior view of typical power transformer.

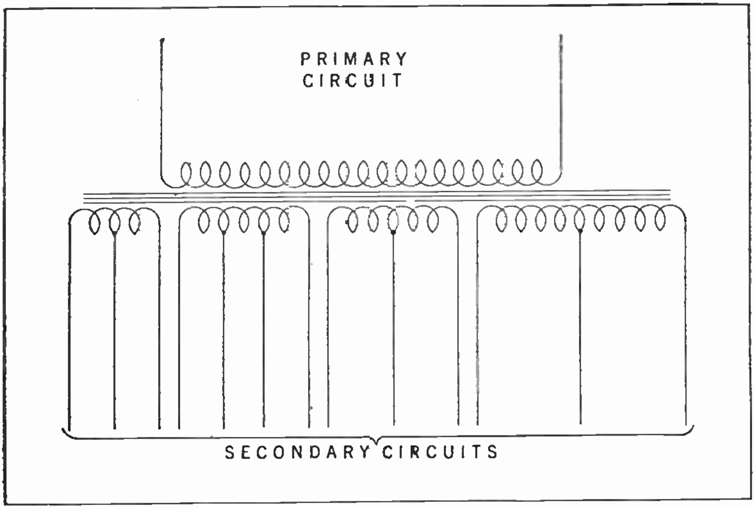


FIG. 2—Conventional diagrammatical representation of power transformer for 5 to 9 tube sets.

assembly and reduces the cost. A power transformer of the type described is shown in fig. 1, and a typical circuit diagram showing the connection of the several windings is shown in fig. 2.

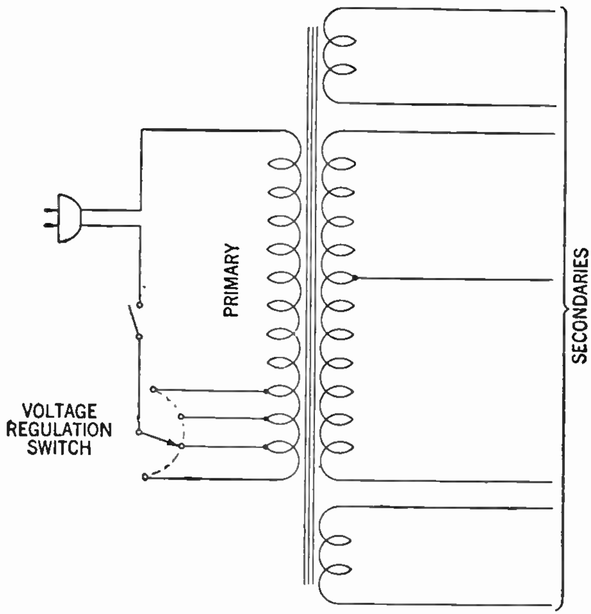


FIG. 3—Power transformer circuit showing voltage regulation switch.

The power transformer should be of ample size to supply the power required in each specific case without over-heating, i.e., the iron and copper should be dimensioned so that the secondary voltage will remain practically constant even in the case of slight variations in primary power supply.

(For further treatment of transformers see transformer chapter.)

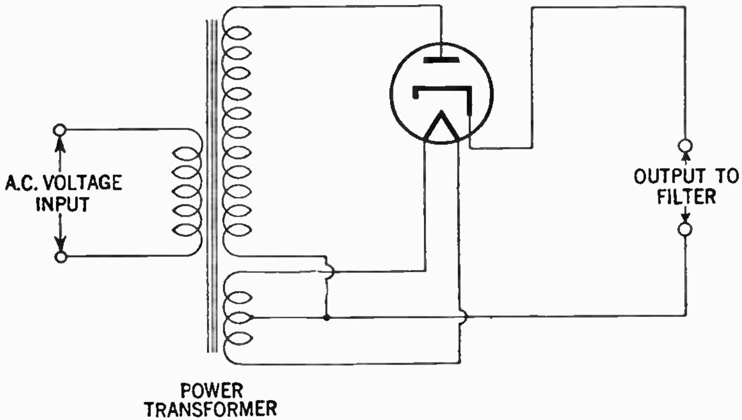


FIG. 4—Illustrates connection and rectifier tube to obtain half-wave rectification.

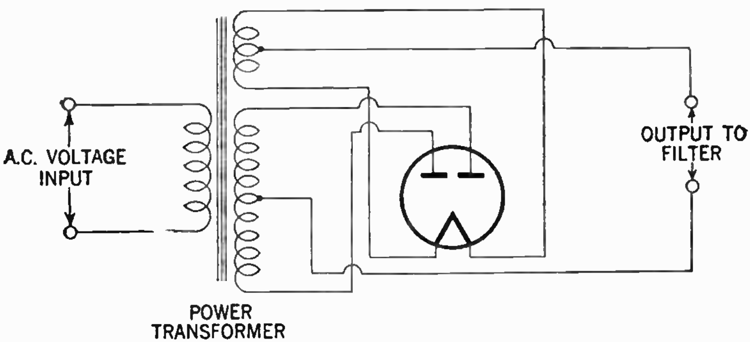


FIG. 5—Illustrates connection and rectifier tube to obtain full-wave rectification.

Method of Line Voltage Regulation.—In certain locations where comparatively large fluctuation in voltage is experienced, due to variation in the load requirements, the reception may be improved by providing a primary voltage regulating switch as shown in fig. 3. The voltage regulation switch is set for a higher voltage value during the time of the day when the line voltage is low, and put back to its original position when the supply voltage again becomes normal.

Rectifier Tubes.—The rectifier tubes are generally divided into two classes namely the half-wave and the full-wave. In modern *a.c.* systems however, the latter is most commonly employed. In half-wave rectifiers only one half of the current wave is utilized as shown in the diagram fig. 4 whereas in the full-wave rectifiers both halves of the waves are utilized. See fig. 5.

It is also possible to connect two half-way rectifier tubes in such a way as to obtain full-way rectification.

As the full-wave rectifier produces twice as many impulses, it is considerably easier to filter into the desired smooth direct current. It is obvious also that because of twice the number of pulsations during a certain time, that the current obtained in this latter system will be twice as great.

There are two general types of rectifier tubes in use. (1) The high vacuum type, in which the conduction is purely by means of the electronic stream from the cathode to the plate and (2) those in which a small quantity of mercury has been introduced after the tube has been evacuated. In the latter type, part of the mercury vaporizes when the cathode reaches its operating temperature and during the part of the cycle in which the rectifier is passing current the mercury vapor is broken down into positive and negative ions. Due to the fact that the positive ions decreases the normal resistance of the plate-cathode circuit the voltage drop in this type is less than in the high vacuum types.

As a result of this lower voltage drop the power loss (I^2R) is lower, and the efficiency of the mercury vacuum rectifier is higher than in the high vacuum type.

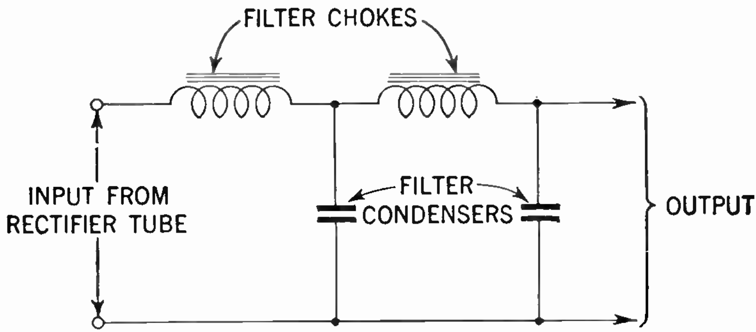


FIG. 6—Choke-input filter.

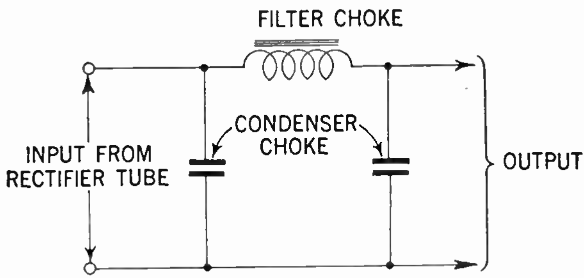


FIG. 7--Condenser-input filter.

Filter Systems.—The function of the filter system aside from that of preventing feed-backs into the receiver, is to smooth out the remaining ripples or pulsations in the voltage received from the rectifier.

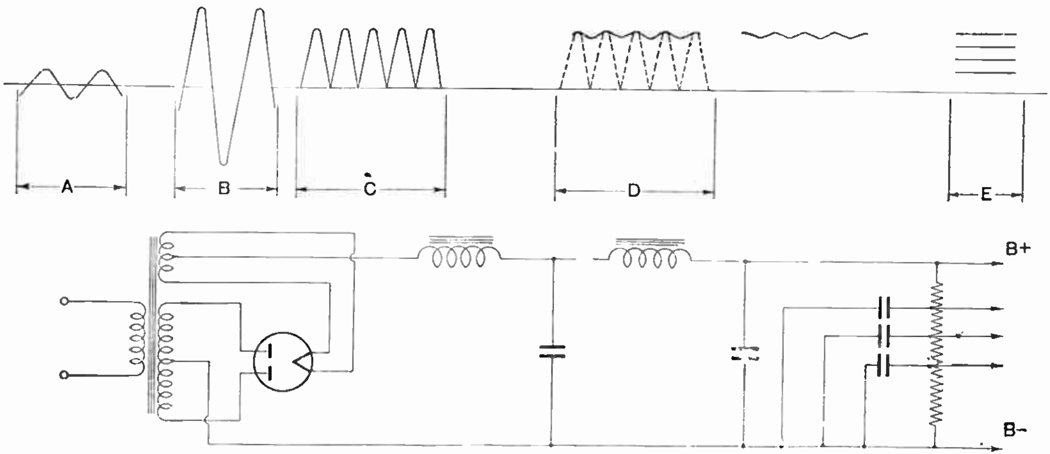


FIG. 8—Illustrates a "*B*" power supply unit of the full-wave type. The choke-input filter section is connected to the conventional voltage divider supplying plate voltages to the various tubes. The upper part of the diagram shows the approximate wave forms at various locations in the power supply unit. For example: "*A*" represents current supplied from power line; "*B*" high voltage current supplied to rectifier tube; "*C*" rectified unfiltered current as obtained from rectifier; "*D*" current as obtained from choke-input filter; "*E*" ripples direct current furnished to plates.

Smoothing filters are generally classified as choke-input or condenser-input according to whether a choke or a condenser is placed next to the rectifier output. Figs. 6 and 7 respectively show a choke-input and condenser-input filter.

If a condenser-input type be used consideration must be given to the instantaneous peak value of the *a.c.* input voltage. This peak voltage is $\sqrt{2}$ times the root mean square (R.M.S.) value as obtained by an *a.c.* voltmeter. Hence, filter condensers especially the input condenser should be of a rating high enough to withstand the instantaneous peak voltage if breakdown is to be avoided.

When the choke-input type is used, the available *d.c.* output voltage will be somewhat less than with the condenser-input type for a given *a.c.* plate voltage; however, in this latter type improved regulation together with lower peak current will be obtained.

D.C. Supply Systems.—Although alternating current is most commonly used in radio receiving sets, there are certain localities in which direct current is furnished, and hence the radio receiving sets in those localities must be designed for operation on *d.c.* current power supply.

It is obvious since the *d.c.* current is practically ripless, that no rectifier unit is necessary. All that is required is a filter system which serves to smooth out the slight remaining "ripples" due to the commutator (brush contact) action on the direct current generator.

The filament supply usually about 6 volts is obtained from the power voltage through a resistor or speaker field of a value to give the necessary voltage drop. See fig. 9.

The filaments may be arranged either in series or parallel. The disadvantage in both cases is a considerable amount of power dissipation in the form of heat, although the power loss is much less when the series arrangement is used.

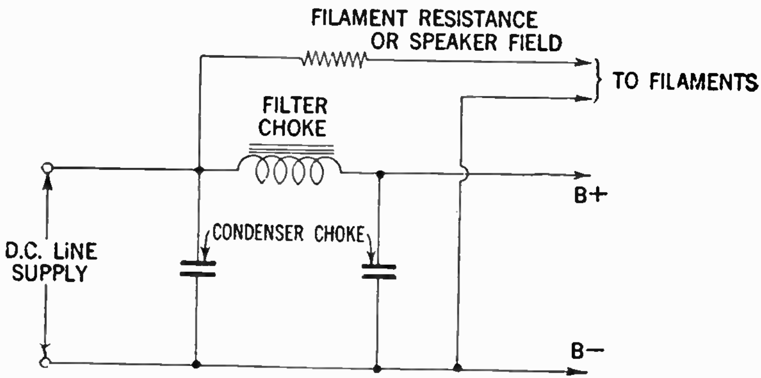


FIG. 9—Conventional filter system used on D.C. receivers.

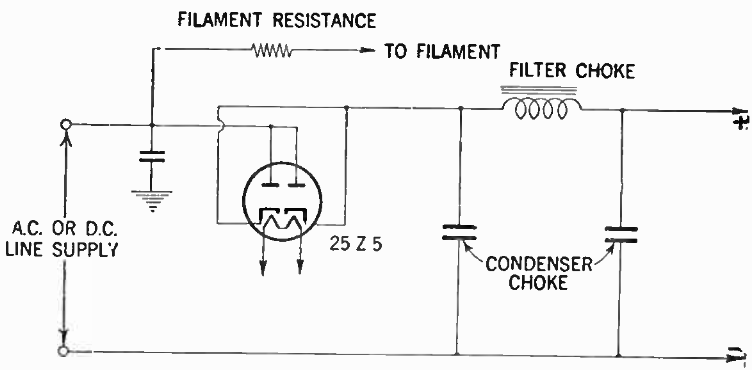


FIG. 10—Full wave rectifier tube circuit used for A.C.-D.C. receivers.

A.C. and D.C. Supply Systems.—When the power supply is alternately *a.c.* or *d.c.* the filament supply is connected through a series resistor as shown in fig. 10. This resistor must be of such value as to give the proper voltage drop. The disadvantage with this arrangement is the same as that of the straight *d.c.* supply system, in that a considerable amount of heat (I^2R) is dissipated in the filament resistor. The plate voltage is usually supplied by utilizing a full wave rectifier tube as shown in fig. 10.

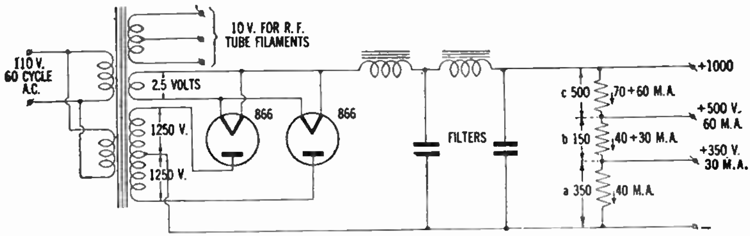


FIG. 11—Full wave rectifier circuit with conventional filters and voltage divider.

Voltage Dividers.—The function of a voltage divider is to supply the various plate voltages required by the various tubes employed in the receiver.

The principal method in each system is to lower the voltage by means of one or more resistors inserted in the circuit. When one resistor is utilized the resistor is tapped at suitable intervals, as shown in fig. 11.

In order to facilitate the calculation of the resistance required between the taps, the voltage divider should be laid off in sections as shown.

Example.—*Assume that the power supply unit shown in fig.* 11 *has* 1,000 *volts across its output terminal and that the required plate voltages and currents are as follows:*

1. 350 volts at 30 m.a. for the oscillator
2. 500 volts at 60 m.a. for the buffer-doubler
3. 1,000 volts for the final amplifier.

Solution.—By using Ohm's law the resistance of (a) or the 350 volt sections will be $\frac{350}{0.04}$ or 8,750 ohms.

The resistance of section (b) or the 150 volt section will be $\frac{150}{0.07}$ or 2,150 ohms approx.

The resistance required for section (c) will be $\frac{500}{0.13}$ or 3,850 ohms.

The current in this last section becomes 60 m.a. in addition to the 70 m.a. already flowing in sections (a) and (b) or $0.06+0.07=0.13$ amps.

The total resistance of the divider will therefore be $8{,}750+2{,}150+3{,}850=14{,}750$ ohms, which is safely below the value necessary to maintain constant output voltage when the tubes are not drawing current from the power supply.

The power loss may be calculated by multiplying the voltage drop across each resistance by the current flowing through it.

Accordingly the power dissipated

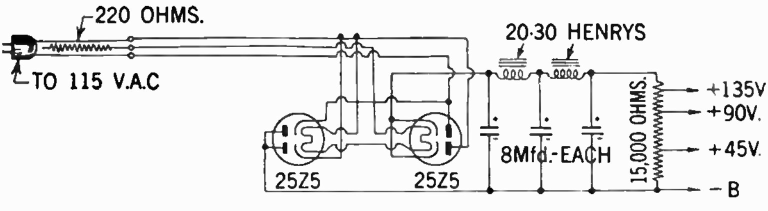
in section (a) $350\times0.04=14$ watts
in section (b) $150\times0.07=10.5$ watts
in section (c) $500\times0.13=65.0$ watts

It is evident from the above that this method of providing operating voltage is uneconomical.

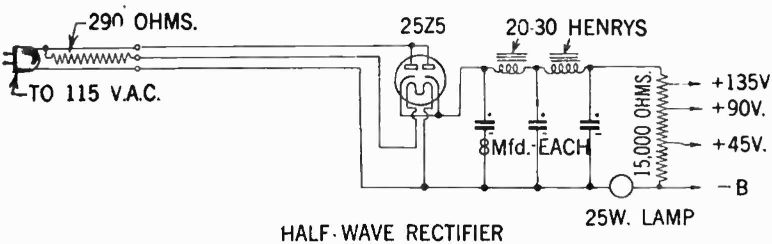
The power calculation should be done for both no-load and full-load conditions, and a resistor selected which should have a rating well above that of the higher of the two values.

In some cases it is desired to have the bleeder resistance total to a pre-determined value— for example, if the bleeder in the above problem is to total 20,000 ohms instead of the calculated value of 14,750 ohms, the same method of calculation may be followed, but different value of idle current should be tried until the correct one is found.

The method outlined may be extended to any number of taps, and is equally applicable to calculation of voltage dividers for radio receivers.



FULL-WAVE RECTIFIER



HALF-WAVE RECTIFIER

FIGS. 12 and 13—Illustrates two transformerless power supplies, for full-wave and half-wave rectification respectively. Here a line cord resistor is utilized to drop the line voltage to that necessary for the filaments of 25Z5 tubes. The third element in the line cord resistor brings the full line voltage for the plate of the tubes.

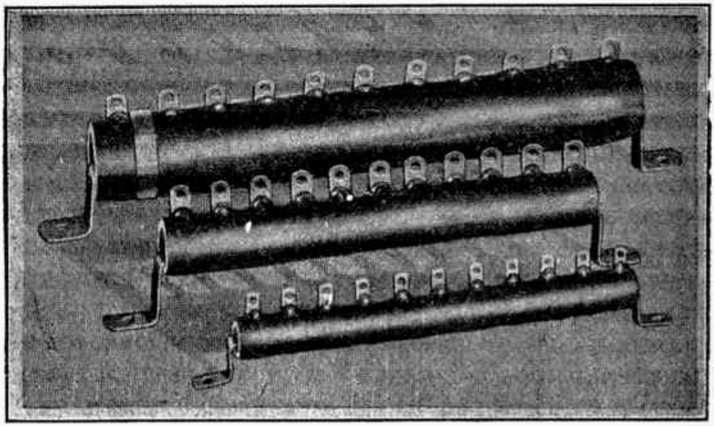


FIG. 14—Typical receiver power supply resistors.

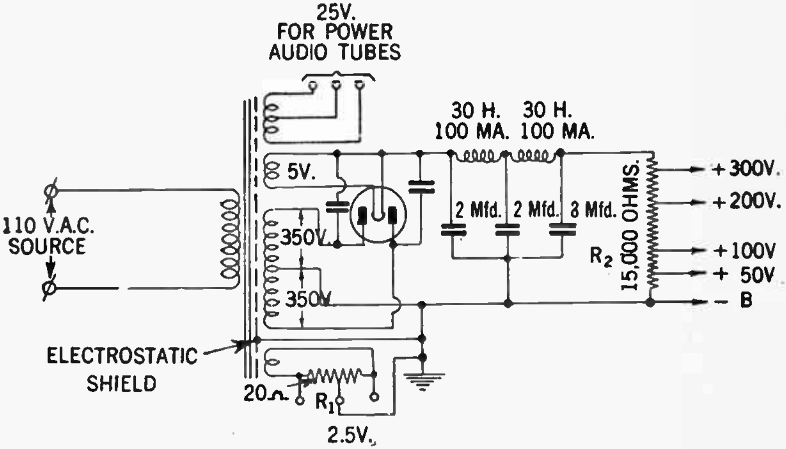


FIG. 15—Here the power transformer is used to step up the 110 volt alternating current to 350 volts on each side of the centre-top. This type of power supply will ordinarily be satisfactory for an ordinary armature receiver as well as an audio amplifier using a 47 or a pair of 45's in push-pull. The 2 m.f.d. condensers and the 30 henry chokes reduces the ripple to satisfactory proportion. Resistor R_1 is centre tapped with a value of 20 ohms. R_2 is the voltage divider for obtaining the different voltages from the power supply.

Bleeder Resistors and Their Use.—It is common practice to connect a bleeder resistor across a power supply to obtain a more stable output—to improve voltage regulation. However, this is often accomplished without any fundamental knowledge of how a bleeder resistor actually works, and how its exact size may be calculated.

Voltage regulation may generally be defined as the change in potential with a change in the load or current consumed.

This is an important consideration in power supply for radio receiving and transmitting circuits because the current may change with signal intensity, modulation, keying, line voltage fluctuation, etc. and it is highly desirable and often imperative that the voltage remains constant.

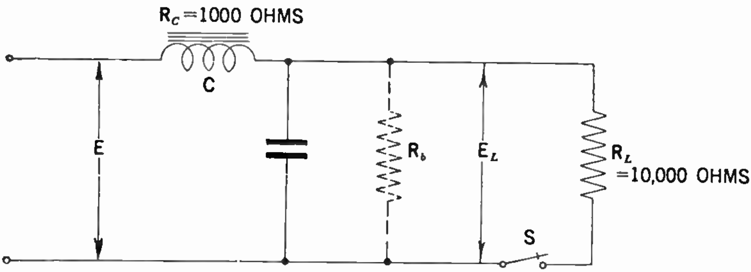


FIG. 16—Showing application of bleeder resistor across power supply.

A problem of this kind may best be studied by considering the arbitrary condition existing in the circuit shown in fig. 16 illustrating a simple filter system of a power supply.

In this circuit *E*, is a source of constant voltage. Choke *C*, has a resistance of 1,000 ohms. E_L is the potential supplied to the load R_L, which may be the plate circuit of a transmitter or receiver. Switch *S*, applies or removes the load.

It is assumed that the load is such that it requires 100 *m.a.* at 1,000 volts for the most efficient operation which according to Ohm's law gives R_L a resistance of 10,000 ohms. R_b is a 10,000 ohms bleeder resistor which at first, is not connected.

If R_L draws a current of 100 *m.a.* the drop through the choke C, will be 100 volts, and E, therefore must be 1,100 volts in order that E_L the load voltage shall provide the 1,000 volt potential.

However, with the switch open, the no load voltage E_L, will be the same as E, or 1,100 volts. When switch S, is closed this 1,100 volt potential will be momentarily applied to the load which will drop almost immediately to the required potential of 1,000 volts.

In other words, the change in voltage with the change in load has been a drop from 1,100 volts to 1,000 volts or a voltage regulation of 100 volts.

Assuming that R_b is also connected in the circuit, it is evident that as R_b also draws current that the drop through R_c will be increased. Hence if E_L is to be maintained at 1,000 volts, the source voltage will also have to be increased.

With E_L at 1,000 volts, R_L and R_b 10,000 ohms each, the current drain through the circuit will be 200 *m.a.* and the drop across C, 200 volts, therefore the voltage at E, will have to be raised to 1,200 volts.

It is evident that the no load voltage (switch S, being open) will no longer be the total voltage at E, but instead the voltage drop across R_b, this may be easily calculated by using Ohm's law.

The bleeder current through R_b will be $\frac{E}{R_c+R_b}$ or 0.109 amperes; the voltage drop across R_b (or the no load voltage) will be $I \times R_b = 0.109 \times 10{,}000$ or 1,090 volts. The no load voltage being 1,000 volts, hence, the change due to regulation will be 90 volts or an improvement of 10 volts over conditions when the bleeder is not employed.

With Resistor in Parallel.— In the above example the power supply was so designed that the correct load voltage was obtained when the bleeder was in the circuit. Very often the bleeder is added merely as an afterthought in hope that the regulation secured will compensate the loss in voltage.

With reference to the diagram, the bleeder resistor is connected without boosting the voltage (1,100) at E.

If considering resistors R_L and R_b in parallel, their combined resistance is 5,000 ohms. This plus R_c gives a total effective resistance of 6,000 ohms, and a total current of 184 *m.a.* The drop across R_c will be 184 volts, and the load voltage E_L will be E minus this value $(1,100-184)$ or 916 volts. The no load voltage will be of course exactly 1,000 and the regulation therefore 84 volts.

This is better than the 100 volt regulations obtained when the bleeder is not employed, but the operating voltage has dropped to 916 volts.

Summary of Improvement in Regulation.—Summing up it will be observed that the improvement in regulation with the utilization of a bleeder resistor is not as much as might be assumed. While the conditions in the above problem have been arbitrarily assumed, similar arithmetic treatment will apply to actual cases.

It is evident that the lower the value of the bleeder resistor, the greater the regulating effect, but at the same time the supply voltage must be increased.

The bleeder is essentially a wasteful proposition and particularly so when its value is made sufficiently low to secure any real measure of regulatory effect. However, a bleeder of even high value, say 100,000 ohms, will be effective in preventing excessively high potentials under no-load conditions which might damage rectifying tubes and filter condensers.

Voltage regulation is best secured through the design of generous size transformer windings, low resistance chokes and mercury-vapor rectifying tubes.

Voltage Doubler Circuits.—By means of this type of circuit it is possible to obtain twice the *a.c.* input voltage without the conventional transformer.

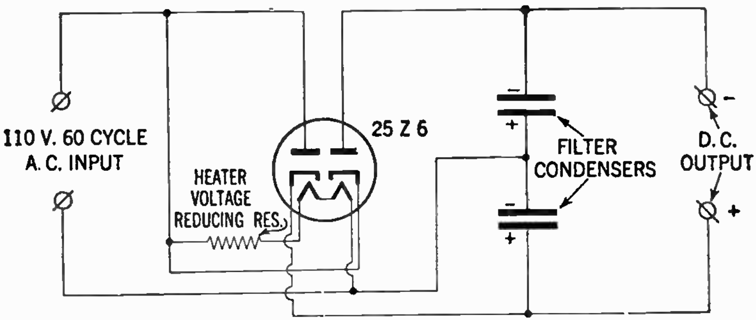


FIG. 17—Voltage doubler circuit utilizing a full-wave rectifier tube.

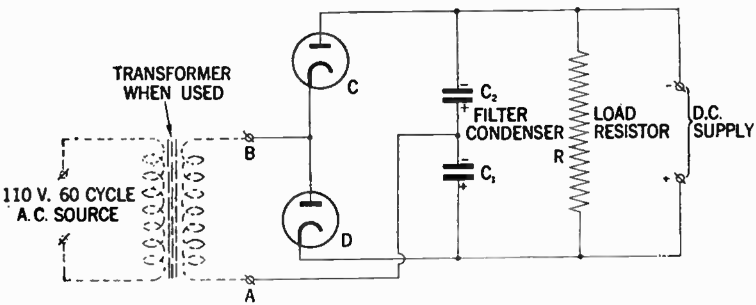


FIG. 18—Voltage doubler circuit utilizing two half-wave rectifier tubes.

The circuit shown in fig. 18 represents a typical voltage doubler without a transformer although a transformer may be used if the voltage requirements thereby will be facilitated.

The action that takes place within this circuit is briefly as follows: With reference to fig. 18 it may be observed that during that one half of the cycle when B, is positive with respect to A, rectifier D, is conducting and the condenser C_1 is being charged. The two condensers are connected in series with respect to the load resistor R, which results in doubling of the voltage appearing across this resistor.

Example.—*A five tube receiver using a* 2 *volt filament supply battery, takes* 1.2 *amperes of filament current. What is the total power expended in heating the filaments? If a* 40 *ohms potentiometer were placed across the battery terminals, what would be the increase in the power consumed?*

Solution.—Since direct currents are being dealt with, the power in watts is given by the product of the voltage and the current in amperes. Thus the power is $2 \times 1.2 = 2.4$ watts. The current taken by the potentiometer is easily found by Ohm's law. This gives $I(\text{amperes}) = \frac{E}{R} = \frac{2}{40}$ or 0.05 ampere. As before, the power taken is equal to the product of the voltage and this current or $2 \times 0.05 = 0.1$ watt. A quicker method is to make use of the formula, power $= \frac{E^2}{R}$ watts or in this case $\frac{4}{40} = 0.1$ watt as before.

Example.—*The current for a multi-tube receiver is furnished by means of a "B" battery having a potential of* 120 *volts. If a milliammeter placed in the negative lead indicates that a steady current of* 8 *m.a.* (*milliampere*) *is passing, what is the d.c. resistance of the circuit?*

Solution.—The comparatively small current flow in the "B" circuit of a receiver is conveniently measured in milliamperes $\frac{1}{1,000}$ of an ampere. When, however, a calculation is to be made, it is better to express it into fundamental units of current—the ampere.

When applying Ohm's law it is always advisable to express the quantities dealt with in terms of the fundamental units—*amperes*, *volts* and *ohms*, since the formula $E = I \times R$ holds true for these denominations.

In the example, therefore, it is required to express the current in ampere or 0.008 amperes. The resistance of the circuit may now easily be found by applying Ohm's law—

$$R = \frac{E}{I} = \frac{120}{0.008} = \frac{120{,}000}{8} \text{ or } 15{,}000 \text{ ohms}$$

Example.—*What amount of power is dissipated in the circuit of the previous example?*

Solution.—The power in watts in any *d.c.* circuit is obtained by multiplying the current through the circuit by the potential across it, or written $W = E \times I$. When substituting the values of current and potential in the above equation we obtain very simply $W = 120 \times 0.008 = 0.96$ watts.

Problem.—*A certain receiver consumes* 46 *m.a. at* 250 *volts, the current being supplied through a smoothing choke of* 25 *henry. If the actual d.c. output from the eliminator is* 270 *volts, what is the resistance of the choke? The high frequency and detector tubes are supplied with* 8 *m.a. through a special smoothing choke of* 200 *henry and* 3,000 ohms. *What is the voltage drop in the choke?*

Solution.—This problem offers a simple exercise in voltage drop calculation. The voltage supplied to the *H.P.* terminal of the receiver is 250 volts while the actual eliminator voltage is 270. The difference in 20 volts represents the (IR) drop across the choke, the symbol R, of course, referring to the resistance and not the inductance of the coil, the latter of which exercises no effect whatever upon the direct durrent. Of this IR product the current value I is known to be 0.046 amperes, thus according to Ohm's law, it may be written

$$20 = I \times R = 0.046 \times R \text{ from which follows}$$

$$R = \frac{20}{0.046} = 435\Omega$$

The (IR) voltage drop across the special choke is similarly found. Here $I \times R = 0.008 \times 3{,}000 = 24$ volts. Such a slight voltage drop is of course immaterial in the case of tubes in the position as specified.

CHAPTER 8

Resistors, Inductors and Condensers

The Tuned Circuit.—In the chapter dealing with radio fundamentals, it has been demonstrated that the flow of electrons through a wire constitutes an electric current.

The law governing this flow of current under various conditions, as well as the conditions necessary for the introduction of resonance in an *a.c.* circuit has also been briefly outlined.

Selectivity of Tuned Circuits.—In order to understand the selectivity of the tuned circuit and the factors governing this important phenomenon, the behavior of a simple circuit as shown in fig. 1, will be considered.

Here the applied *a.c.* voltage (E) forces a current of (I) amperes (r.m.s. value) through the loop of the circuit. The circuit itself opposes or impedes the flow of current and this opposition is known as *impedance*.

Now the circuit under consideration comprises the three quantities resistance R, (ohms) inductance L, (henries) and capacity C, (Farads) and the total opposition is due to all three.

That part of the impedance due to coil inductance is referred to as inductive reactance and is given in ohms by the expression $2\pi fL$ where f is the frequency. Similarly the condenser possesses a reactance of $\frac{1}{2\pi fC}$ ohms capacitive reactance.

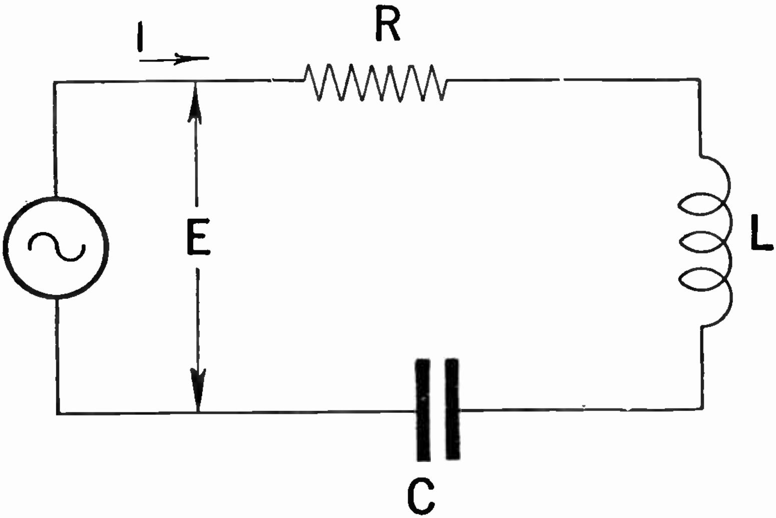


FIG. 1—Circuit containing resistance, inductance and capacity connected in series.

It is a well known fact that the *a.c.* voltage required to force a current through an inductive reactance is a quarter of a cycle in advance of the current, whereas for a condenser the applied voltage lags by a quarter of a cycle behind the resulting current.

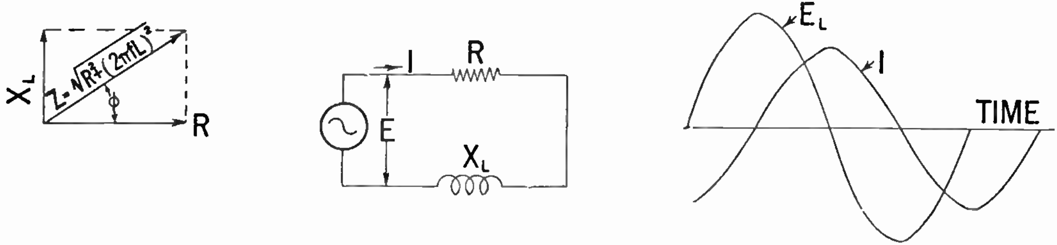


FIG. 2—Voltage and current vectors for a circuit containing resistance and inductance in series.

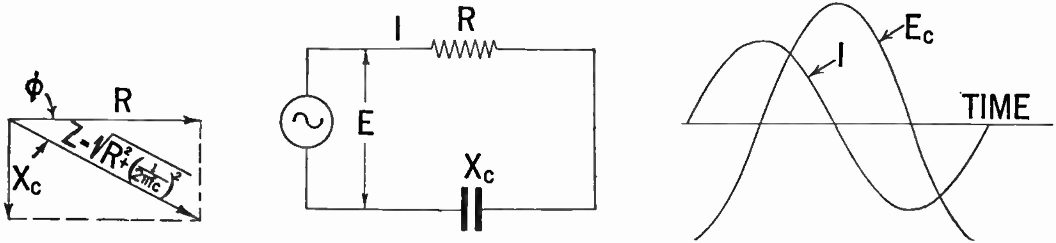


FIG. 3—Voltage and current vectors for a circuit containing resistance and capacity in series.

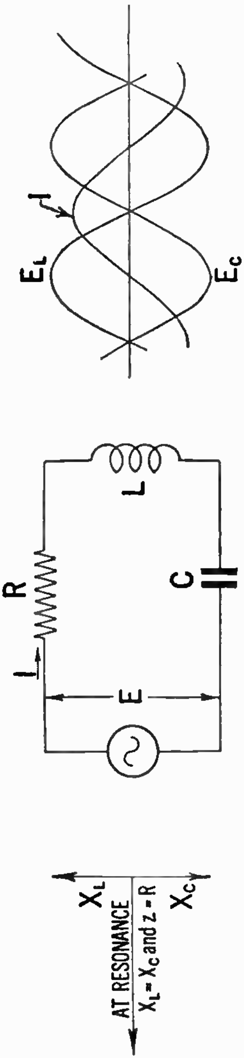


FIG. 4—Resonance conditions in a series circuit.

Circuit Resonance.—Consequently the closed loop, where the same current flows throughout, the component voltage absorbed in overcoming the inductive and capacitive reactance are in opposition—when one is positive and the other negative at all times.

Thus the voltage absorbed by the two reactances in series is the difference of the individual voltage. From this it follows that the inductive and capacitive reactances tend to neutralize each other's effects and the resultant reactance of the circuit is given by $2\pi fL - \frac{1}{2\pi fC}$ ohms.

It is evident from the above that the inductive reactances increase as the frequency is raised, whereas the capacitive reactance decreases. Thus there must be one particular frequency at which the two become equal and neutralize each other completely as far as their influence of the current is concerned. When this happens the circuit is tuned to resonance with the applied frequency, and the formulae for the resonant frequency is derived by equating the inductive and capacitive reactances namely $2\pi fL = \frac{1}{2\pi fC}$ from which $f = \frac{1}{2\pi\sqrt{L \times C}}$ cycles per second.

It follows that at resonant frequency the resultant reactance of the circuit is zero, so that only the resistance remains to oppose the flow of current and hence ohms law may be applied, $I = \frac{E}{R}$ amperes.

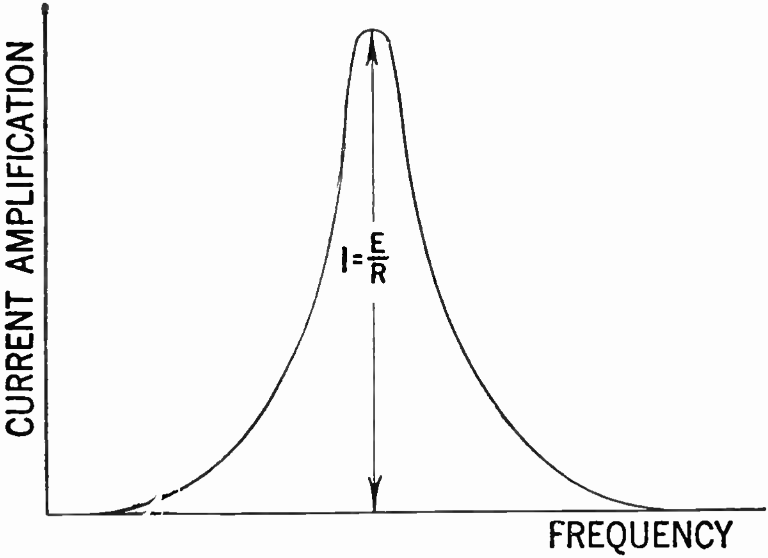


FIG. 5—Typical current resonance characteristic.

At any frequency different from the resonant value the inductive and capacitive reactances become unequal and their resultant is no longer zero so that the current now experiences an additional opposition which increases as the frequency departs from the resonant value in either direction, the current being reduced as a consequence.

Obviously then the current is greatest at the resonant frequency, its value being $\frac{E}{R}$ amperes.

The formula for the current at any frequency is

$$I=\frac{E}{\sqrt{R^2+\left(2\times\pi\times f\times L-\frac{1}{2\times\pi\times f\times C}\right)^2}}\text{ amperes.}$$

If a curve be plotted of current against the frequency the familiar resonance curve depicted in fig. 5 will be obtained, the maximum height being $\frac{E}{R}$ ampere, now in receiving circuits the current is of little significance compared to the voltage built up across it.

Voltage Amplification.—The voltage across the condenser is $I\times\frac{1}{2\pi fC}$ and since at resonance $\frac{1}{2\pi fC}=2\pi fL$ it follows that the voltage developed across the tuned circuit is $I(2\pi fL)$ volts. From Ohm's law the applied voltage is IR and so the ratio of the developed voltage and the applied voltage is $\frac{2\pi fL}{R}$. This is a very important number and is known as the *voltage amplification* of the tuned circuit.

At resonance $2\pi f=\frac{1}{\sqrt{LC}}$ and so the previous expression for voltage amplification may be re-written in the form

$$E_a=\frac{1}{R}\sqrt{\frac{L}{C}}$$

It now remains to be shown that the selectivity of the tuned circuit is directly proportional to the voltage amplification. This may best be accomplished with a graphic illustration.

In the first place, consider a circuit of fixed inductance and capacity and assume that a number of resonance curves be plotted each for a different resistance value.

With reference to fig. 6, it may be observed that the peak of the curves all appear at the same frequency and it will further be noted that their various heights are inversely proportional to their respective resistance.

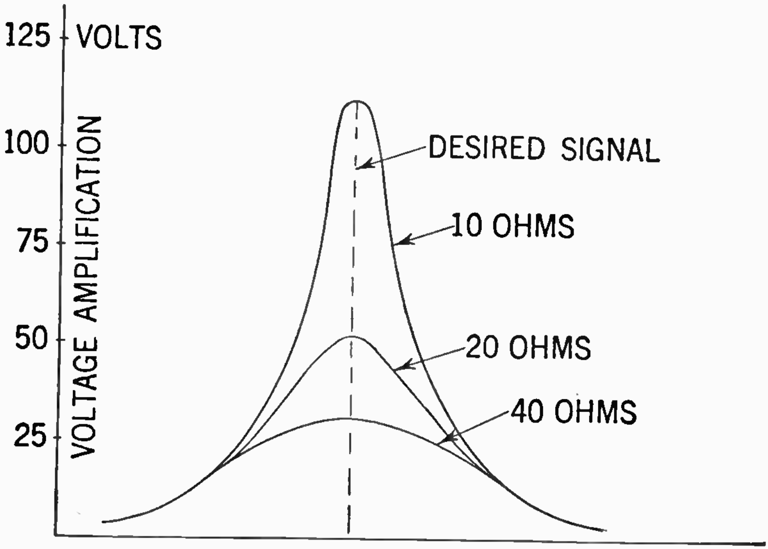


FIG. 6—Typical voltage resonance characteristics indicating the effect of varying the effective resistance.

It is important to note that all the resonance curves have approximately the same width near the base, so that by decreasing the resistance the strength of the desired signal increases at the resonant frequency without appreciably strengthening any signals whose frequency differ moderately from the resonant value.

This the degree of selectivity is approximately proportional to the height of the resonant curve and so inversely proportional to the resistance, like the amplification factor.

Mutual- and Self-induction.—Without a knowledge of the fundamental principles of mutual induction, it is difficult to comprehend the theory of coil coupling.

By definition, *mutual induction* is the electro-magnetic property of two circuits or two parts of a single circuit, by virtue of which a changing current in one causes an electromotive force to be induced in the other.

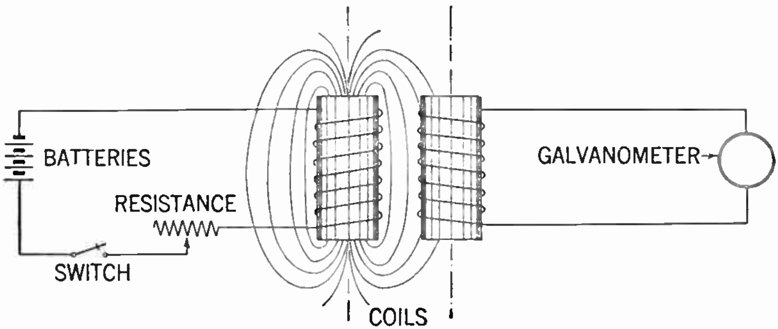


FIG. 7—Diagram showing the action of mutual induction between two coils; the one including a source of electrical energy and a switch, the other a current measuring instrument but having no source of electrical energy. During the increase or decrease in strength of current as on closing the switch the current is induced in the secondary circuit. This secondary current is flowing in a direction opposite to that of the primary current.

Similarly it can be said that mutual induction is an electromagnetic property of two circuits so situated with respect to each other that a current in one sets up a magnetic field which is linked with the latter, that is to say, a property of two circuits which are magnetically coupled together.

It is a fundamental principle that when a magnetic flux linked with a circuit is changing, an electromotive force is induced in the circuit, its magnitude being proportional to the rate of change.

When the magnetic flux linked with a circuit is produced by a current in the circuit itself, then, if the current is varied, the flux will vary also and an E.M.F. is induced in the circuit proportional to the change in current.

This property in a single circuit is called *self-induction*. If, however, there be two circuits magnetically coupled together as explained above, a variation in the current in the one will cause a variation of the magnetic flux through the turns of the other, and an E.M.F. proportional to the *rate of change* of current in the first will cause an E.M.F. to be generated in the other. This property is referred to as *mutual induction*.

The first circuit in which the current is varied, is called the *primary* and the second in which the induced E.M.F. is considered, is called the *secondary* circuit.

As in the case of self-induction, the practical unit in which mutual induction is expressed numerically is the *henry*. *The mutual inductance or co-efficient of mutual inductance between two circuits is said to be one henry if one volt is induced in the secondary circuit, when the current in the primary is changing at the rate of one ampere per second.*

The mutual inductance in henries is usually denoted by the symbol M, and the induced E.M.F. in volts in one circuit is equal to the product of M, and the rate of change of current in amperes per second in the other.

The mutual inductance M, is the same whichever of the two circuits is taken as the primary.

Degree of Coupling.—As an example, consider two coils whose self inductances are L_1 and L_2 henries respectively placed in close proximity to each other as shown in fig. 8. When a current is passed through L_1 a magnetic field is established and some of the magnetic loops are linked with the second coil L_2.

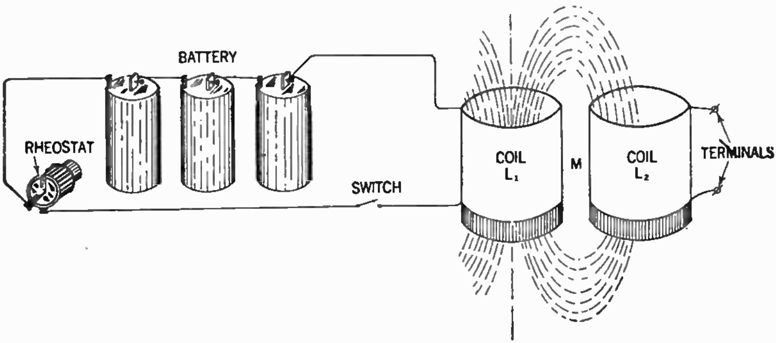


FIG. 8—Illustrating the degree of coupling of two coils.

Let M be the mutual inductance in henries between the coils. Now if the current in L_1 is varied by changing the rheostat setting the flux linked with L_2 will be varied in proportion and an E.M.F. will be induced in L_2. The value of this secondary induced E.M.F. is equal to $M \times$ (rate of change of primary current). The degree of magnetic coupling obviously depends upon the proximity and relative positions of the two coils and is expressed numerically as the ratio of the mutual inductance to the square root of the product of the individual self inductances. This is called the co-efficient of coupling and is given

by $K = \dfrac{M}{\sqrt{L_1 \times L_2}}$.

This number cannot exceed unity, and in practice never reaches unity. Coils are said to be tightly coupled when they are brought close together to give a relative high value of M and K and vice versa. The tightest coupling is obtained when two coils are wound on the same form (as for example in a transformer) or with the wires wound side by side, but even in this case the co-efficient is less than unity.

Example.—*The mutual inductance of two coils* L_1 *and* L_2 *is* 160 *micro-henries. If their self-inductances are* $L_1=150$ *and* $L_2=275$ *micro-henries respectively, what is the value of the co-efficient of coupling in the system?*

Solution.—Since the co-efficient of coupling is expressed by the relation $K=\frac{M}{\sqrt{L_1\times L_2}}$ by substituting

$$K=\frac{160}{\sqrt{150\times275}}=\frac{160}{203} \text{ or } 79\% \text{ approximately}$$

It should be observed that since in problems of this kind only a ratio between the mutual induction and self-inductances are required the values may be expressed in henries, milli-henries or micro-henries.

Example.—*Determine the resonance frequency and wave-length of a circuit containing a coil of* 500 *micro-henries inductance and a condenser of* 0.005 *micro-farads capacitance.*

Solution.—The frequency of resonance may be determined from the following formula:

$f=\frac{1}{2\pi\sqrt{LC}}$ by substituting L, and C in henries and farads respectively, the following is obtained:

$$f=\frac{1}{2\pi\sqrt{5\times10^{-4}\times5\times10^{-9}}}=100{,}700 \text{ cycles per second or}$$

100.7 kilocycles.

In a similar manner the wave-length in meters may be obtained from the formula for natural wave-length $L=1{,}885\sqrt{L\times C}$. Where L and C are expressed in micro-henries and micro-farads, and L, is the wave-length in meters. By inserting the above values $L=1{,}885\ \sqrt{500\times0.005}$ or 2979 meters approximately.

CONDENSERS

Condensers in Series and Parallel.—When condensers are connected in series or parallel, the effect is just opposite to that of connecting resistances and inductances in series or parallel. A simple method, therefore and one which is easy to remember is as follows: Capacities connected in series should be added in similar manner as that of resistances connected in parallel, and capacities connected in parallel should be added similarly as that of resistances connected in series. Thus, the total capacitance of two or more condensers connected in series may be written:

$$\frac{1}{C}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3} \text{ etc. or}$$

$$C=\frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}}$$

Where C is the combined capacitance and C_1, C_2 and C_3 are the individual capacities.

Where two or more condensers are connected in parallel the total capacitance $C=C_1+C_2+C_3$, etc. In this formula C_1, C_2 and C_3 represent the individual capacities.

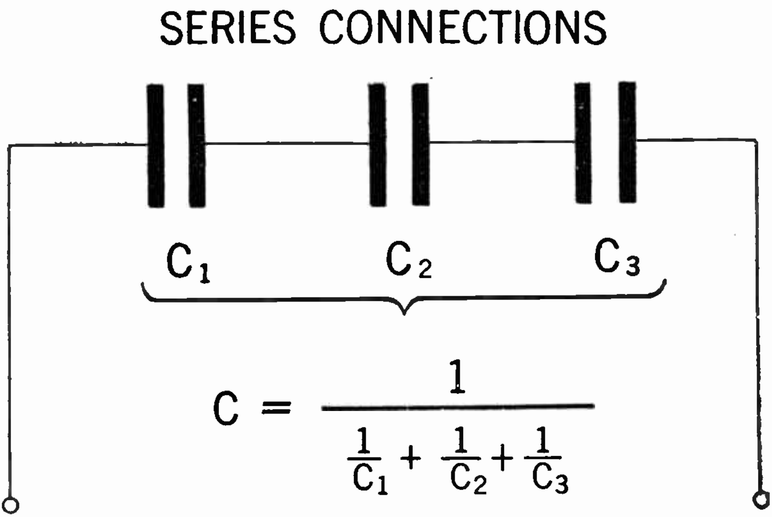


FIG. 9—Mathematical relation between the total capacitance and the individual capacities when connected in series combination.

Type of Condensers.—Condensers for radio application may be classified according to their construction as:

1. Mica and paper type
2. Electrolytic type
3. Ganged or air type.

Their capacity may be either *fixed* or *variable*.

As the two first classes utilized in radio circuits do not vary appreciably from those employed in other electrical systems, we shall here deal only with the *ganged condenser* type used in tuning of radio circuits.

This type of condenser generally consists of two parallel connected sets of plates of which one is stationary and the other movable.

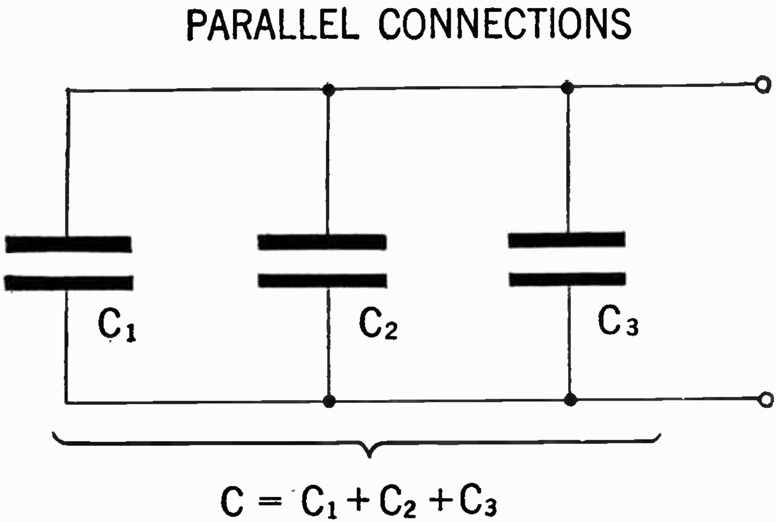


FIG. 10—Illustrating condenser connection and mathematical relation between the total capacitance and the individual capacities when connected in parallel combination.

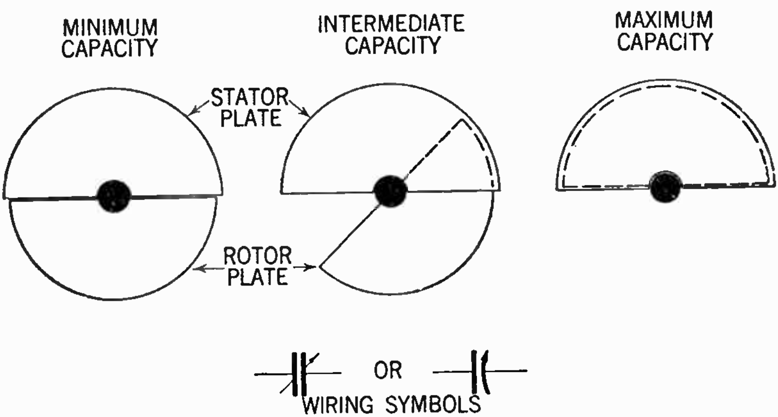


FIG. 11—Arrangement of straight line capacity condensers for various capacities.

The movable plates are made to intermesh (without touching) with those of the stationary plates, and the maximum capacity is obtained when the full areas of the two sets of plates are exposed to each other, and for various other positions some intermediate value of capacitance exists.

The ganged type of condenser is usually made of brass or aluminum sheets. Commercial types are stamped in a die press and will hence be very exact in shape and size.

Condensers of this kind are usually rated by the total number of plates in the combination; that is, a condenser having 8 plates in the rotor and 9 plates in the stator would be rated as a seventeen plate condenser.

When it is found necessary to accomplish very small changes in capacity, the condensers sometimes are provided with one additional plate, which may be separately rotated, and when so used are called *vernier condensers*.

Commercial types are made with various standard capacitance values, and the relation between the number of plates and their maximum capacity in microfarads is approximately as follows:

No. of plates	*Max. Capacity in microfarads*
11	0.00025
13	0.00025
17	0.00035
21	0.000365
23	0.0005

Straight Line Capacity Condensers.—Condenser plates of this type are semi-circular in shape, and the change in capacity is accomplished by rotation as previously discussed. However due to the geometrical form of the plates, the *capacity* will vary in direct *proportion* to the angle of rotation, i.e. if a change in capacity of 0.0001 *Mfd.* be made by changing the rotor setting from 15 to 20 degrees, a similar change in capacity will be made by changing the setting from 35 to 40 degrees.

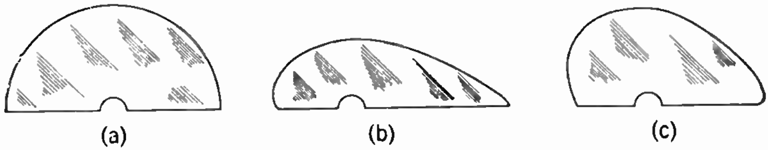
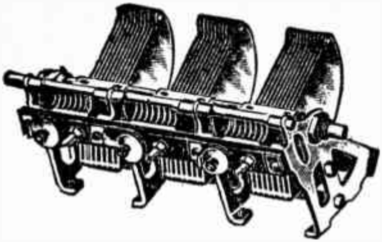


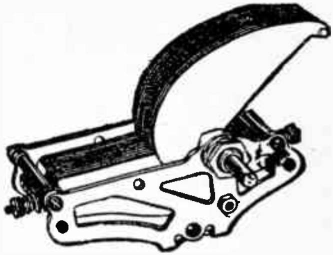
FIG. 12—Shape of rotor plates in various type air condensers. Figs. *a*, *b*, and *c* represent straight line capacity, straight line frequency and straight line wave—length respectively.

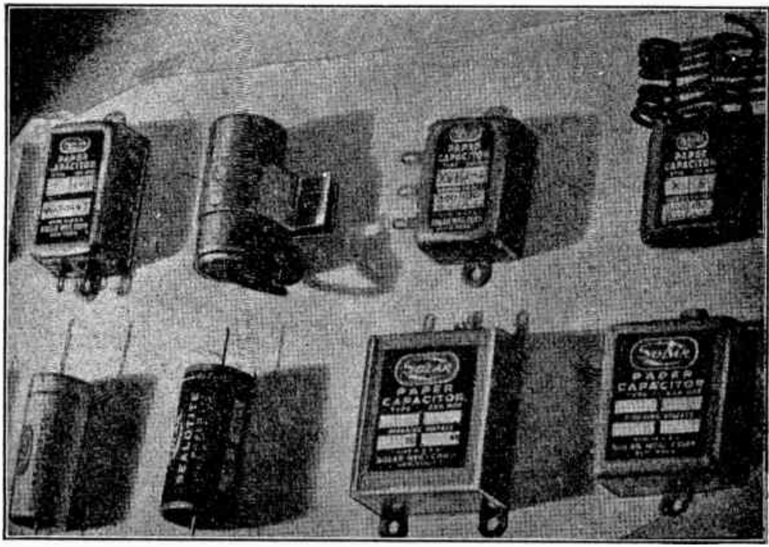
Straight Line Frequency Condensers.—In modern condensers, however, for convenience in tuning, the condensers are made with logarithmic plates, i.e. the shape of the plates are such that a linear relationship exists between the *rotor setting in degrees* and the *frequency* in the circuit.

The advantage of this arrangement is obvious since the primary employment of the gauged type condenser in oscillatory circuits is for adjustment of frequencies.

The frequency of such a circuit varies inversely as the square root of the capacity, and the wave-length varies directly as the square root of the capacity, hence it is evident that in order to obtain a direct relationship between the rotor setting in degrees and the frequency in the circuit, the rotor plates must therefore possess an exponential characteristic.







FIGS. 13 to 22—Various types of condensers used in radio work.

Example: *A condenser of* 0.0002 Mfd. *is connected in series with one of* 0.002 Mfd. *What is the value of the resulting capacitances and what would be the capacity if they had been connected in parallel?*

Solution.—If C denotes the resultant capacity of the two capacities in series, then according to the aforementioned formula:

$$\frac{1}{C}=\frac{1}{0.0002}+\frac{1}{0.002} \text{ or}$$

$$\frac{1}{C}=5{,}000+500=5{,}500 \text{ from which follows that—}$$

$$C=\frac{1}{5{,}500} \text{ or } 0.00018 \; Mfd. \text{ (approximately)}$$

If connected in parallel the total capacitance is simply the sum of individual capacities or 0.002+0.0002 which adds up to 0.0022 *Mfd.*

Code colors for indication of resistor values.—The Standard Radio Manufacturers' Association Code (R.M.A. color code) for resistor values is as follows: With reference to fig. 23 the resistor has 3 colors; *a body color*, *a tip color* and a *central dot color*. The dot color indicates the number of zeros or ciphers to be added to the numerals of the other two colors; and the color of the body is taken first; for instance, if the body color be blue, which means 6, and the tip color be red, which means 2, and the dot is orange, which means 3 ciphers (000), the resistance of the resistor is 62000 or 62,000 ohms. The color values are as follows:

Color	*Body and tip numerals*	*Dot ciphers*
Black	0	—
Brown	1	0
Red	2	00
Orange	3	000
Yellow	4	0000
Green	5	00000
Blue	6	000000
Violet	7	0000000
Gray	8	00000000
White	9	000000000

If no difference in colors are visible, the colors are assumed to be the same and their values are accordingly. For instance, an all brown resistor would be 1, 1, 0; or 110 ohms.

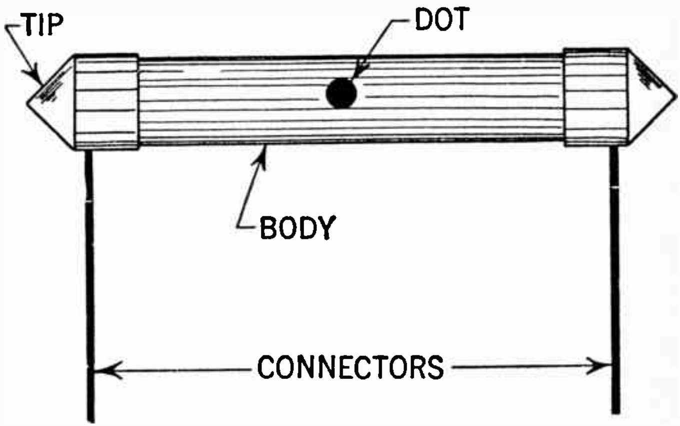


FIG. 23—Illustrating Standard Radio Manufacturer's Association (R.M.A.) color code for carbon resistance.

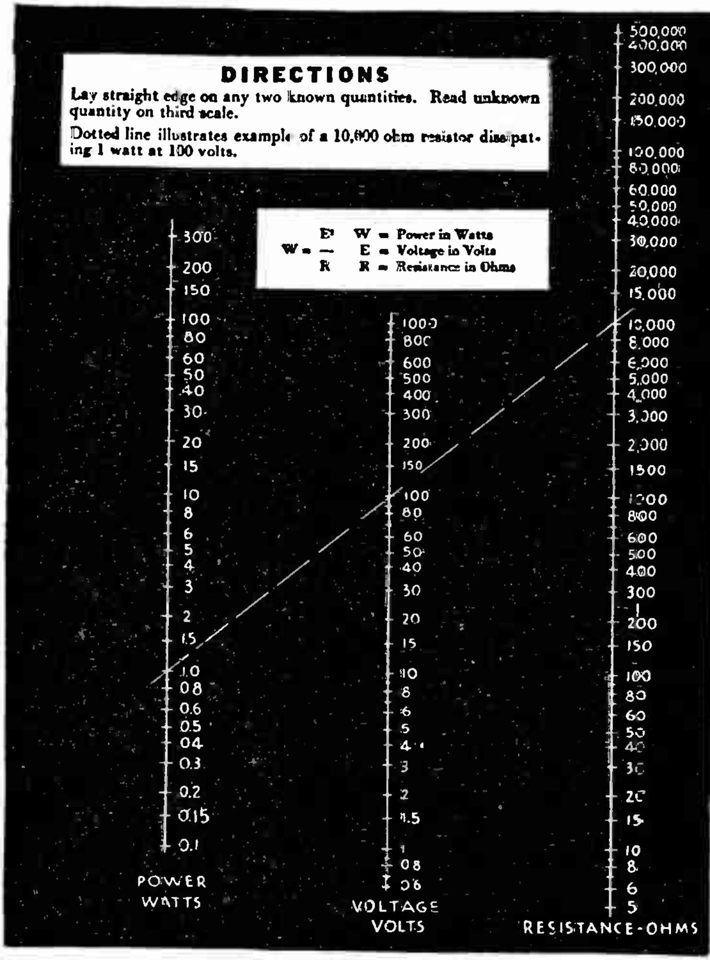


FIG. 24—Convenient table giving the scalear relation between resistance (R), voltage (E) and power (W). With the chart and a straight edge any of the above quantities can be determined if the other two are known.

CHAPTER 9

Transformers

The alternating current transformer represents an example of the practical utilization of mutual inductance. By definition a transformer is a form of stationary induction apparatus in which the primary and secondary coils or windings are ordinarily insulated from one another, their relative position being fixed. In the case of low frequency and power transformers, the primary and secondary windings are wound on a common iron

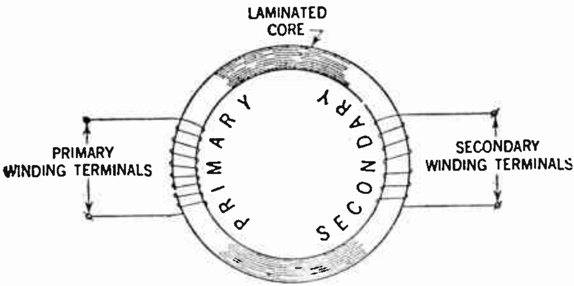


FIG. 1—A transformer in its simplest form consists of two separate and distinct coils of insulated wire wound around the laminated iron core, as shown in the above representation.

core as shown schematically in fig. 1. In this case, the co-efficient of coupling approaches 100%, but for radio frequency transformers the windings are usually carried on a non-magnetic form and are hence said to be *air cored*.

Transformer Function.—A transformer does not generate power, its purpose being merely to change the power from one voltage to another. Generally when used in connection with transformation of large amounts of power, from one voltage to another, a transformer utilized to raise the received voltage is called a *step-up transformer*, and when used to lower the voltage, a *step-down transformer*.

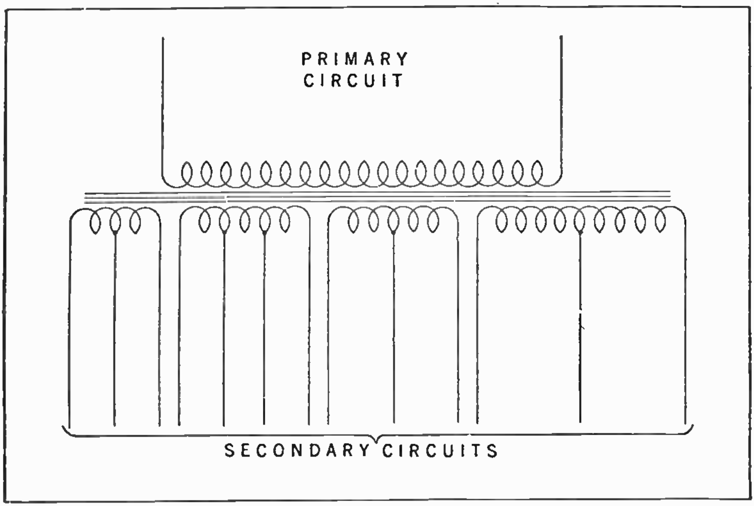


FIG. 2—Typical schematic diagram of power transformer used in radio work.

In radio service, a power transformer is used to supply a high voltage to the rectifier tube for rectification of the alternating current, (furnished through the wire cord leading from the wall outlet to the transformer) and also to supply the filament or heaters with the required voltage and current. For this purpose, the transformer is usually equipped with a single primary winding and several secondary windings as shown in fig. 2.

Transformer Theory.—A transformer is said to be loaded when a current is flowing in the secondary coil. When the secondary circuit is open and an alternating current from the power line flows through the primary coil, it causes an alternating magnetic flux to flow in the core.

This magnetic flux rapidly rising, falling and changing direction with the impressed frequency, cuts both primary and secondary coils and induces a voltage in each.

The voltage produced in the primary coil is opposite in direction and nearly equal to the voltage in the power line. The voltage of the secondary coil is proportional to the number of turns of the wire in the primary and secondary coils.

The choking effect produced within the highly inductive primary coil, allows only a small current to flow continually through it. This small current, proportional to the difference between the power line voltage and the voltage or counter electromotive force of the primary coil, keeps the core magnetized and maintains the voltage in the coils.

When the secondary circuit is closed a current flows through it. This secondary current is opposite to the primary current and its magnetizing action in the core opposes and neutralizes to a certain extent the primary flux and reduces the choking effect or counter electromotive force. In the primary coil when this happens more current rushes into the primary coil from the power line and balances the de-magnetizing action of the secondary current.

In this way the transformer is made automatic and maintains its core flux practically constant regardless of the load on the secondary. The variation of the load through the primary varies directly with the load on the secondary.

Relation of Voltage in Primary and Secondary Coils.—The induced electromotive force in a transformer coil is due to the three factors: flux, frequency and the number of turns.

Assuming a sine wave current, the fundamental equation used in transformer design is as follows:

$$E = \frac{4.44 \times f \times \phi \times N}{10^8} \quad \text{.......... (1)}$$

where f = frequency in cycles per second

ϕ = maximum flux on the sine wave

N = number of turns in the respective coils.

The voltages in the secondary and primary coils are proportional to their respective turns as both have the same frequency and are cut by the same flux. It has also been found that—

$$\phi = B \times A \quad \text{.......... (2)}$$

where B = maximum flux density in lines per square inch.

A = cross section area in square inches.

If $B \times A$ be substituted for ϕ in equation (1) then

$$E = \frac{4.44 \times B \times N \times f \times A}{10^8} \text{ volts} \quad \text{.......... (3)}$$

This formula may be used in transformer calculations as shown in the following example.

Example.—*In designing a special* 60 *cycle step-down transformer a core of* 2 ***sq. ins.*** *cross section was chosen. Using a flux density of* 65 *kilolines per square inch of the core area, what will be the voltage of primary and secondary winding if the turns are* 320 *and* 80 *respectively?*

Solution.—

$$E_1 = \frac{4.44 \times 65{,}000 \times 320 \times 60 \times 2}{10^8} = 110.8 \text{ volts}$$

$$E_2 = \frac{4.44 \times 65{,}000 \times 80 \times 60 \times 2}{10^8} = 27.7 \text{ volts}$$

Another handy formula for small power transformers is obtained by solving equation (3) with respect to turns per volt.

$$\frac{N}{E}=\frac{10^8}{4.44\ B\times f\times A} \quad \text{(4)}$$

A useful transformer design chart based on this equation is shown in fig. 3 in which the left column represents the flux density (B), the centre column the core area (A) and the right column the turns per volt.

Using the data given in the previous example with respect to the primary winding, it may readily be found that if a straight line is drawn through the chart at 65 kilolines per square inch, and 2 square inches area, the line will intersect the right column at approximately 2.9 turns per volt, which is equal to $\frac{320}{110.8}$ being the primary number of turns divided by the primary voltage.

It is customary to change the turns per volt to an even number so that the proper center taps may easily be made.

Due to the previously described automatic action of the transformer which causes the core flux to remain constant regardless of load, the primary and secondary induced voltages remains practically constant, hence:

$$\frac{E_1}{E_2}=\frac{N_1}{N_2} \quad \text{(5)}$$

Where E_1 = voltage of primary coil

E_2 = voltage of secondary coil

N_1 = number of turns in primary coil

N_2 = number of turns in secondary coil.

It follows from the above that if N_1 and N_2 are the number of turns in primary and secondary coils respectively, and if a

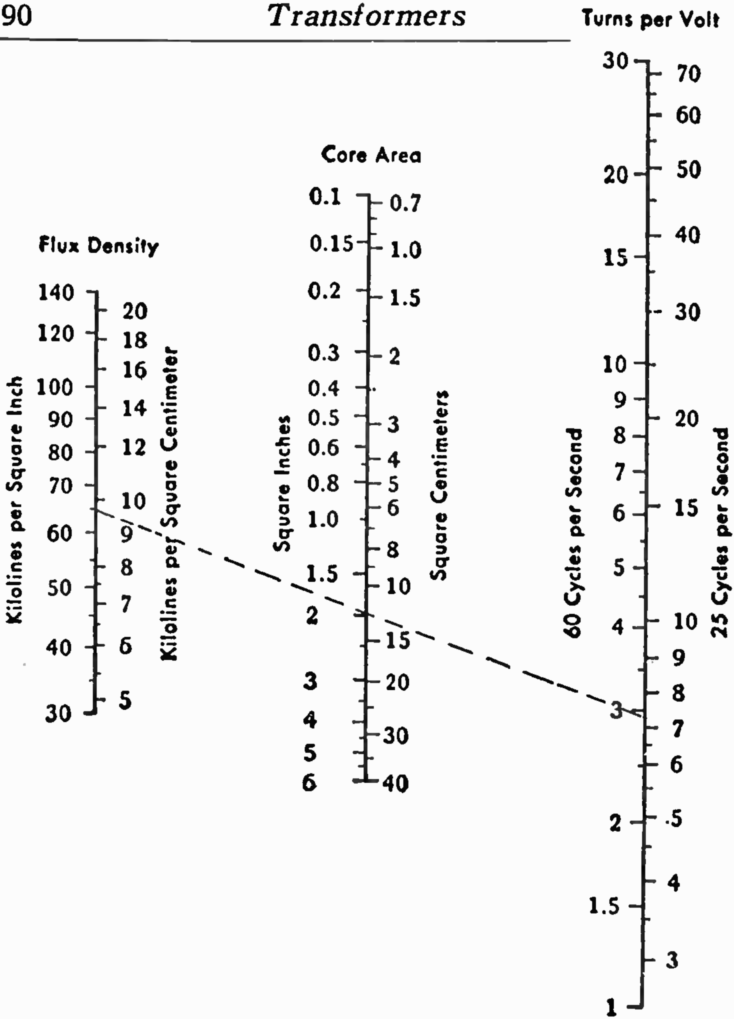


FIG. 3—Turns per volt chart. When it is desired to use flux density in kilolines per square centimeter as well as the core area in square centimeters respectively, the data supplied at the left and center columns of chart should be used.

voltage E_1 is impressed on the end of the primary coil, the secondary voltage is given by the following relationship

$$E_2 = \frac{E_1 \times N_2}{N_1} \qquad \text{(6)}$$

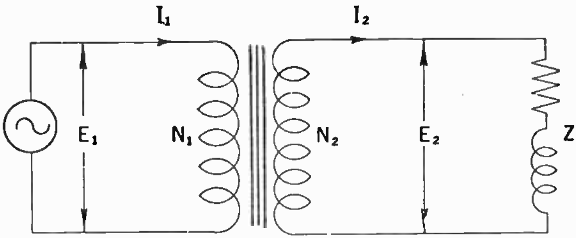


FIG. 4—Simple diagrammatical representation of typical transformer.

Example.—*What will be the ratio of the primary and secondary turns in a power transformer having* 110 *volts impressed upon the primarp coil when* 660 *volts is required across the plates of the rectifier tubes?*

Solution.—

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \text{ or } \frac{110}{660} = \frac{N_1}{N_2} = \frac{1}{6}$$

That is the secondary coil should have six times as many turns as that of the primary coil.

Ampere Turns.—When a load of impedance Z, of some form is connected across the secondary coil of a transformer as shown in fig. 4, a current flows in the secondary winding and this in turn reacts back on the primary winding through the medium of the mutual induction. Therefore, the current taken by the primary winding will depend upon not only the impedance of the secondary winding itself, but also on the amount of current flowing in the secondary, although there is no direct electrical connection between the windings.

The extra current taken by the primary winding of a transformer when a current is allowed to flow in the secondary is exactly proportional to the secondary current and these two currents have equal and opposite magnetic effects on the core, the extra primary ampere turns just opposing the secondary ampere turns, so that apart from the initial magnetizing current
$I_1 \times N_1 = I_2 \times N_2$ . . . . (7)

Example.—*If in a certain step-up transformer, the turns of the primary and secondary windings are* 40 *and* 400 *respectively, what will be the current ratio?*

Solution.—Inserting the values in equation (7) the following is obtained:

$$\frac{40}{400} = \frac{I_2}{I_1} \text{ or the current ratio} = \frac{1}{10}$$

from which it follows that the current in the primary winding is ten times larger than the current in the secondary winding or $I_1 = 10I_2$.

This is just the reverse compared with the relationship for the electromotive force, therefore a transformer which steps the voltage up will step the current down in the same ratio and vice versa.

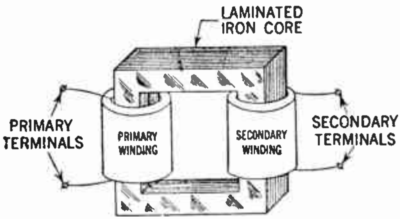
Consequently the products of primary volts and amperes is approximately equal to the products of the secondary volts and amperes for iron cored transformers, but these conditions do not hold true for *r.f.* transformers where the coupling co-efficient is considerably less than unity.

Types of Transformers.—The two transformer types usually found in radio work are:

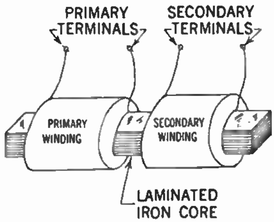
1. Core type
2. Shell type.

The core types shown in figs. 5 and 6 may have either a closed or open magnetic circuit, and are thus referred to as the *closed core type* and the *open core type.*

The open core type consists primarily of two windings, wound on a straight piece of laminated iron. This type of construction is very economical, but on account of very large leakage losses (its magnetic path being completed mainly through the surrounding air) it is used very sparingly in the radio field.



CLOSED CORE TYPE



OPEN CORE TYPE

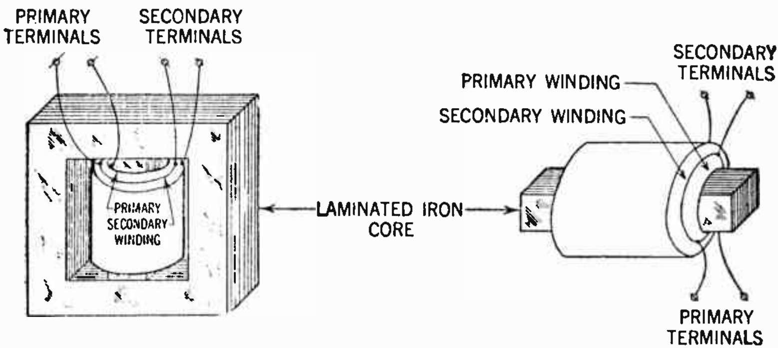
FIGS. 5 and 6—Closed and open core-type transformers respectively.

In the closed core type the windings are generally placed opposite each other as shown in fig. 5. the sides supporting the windings are referred to as the "core legs."

The coils generally consist of closely wound cotton insulated copper wire, dimensioned so as not to cause excessive heating, i.e. the wire should be of sufficient size to carry the load of the transformer without *over-heating.*

Insulation.—In transformers of higher voltage each layer of the winding is usually separated from the next by a thin insulating paper, in order that the effective voltage between each layer may not break down the insulation, causing a short circuit between the wires.

The best possible economy is secured when the winding encloses a maximum of core area with a minimum of wire, and when in addition the magnetic path is the shortest possible. A method widely adopted in small transformer design is the use of a single winding form, all secondaries and primary being placed on one leg of the core.



FIGS. 7 and 8—Shell and open core type transformers having the primary and the secondary winding placed directly on top of each other.

Shell Type Transformers.—Referring to fig. 7, this type has a completely closed core with a centre and two outside legs, forming two outside parallel paths for the magnetic lines of force.

On account of the above mentioned feature, this type has a very low magnetic leakage, and is hence most commonly used for power and audio transformers in the radio field.

As shown in fig. 7, the windings are placed directly over each other on the centre leg, thereby providing for an economical and compact design.

Transformer Losses.—All of the energy drawn from the power line by a transformer is not transformed. The various losses incurred in the transformation process are known as *hysteresis loss*, *eddy current loss*, *iron loss*, *copper loss*, *magnetic leakage loss*, etc.

The hysteresis loss is energy spent in overcoming the friction between the molecules of iron as they move backward and forward with the change of direction of flux; this is theoretical as some believe it is the natural resistance of the metal to the flow of flux and that the molecules of iron do not move backward or forward.

The eddy current loss is the energy spent in the heating action of the induced currents in the iron core by the varying flux. Voltages are induced in the core by the alternating flux and these voltages produce eddy currents.

Iron losses are practically constant with or without load and are manifested by heating. The energy loss in overcoming the ohmic resistance of both coils of the transformer when current flows through them (I^2R) is known as the copper losses.

Copper losses vary directly with the square of the current due to the load of the transformer. The total copper loss in the transformer is ($I_1^2 \times R_1$) of the primary, plus ($I_2^2 \times R_2$) of the secondary.

Magnetic leakage is another loss. When the magnetic line of force flows through the core some of them do not interlink both coils, thus causing an inductive resistance or counter electromotive force in the primary coil, which is not transmitted to the secondary coil and therefore causes a loss of voltage analogous to the ohmic resistance loss of the primary winding.

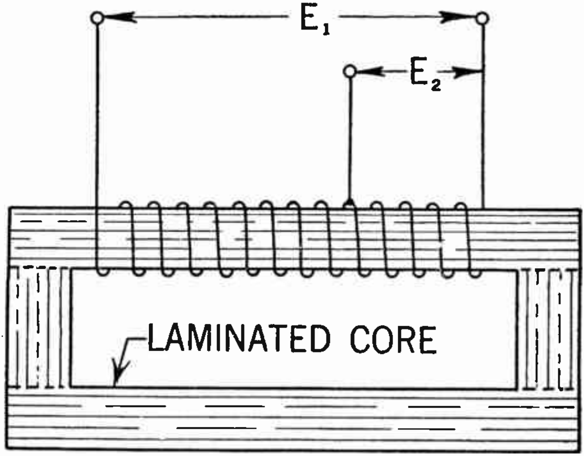


FIG. 9—Typical schematical representation of an auto-transformer in which E_1 is the primary and E_2 the secondary voltage.

Transformer Efficiency.—On account of the relatively small power involved in radio transformation, there is no urgent need for high efficiency. Generally an 80% efficient transformer which takes 75 watts to supply 60 watts is satisfactory.

The efficiency of a transformer may be written in the form of an equation as follows:

$$\text{Efficiency} = \frac{\text{output of secondary}}{\text{output of secondary} + \text{transformer losses}}$$

when the iron loss is small the transformer has a high efficiency on light loads. When the iron loss is equal to the copper loss the transformer has a high efficiency on full load or overload.

The efficiency of a transformer may also be written:

$$\frac{\text{output in watts of secondary}}{\text{input in watts of primary}}$$

Auto-transformers.—The auto-transformer is commonly used in audio frequency amplifier couplings, and in connection with battery chargers, bell ringing transformers, etc.

Principally the auto-transformer consists of one coil tapped at certain points, dividing it into parts, any part of which can be used as primary or secondary. The ratio depends upon the number of turns in each part.

On account of its simplicity this form of transformer is economical to build, but is hazardous on high voltage and should be used only for small ratios of transformation. The transformation at low ratios is accomplished partly by transformer action; however, at higher transformation ratios more and more of the power is transformed by regular transformer action and less by direct conduction.

Wire Size.—After the current in each winding has been obtained the wire size is determined by the number of circular mils per ampere. Generally it is considered safe to use 1,000 circular mils per ampere for transformers of less than 50 watts, and 1,500 circular mils per ampere for larger transformers.

The design, repair and service of radio and electrical apparatus will be greatly facilitated by utilizing the copper wire table shown on the following page. The reader is, therefore, advised to familiarize himself with this time saving wire table, as it is an easy matter by means of it to find the relation between a certain wire gauge and its diameter in mils, area in circular mils, the number of turns per linear inch, resistance in ohms per 1,000 feet of length, etc.

COPPER WIRE TABLE

Gauge No. B. & S.	Diam. in Mils[1]	Circular Mil Area	Turns per Linear Inch[2]				Turns per Square Inch[2]			Feet per Lb.		Ohms per 1000 ft. 25° C.	Current Carrying Capacity at 1500 C.M. per Amp.[3]	Diam. in mm.	Nearest British S.W.G. No.
			Enamel	S.C.C.	D.S.C. or S.C.C	D.C.C.	S.C.C.	Enamel S.C.C.	D.C.C.	Bare	D.C.C.				
1	289.3	82690	—	—	—	—	—	—	—	3.947	—	.1264	55.7	7.348	1
2	257.6	66370	—	—	—	—	—	—	—	4.977	—	.1593	44.1	6.544	3
3	229.4	52640	—	—	—	—	—	—	—	6.276	—	.2009	35.0	5.827	4
4	204.3	41740	—	—	—	—	—	—	—	7.914	—	.2533	27.7	5.189	5
5	181.9	33100	—	—	—	—	—	—	—	9.980	—	.3195	22.0	4.621	7
6	162.0	26250	—	—	—	—	—	—	—	12.58	—	.4028	17.5	4.115	8
7	144.3	20820	—	—	—	—	—	—	—	15.87	—	.5080	13.8	3.665	9
8	128.5	16510	7.6	—	7.4	7.1	—	—	—	20.01	19.6	.6405	11.0	3.264	10
9	114.4	13090	8.6	—	8.2	7.8	—	—	—	25.23	24.6	.8077	8.7	2.906	11
10	101.9	10380	9.6	—	9.3	8.9	87.5	84.8	80.0	31.82	30.9	1.018	6.9	2.588	12
11	90.74	8234	10.7	—	10.3	9.8	110	105	97.5	40.12	38.8	1.284	5.5	2.305	13
12	80.81	6530	12.0	—	11.5	10.9	136	131	121	50.59	48.9	1.619	4.4	2.053	14
13	71.96	5178	13.5	—	12.8	12.0	170	162	150	63.80	61.5	2.042	3.5	1.828	15
14	64.08	4107	15.0	—	14.2	13.8	211	198	183	80.44	77.3	2.575	2.7	1.628	16
15	57.07	3257	16.8	—	15.8	14.7	262	250	223	101.4	97.3	3.247	2.2	1.450	17
16	50.82	2583	18.9	18.9	17.9	16.4	321	306	271	127.9	119	4.094	1.7	1.291	18
17	45.26	2048	21.2	21.2	19.9	18.1	397	372	329	161.3	150	5.163	1.3	1.150	18
18	40.30	1624	23.6	23.6	22.0	19.8	493	454	399	203.4	188	6.510	1.1	1.024	19
19	35.89	1288	26.4	26.4	24.4	21.8	592	553	479	256.5	237	8.210	.86	.9116	20
20	31.96	1022	29.4	29.4	27.0	23.8	775	725	625	323.4	298	10.35	.68	.8118	21
21	28.46	810.1	33.1	32.7	29.8	26.0	940	895	754	407.8	370	13.05	.54	.7230	22
22	25.35	642.4	37.0	36.5	34.1	30.0	1150	1070	910	514.2	461	16.46	.43	.6438	23
23	22.57	509.5	41.3	40.6	37.6	31.6	1400	1300	1080	648.4	584	20.76	.34	.5733	24
24	20.10	404.0	46.3	35.3	41.5	35.6	1700	1570	1260	817.7	745	26.17	.27	.5106	25
25	17.90	320.4	51.7	50.4	45.6	38.6	2060	1910	1510	1031	903	33.00	.21	.4547	26
26	15.94	254.1	58.0	55.6	50.2	41.8	2500	2300	1750	1300	1118	41.62	.17	.4049	27
27	14.20	201.5	64.9	61.5	55.0	45.0	3030	2780	2020	1639	1422	52.48	.13	.3606	29
28	12.64	159.8	72.7	68.6	60.2	48.5	3670	3350	2310	2067	1759	66.17	.11	.3211	30
29	11.26	126.7	81.6	74.8	65.4	51.8	4300	3900	2700	2607	2207	83.44	.084	.2859	31
30	10.03	100.5	90.5	83.3	71.5	55.5	5040	4660	3020	3287	2534	105.2	.067	.2546	33
31	8.928	79.70	101.	92.0	77.5	59.2	5920	5280	—	4145	2768	132.7	.053	.2268	34
32	7.950	63.21	113.	101.	83.6	62.6	7060	6250	—	5227	3137	167.3	.042	.2019	36
33	7.080	50.13	127.	110.	90.3	66.3	8120	7360	—	6591	4697	211.0	.033	.1798	37
34	6.305	39.75	143.	120.	97.0	70.0	9600	8310	—	8310	6168	266.0	.026	.1601	38
35	5.615	31.52	158.	132.	104.	73.5	10900	8700	—	10480	6737	336.0	.021	.1426	38–39
36	5.000	25.00	175.	143.	111.	77.0	12200	10700	—	13210	7877	423.0	.017	.1270	39–40
37	4.453	19.83	198.	154.	118.	80.3	—	—	—	16660	9309	533.4	.013	.1131	41
38	3.965	15.72	224.	166.	126.	83.6	—	—	—	21010	10666	672.6	.010	.1007	42
39	3.531	12.47	248.	181.	133.	86.6	—	—	—	26500	11907	848.1	.008	.0897	43
40	3.145	9.88	282.	194.	140.	89.7	—	—	—	33410	14222	1069	.006	.0799	44

[1] A mil is 1/1000 (one thousandth) of an inch.
[2] The figures given are approximate only, since the thickness of the insulation varies with different manufacturers.
[3] The current-carrying capacity at 1000 C.M. per ampere is equal to the circular-mil area (Column 3) divided by 1000.

CHAPTER 10

Metallic Rectifiers

A metallic rectifier also termed *disk type rectifier* is a device which presents a high resistance to the flow of current through it in one direction, and a comparatively low resistance to the flow of current through it in the opposite direction. Thus, if an alternating voltage be applied to the terminals of a single rectifier, electric current will flow easily in one direction, but practically not at all in the other direction, so that the current flow is a pulsating *d.c.* current as noted in fig. 2, since it flows for half a cycle only, during each cycle of the applied *a.c.* voltage.

The unilateral conductivity possessed by the junction of various combinations of different solids, usually in the form of disks or plates, is the basis of metallic rectifiers.

Depending upon the solids involved, rectifiers of the foregoing type may be divided into three classes. They are:

1. Selenium
2. Copper-oxide, and
3. Magnesium.

The type of rectifier to use for a certain application depends a great deal upon such factors as, first cost of the rectifying

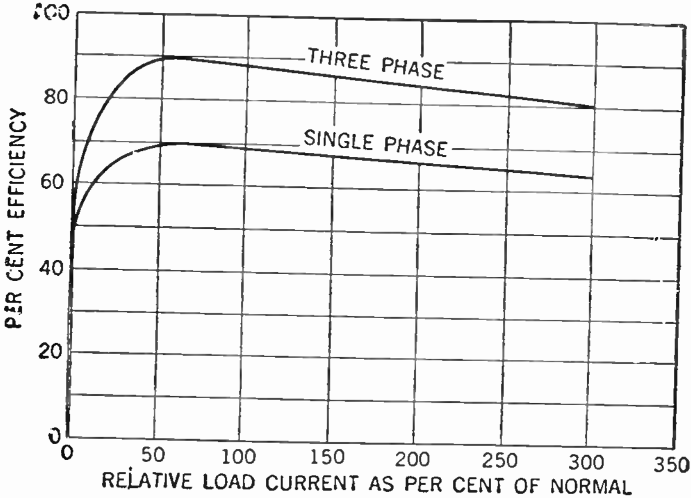


FIG. 1—Illustrating efficiency characteristics for various loads of single and three phase selenium rectifier circuits. It will be noted that nonlinear characteristics of selenium rectifiers contribute to high efficiencies even at large overload factors.

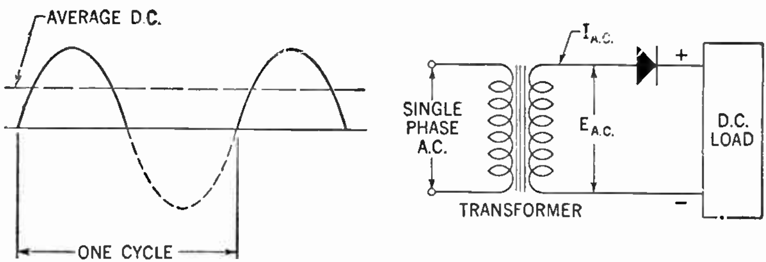


FIG. 2—Showing method of connection of simple half-wave rectifier in a single phase alternating current circuit. As noted in the diagram, the rectifier allows current to flow in one direction only, thus supplying a pulsating direct current to the load.

device, efficiency of operation, useful life, *d.c.* power requirements, ripple factors, etc.

Since metallic rectifiers usually require transformation of *a.c.* voltages, this additional cost with accompanying power losses in the transformer or transformers, also must be considered.

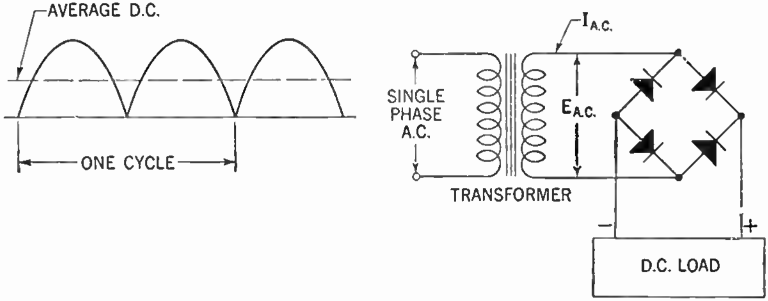


FIG. 3—Illustrating rectifier connections in a bridge circuit to obtain full-wave current rectification.

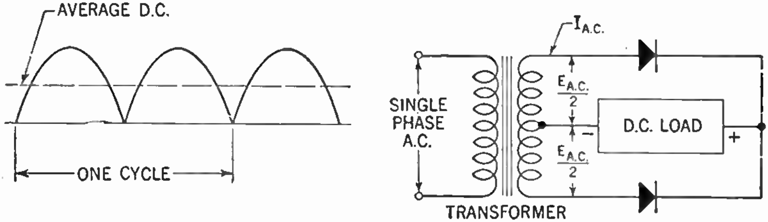


FIG. 4—Method of rectifier connections in a center tap single phase circuit. As shown in the diagram a circuit of this type in common with the bridge circuit provides full-wave rectification of the alternating current.

In low power rectifier circuits, such as in battery charging and similar applications, it is not necessary to have a steady output current and in many cases a simple half-wave rectification circuit is satisfactory.

Where full-wave current rectification is desired a bridge or transformer tap circuit such as illustrated in figs. 3 and 4, has found numerous applications.

In the selenium type of rectifier, the basic materials are: selenium, aluminum and a low melting point alloy. In the manufacturing process, aluminum base plates are prepared by chemical etching and are electroplated with a thin layer of nickel.

The undercut etch serves as a mechanical means of bonding the selenium layer to the base plate during the subsequent pressing operation. The nickel plating governs crystal growth and orientation in the selenium layer.

High purity selenium is then sprinkled over the nickel plated base plate in fine powder form and is then subjected to high temperature and pressure in hydraulic presses with electrically heated platens.

After the powder press operation, selenium rectifier cells are placed in ovens for heat treatment which completes the crystallization process. Here the selenium is completely converted to a metallic form and the crystals are arranged to cause rectification.

During the foregoing heating process the temperature is exceedingly critical, since a one per cent deviation could cause poor crystallization and consequently a poor rectifier cell. This heat treatment also forms a very thin "barrier layer" on the selenium and it is believed that current rectification is accomplished in this layer.

Selenium rectifiers are used alternately with copper oxide rectifiers for alternating current rectification. Typical applications include radio and television receivers, business machines, communications equipment, battery chargers, electroplating equipment, etc.

Since selenium rectifiers are thermally as well as electrically rated devices, it is important the rectifier stack be located away from all heating sources such as resistors, tubes, transformers, ballasts or any other heat radiating element.

In larger installations, forced air cooling is quite often used as a means of dissipating heat. Thus, for example, a rectifier that is rated at 10 amperes with normal convection cooling can be operated at 25 amperes if sufficient cool air is passed between the cells. Also, to decrease the effects of very high ambient temperatures, forced air is often used to allow higher percentages of normal rating. In all cases, however, manufacturers' recommendations should be adhered to.

The efficiency of conversion in selenium rectifiers is relatively high or in the order 90% in three phase, full-wave circuits and 70% in single phase, full-wave circuits. The nonlinear characteristics of selenium rectifiers, fig. 1, contribute to high efficiency even at large overload factors.

By the very nature of its construction (two metals separated by a semi-conductor) selenium rectifiers have a considerable amount of inherent capacity. This capacity, 0.1 to 0.15 microfarad per square inch of rectifying area, limits the frequency at which rectifiers can be used. The practical limit varies between 1,000 and 15,000 cycles, depending upon cell size and electrical requirements.

In general, in applications that require small values of direct current, the maximum practical frequency is 15,000, and 1,000 where relatively large direct current loads are involved.

Operation of selenium rectifiers at frequencies above the practical limit, results in sharp reduction of the rectification ratio and efficiency, due to increased reverse current.

Selenium rectifiers can be overloaded with respect to their current output under momentary or cyclic condition without serious damage. A prolonged overload, however, such as that occasioned by a short circuit, will damage or destroy the rectifier. Thus, it is important that proper circuit protection in the form of fuses or other devices be used, and that proper precaution be observed to locate and correct the trouble before power is applied to the rectifier.

Over-voltage conditions are more serious than current overloads. A potential in excess of rectifier rating may cause a breakdown across the selenium layer and while a selenium rectifier is "self-healing" to a certain extent, prolonged over-voltage conditions will cause rectifier failure. If an over-voltage condition occurs and the breakdown across the rectifier be sustained, the odor of selenium fumes can be detected and power should be turned off immediately to minimize the damage.

In the copper-oxide type the rectifying layer is permanently established in a solid piece of material consisting of copper with cupreous oxide formed thereon by partial oxidation of the copper at high temperature.

Pressure or electric forming is not necessary although pressure is often used in the assemblies as a convenient method of making low resistance contact to the unit. Various methods are used for making contact to the free surface of the oxide without pressure, such as spraying it with metal, Aquadag, etc.

Copper oxide rectifiers may be used in either half-wave, full-wave or bridge circuits figs. 2 to 4, with junctions in series or multiple as required. Thus, for example, a bridge circuit with four junctions 1½ inches in diameter will supply a rectified potential of 3 to 6 volts and an output current of from ⅛ to 3½ amperes, depending upon the exposed radiating surface of the disks, the means taken to cool the units, and other factors.

In overloading the rectifier its life will be considerably shortened because of high temperature. By keeping the temperature below 60°C, a life of many years may be obtained.

An efficiency of 60 to 70% is an average figure, under normal operating conditions, although under certain limited conditions, efficiencies as high as 80% may be obtained. Frequencies of very high value can be rectified, although a considerable capacitance effect will be encountered at the higher frequencies.

Magnesium type rectifiers are made up of layers of magnesium, cupric sulfide and copper. The general operating characteristic is similar to other types of disk rectifiers, although magnesium rectifiers have somewhat shorter life at normal operating temperatures than have the copper-oxide and selenium type.

On the other hand it is claimed that magnesium rectifiers can operate satisfactorily at temperatures as low as –40°C with practically no change in their operating characteristics.

The efficiency of a three phase, full-wave magnesium rectifier is in the neighborhood of 50 to 55%, while that of single phase, full-wave rectifier is 35 to 40% depending upon whether the load is resistive, inductive or capacitive.

Magnesium type rectifiers are employed to some extent in industrial applications such as in battery charging, electroplating and the like.

Rectifier Circuits

Rectifiers may be connected in various ways depending upon the direct current power requirement for a certain application. When rectifiers are connected in single and three phase circuits, they are termed:

1. Half-wave
2. Bridge
3. Center tap.

Single Phase Circuits.—*Half-wave rectification* is generally used in applications that require small amounts of power. Most popular applications have been in radio and television receivers to deliver B+ power. The ripple frequency is the same as the supply frequency and the ripple component is large since the rectifier conducts only during one-half of the input cycle as noted in fig. 2.

Equipment using this form of rectification usually requires a special transformer design because of the unidirectional flow of *d. c.* current through the secondary.

The single phase bridge rectifier, fig. 3, is popular because it offers flexibility of design, full-wave rectification, a ripple frequency that is twice the source frequency in addition to high efficiency and utilization of an economical transformer design. Its field of application covers every phase of electronic and electrical design.

The center tap single phase rectifier which connection is shown in fig. 4, in common with the single phase bridge type, has a high ripple frequency and efficiency. The transformer design, however, is more complicated. The full-wave center tap circuit is commonly used in low-voltage applications (less than 10 volts *d. c.*) such as laboratory, electro-plating, battery charging equipment and the like.

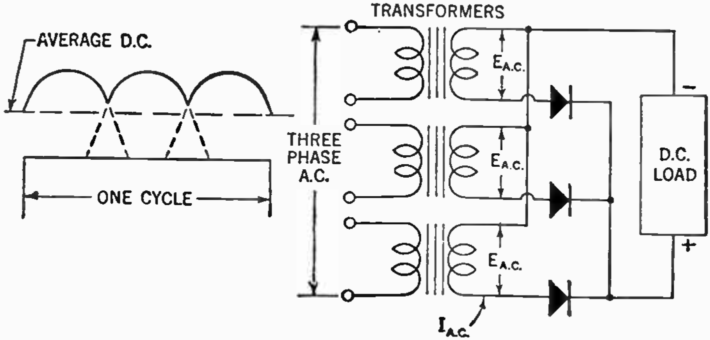


FIG. 5—Illustrating connection methods of three phase, half-wave rectifier. A circuit of this type is used in applications requiring very large current at a low voltage.

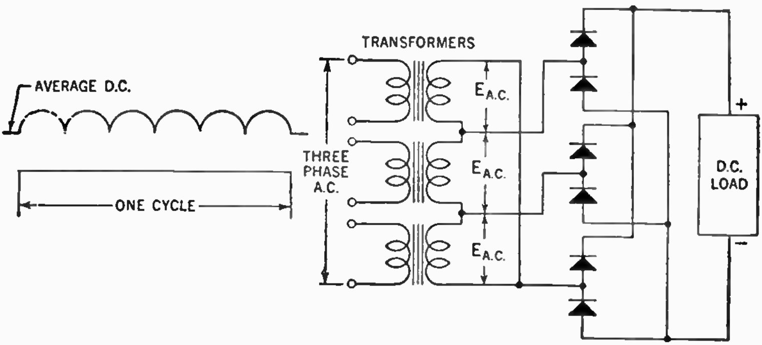


FIG. 6—Method of connections in a three phase bridge rectifier system. This circuit provides good economy where the direct current power requirements are large because of its high efficiency.

Three Phase Circuits.—The three phase, *half-wave rectifier* connections, fig. 5, are used primarily in low voltage high current applications. The output ripple frequency is three times the source frequency and the load ripple component is approximately 20 per cent. The three phase, half-wave rectifier is commonly used in commercial electroplating applications that require thousand of amperes of current.

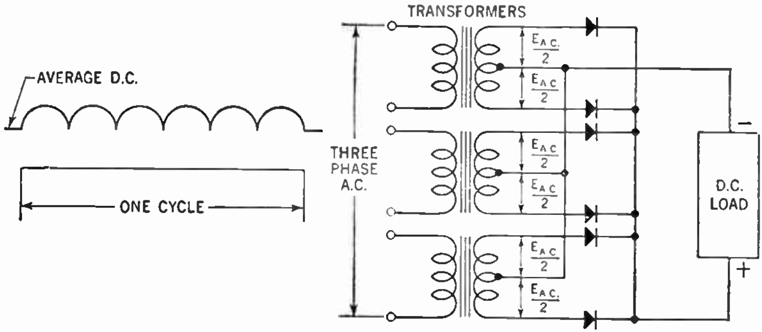


FIG. 7—Center tap three-phase rectifier circuit. Circuits of this type are employed in applications where direct current requirements are high and voltages are low.

The three phase bridge rectifier connections, fig. 6, supply the most economical and useful circuit where *d. c.* power requirements are high and efficiency is an important factor. Here the ripple frequency is six times the source frequency and the load ripple component is only 4.5%. In most applications filtering is not required. Popular applications include aircraft motor starters, electrolysis equipment, large power supplies, and arc welding equipment.

The three phase center tap circuit is used where the *d. c.* voltage requirements do not exceed 15 volts and load current requirements are high. Special transformer design is required to provide a six-phase secondary. This connection method, fig. 7, is used to some extent in electroplating equipment.

CHAPTER 11

Vacuum Tubes

Vacuum Tubes.—A vacuum radio tube in its simplest form is somewhat similar to an electric light bulb, but contains a number of metallic elements for various purposes for use in conjunction with radio transmission and reception. The parts of a typical vacuum tube is shown below.

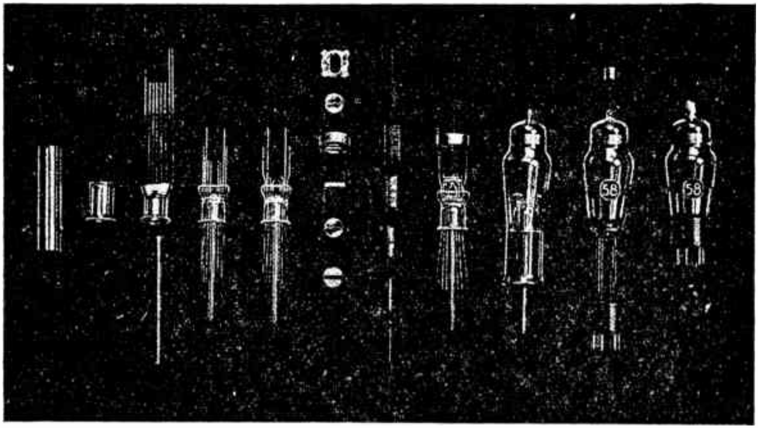


FIG. 1.—Parts and assembly of a typical glass radio tube. The filament, grid screen and plate are sealed in the tube, from which the air has been removed. (Courtesy R.C.A. Mfg. Co.)

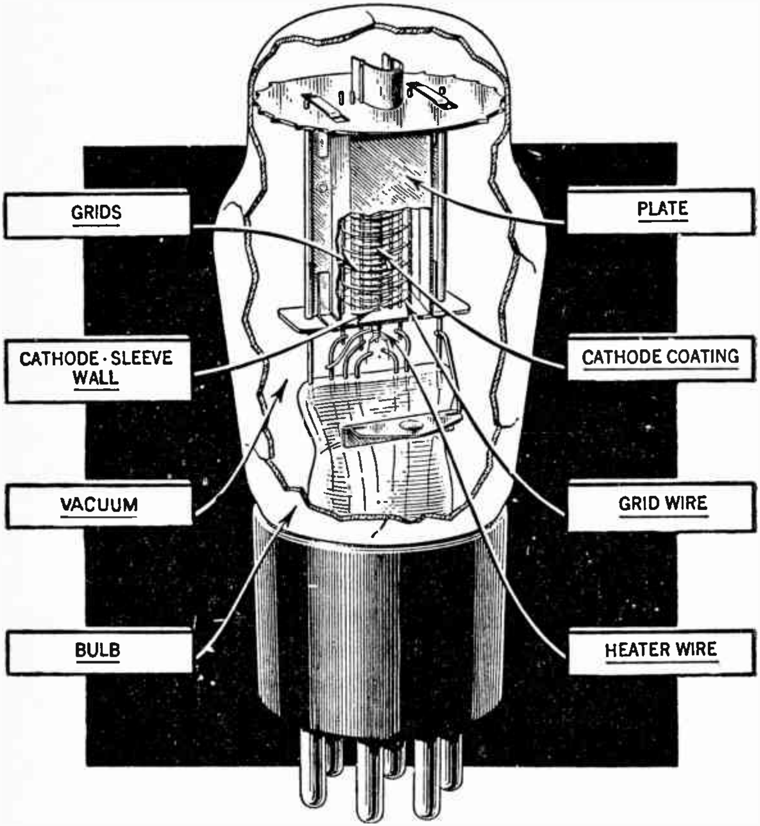


FIG. 2.—Internal structure of a glass radio tube. There is at present a great number of tubes utilized for various requirements. In radio applications they are used for amplifying radio waves; for converting radio waves to sound waves; for converting alternating current to direct current, etc. (Courtesy R.C.A. Mfg. Co.)

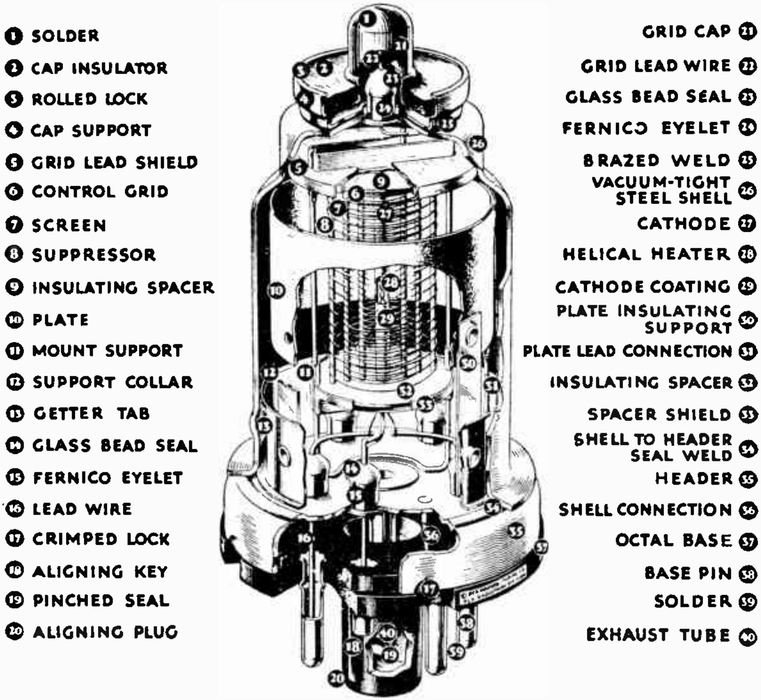


Fig. 3.—Inside view of a metal radio tube. The inside parts are similar to those of a glass radio tube. The housing of the parts consists of metal, which has certain advantages to that of the glass in required electrical shielding. These types of tubes generally are smaller and have a central guide pin projecting from the base for easy insertion in the sockets, and are therefore not as a rule interchangeable with glass tubes. (Courtesy R.C.A. Mfg. Co.)

Purpose of Vacuum Tubes.—The general purpose of a vacuum tube is to detect and amplify radio waves; for changing alternating current into direct current; for producing oscillations or rapid electrical pulsations; for changing an electric current of one degree of pulsation to those of another, and for innumerable other purposes.

Materials Used in Vacuum Tubes.—The materials used for housing the elements of a vacuum tube may be glass or metal—sometimes a combination of the two. The essential difference between metal and glass tubes is that the metal tubes as a rule are smaller, and have a central guide pin for insertion in the sockets and hence they are not readily interchangeable with one another.

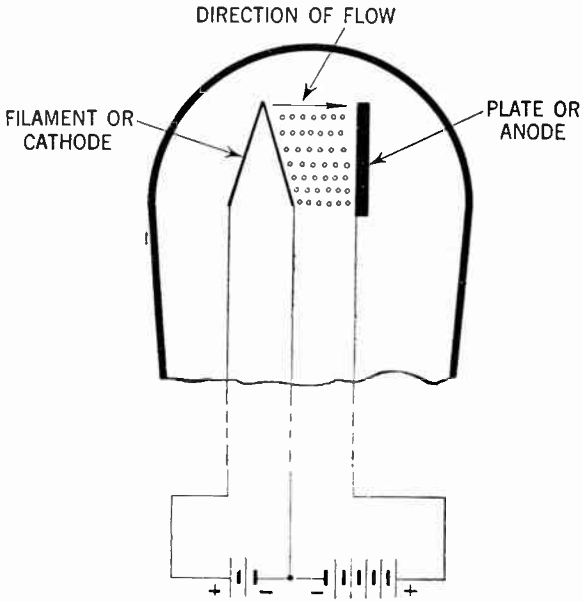


Fig. 4.—Illustrating the flow of electrons in a vacuum tube.

Principles of Operation of Vacuum Tubes.—In any electronic tube, thinny electrical charges called electrons jump from a heated metallic surface, in a vacuum, to another metallic surface and cause current to flow between the two when connected together as shown in fig. 4. This current flow is always *one-directional* in that it will flow in *one direction only*—never in the reverse.

To produce such a flow of electrons, which constitutes an electric current the following fundamental requirements must be obtained:

1. There must be a continuous source of supply for the *cathode* which produces the current flow.

2. It must be maintained at the high temperature necessary for the dissipation of electrons from it.

3. To produce this continuous flow of electrons a force must be supplied to transfer them through space.

Now, as the electrons consist of infinitely small negative charges of electricity, it is evident that they are attracted to a positively charged body and repulsed by a similarly or negatively charged substance. (See page 27.)

Hence if a second *element* (anode) be added within the vacuum enclosure and in addition be maintained at a positive potential with respect to the cathode, it will in accordance with the above reasoning, attract the negatively charged electrons to it and at a rate which is dependent upon the rate at which they are supplied by the cathode.

In its simplest form therefore a vacuum tube consists of two electrodes—a *cathode* and an *anode* (sometimes referred to as filament and plate), the former emitting or discharging the electrons and the latter acting as a collector of electrons. When this condition exists the vacuum tube is called a *diode* or *two-electrode* vacuum tube.

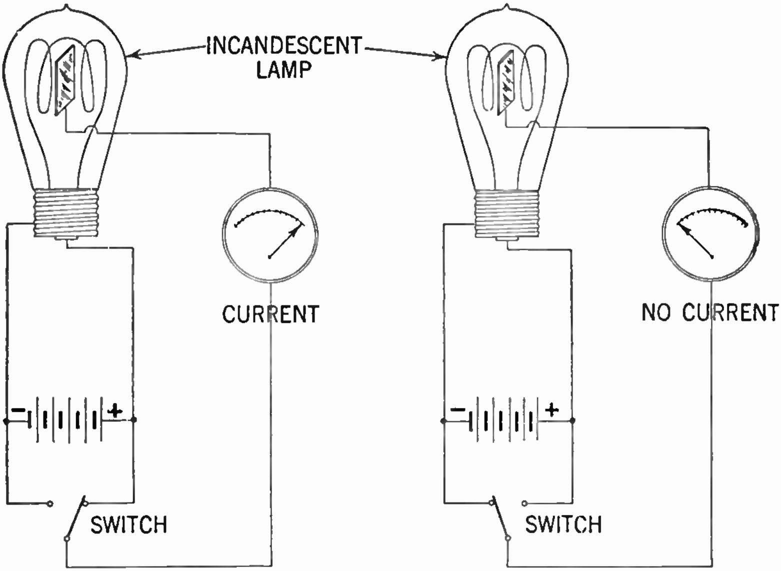


Fig. 5.—Shows how a current will be registered by the galvanometer when the switch is connected to make the insulated plate positive. The current flow, however, will cease when the plate is made negative—the switch connects the insulated plate with the negative terminal of the filament.

Electron Emission.—The phenomenon that electrons can be made to leave a conductor when properly stimulated to do so as in the case of a radio vacuum tube, is called *thermonic electron emission*, sometimes called only electron emission.

The electron emission also known as the *Edison effect* was found by the famous inventor in his early experiments with the incandescent lamp sometime before 1890.

Edison observed that when a metal plate was sealed inside a lamp bulb so that it was between and separated the two sides of the carbon filament, but was entirely insulated electrically from the filament, that an electric current flowed through a galvanometer when connected between the *outside* terminal of the metal plate and the *positive* terminal of the filament.

When on the other hand, the connection was reversed, and the galvanometer connected between the negative terminal of the filament and the outside terminal of the plate, the current flow stopped.

Although this phenomena was known at this early date, its availability could not be utilized, due to the absence of the *vacuum tube*. It was only after discovery of the vacuum tube by Prof. J. A. Fleming and Dr. De Forest that this perhaps greatest invention in the twentieth century could be made serviceable.

The flow of current can be amplified by small voltage changes, the control of all changes is very marked and instantaneous in action—there being no lagging, also the electricity utilized or generated can be almost limitless in their number of pulsations.

This current flow or movement of electrons may be accelerated by increasing the temperature of the conductor. Once free, most of the emitted electrons, in a vacuum tube make their way to the plate, but others return to the cathode, repelled by the cloud of negative electrons immediately surrounding the cathode. This cloud of electrons surrounding the emitting cathode is known as the *space charge*.

A few of the electrons that reach the plate may have sufficient velocity to dislodge one or more electrons already on the plate. The dislodging of those electrons from the plate by other fast moving electrons are called *secondary emission*.

When this occurs there is actually a simultaneous electron flow in two directions.

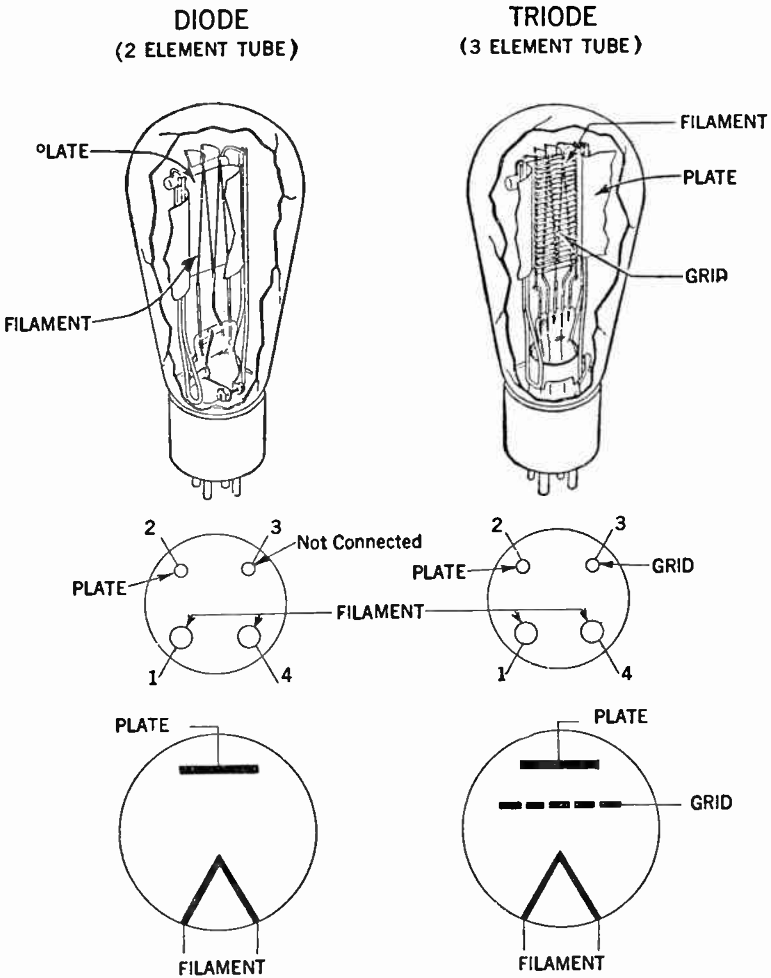


FIG. 6.—Views of two and three element vacuum tubes showing arrangement of prongs and wiring symbols.

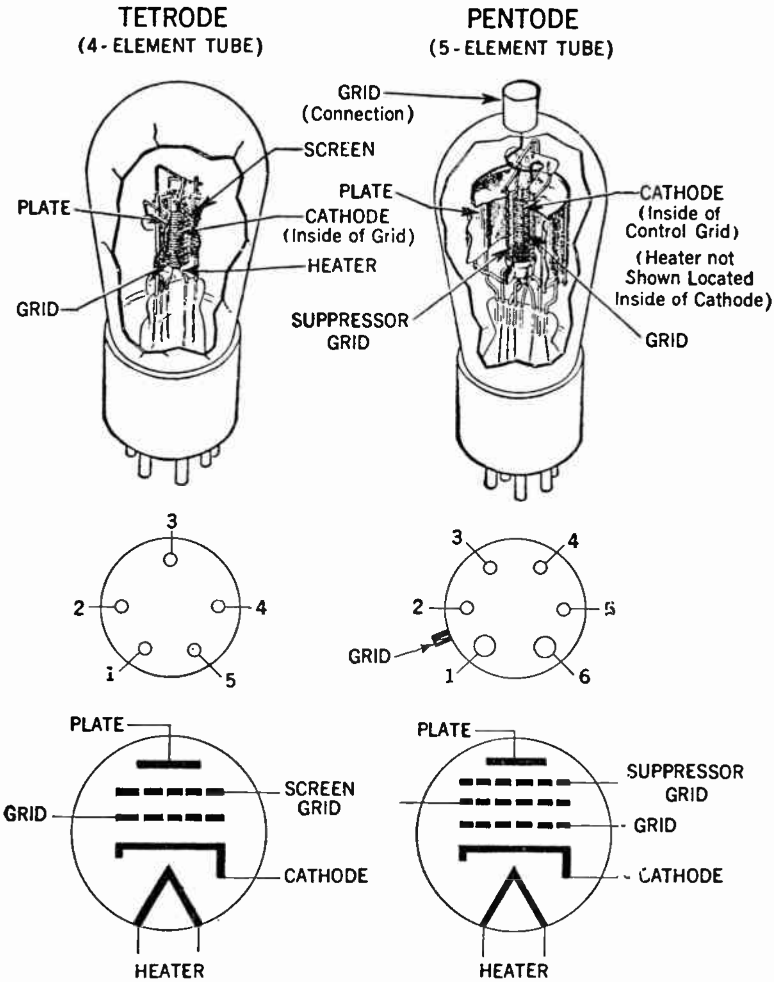


FIG. 7.—Views of four and five element vacuum tubes, showing arrangement of prongs and wiring symbols.

Vacuum Tube Fundamentals.—By definition a vacuum tube consists of a cathode, which supplies electrons and one or more additional electrodes whose function it is to control and collect these electrons, mounted in an evacuated envelope. This envelope may consist of a glass bulb or it may be the more compact and efficient metal shell.

The outstanding properties of the vacuum tube lie in its ability to control almost instantly the motion of millions of electrons supplied by the cathode. On account of its almost instantaneous action the vacuum tube can operate very efficiently and accurately at electrical frequencies far above those obtainable with rotating machinery.

As previously stated the electronic movement may be accelerated by the supply of additional energy in form of heat. When the temperature of a metal becomes hot enough to glow, the agitation of the electrons becomes sufficiently great to enable a certain amount of them to break away from the metal, it is this action which is utilized in the radio tube to produce the necessary electron supply.

The Function of the Cathode.—A cathode is that part of a vacuum tube which supplied electrons which are essential for its operation. All cathodes in vacuum tubes are universally heated by electricity. The method of heating the cathode may be used to distinguish between the different forms.

The simplest form of a cathode is in the form of a wire or ribbon, heated directly by the passage of current through it as in (b) and (c) fig. 8. Radio tubes having such filaments for cathodes are sometimes referred to as *filamentary tubes* to distinguish them from tubes having indirectly heated cathodes.

A common arrangement of an indirectly heated cathode is shown in fig. 8 (a). Here the cathode consists of a metallic cylindrical sleeve, usually of nickel, coated with a mixture of barium and strontium oxides. This oxide coating is used on

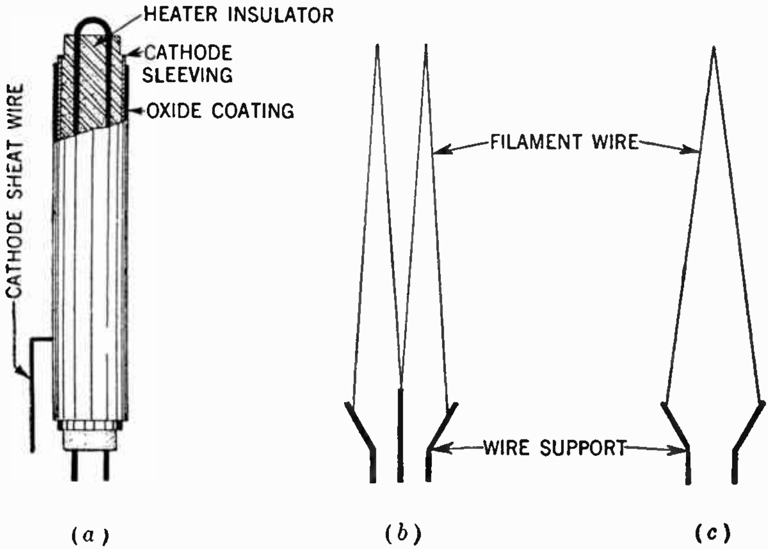


FIG. 8.—Schematic diagram of directly and indirectly heated cathodes.

account of their property to greatly increase the electron emission at a given temperature.

A lead wire from the cathode sheath is carried out to an external tube terminal in order that the cathode may be maintained at any desired potential.

The heater wire consists usually of tungsten and may be in the form of a spiral or as in the illustration, in the form of a hairpin threaded through parallel tubular holes in a ceramic insulator. Tubes having cathodes of this type are referred to as **heater type tubes.**

The heaters may be operated on either direct or alternating current. The one disadvantage of using alternating current

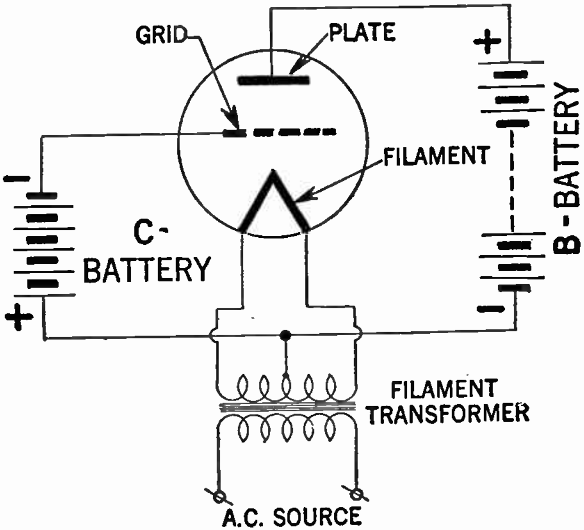


FIG. 9.—Diagram of connection to a triode employing a filament transformer.

for the filament of tubes used in audio-frequency circuits, is that it introduces objectionable hum in the output.

This hum may be lessened by connecting the plate and the grid circuits to the midpoint of the secondary of the transformer, as shown in fig. 9. Generally, however, it is not possible to use alternating current in the filament of tubes used in the early stages of high-gain amplifiers.

Classification of Tubes.—Tubes are usually classified according to the number of electrodes present, so for example a two-element tube is called a *diode;* a three-element tube a *triode*, and so on to tetrodes and pentodes. A pentode therefore is a tube having five elements. See pages 228 and 229.

Tubes may also be classified according to whether there be high vacuum, gas or an element which vaporizes in the bulb.

Diodes.—From the foregoing it is evident that electrons are of no value in a tube unless they can be controlled or made to work according to a pre-determined schedule. The very simplest form of tube consists of two electrodes—a cathode and a plate, and is most often referred to as a *diode*, which is the family name for two-electrode tubes.

In common with all tubes, the electrodes are enclosed in an evacuated envelope with the necessary connection projecting out through airtight seals. The air is removed from the envelope to allow free movement of the electrons and to prevent injury to the emitting surface of the cathode. If the cathode be heated, electrons leave the cathode surface and form an invisible cloud in the space around it. Any positive electric potential within the evacuated envelope will offer a strong attraction to the electrons.

In a diode, the positive potential is applied to the second electrode, known as the anode, or plate. The potential is supplied by a suitable electrical source connected between the plate terminal and a cathode terminal. See fig. 10. Under the influence of the positive plate potential, electrons flow from the cathode to the plate and return through the external plate-battery circuit to the cathode, thus completing the circuit. This flow of electrons is known as the plate current and may be measured by a sensitive current indicator.

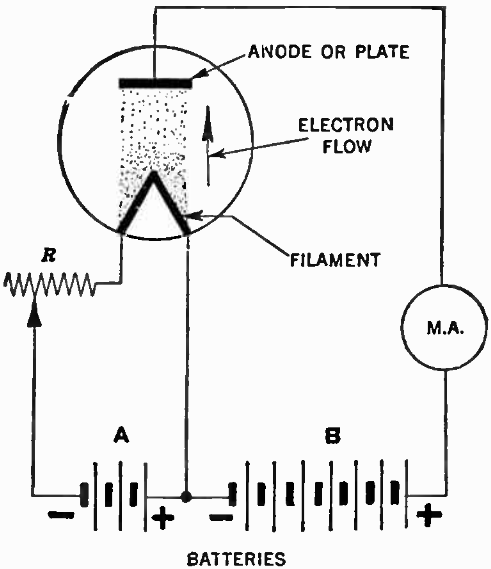


FIG. 10.—Connection diagram for a two electrode tube.

The Diode as a Rectifier.—It is obvious that under no conditions can the current flow from the plate to the cathode, i.e., the tube is as far as the direction of the current is concerned a one-way proposition. Increasing the positive potential will of course increase the flow of electrons from cathode to plate and consequently increase the current flow in the plate circuit, but if the plate is made negative instead of positive it will repel the electrons and no current will flow.

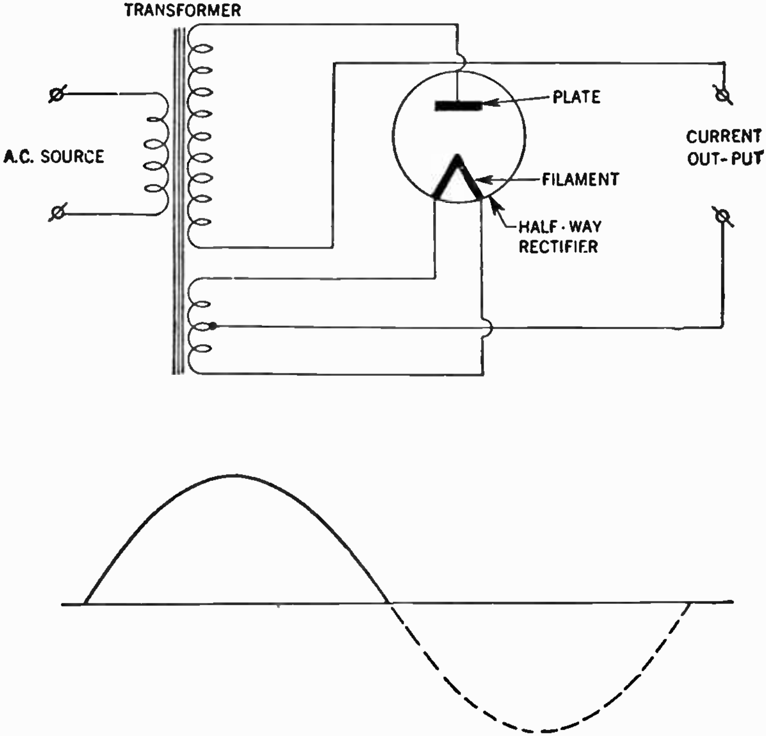


FIG. 11.—Connection diagram of the half-wave rectifier. The rectified current is depicted on the upper half of the wave diagram.

The diode therefore acts as an *electrical valve* that will permit current to flow in one direction, but not in the other. It is this characteristic of the diode that has been utilized as a means of converting or rectifying an alternating current into a direct current.

The diode is therefore commonly used as a signal rectifier or detector in a radio receiver, and as a power rectifier in the unit employed to change the *a.c. house current* into a direct current for the operation of home receivers or transmitters.

Diode rectifiers may have one plate and one cathode and are as such called *half-wave rectifiers*, (See fig. 11) since as stated the current can flow only during one-half of the alternating current cycle.

Full Wave Rectifier.—If two plates and one or more cathodes are used in the same tube, current may be obtained during both halves of the alternating current cycle as shown in fig. 12. The tube is then called a *full wave rectifier*. If as in the diagram shown the rectifier tube be connected to a power transformer, the primary of which is connected to a 110 volt a.c. source, then the disposition of the voltage developed in the secondary of the transformer winding will be such that the center tape will be at zero voltage with respect to terminals 1 and 2, and during the period terminal 1 is positive, terminal 2 will be negative.

Therefore plate P_1 will draw current while plate P_2 is idle and vice versa. In this manner both the positive and the negative half of the alternating current cycle are utilized and the resultant output current consists of a series of unidirectional pulses with no spacing between them as shown in the lower part of fig. 12. These unidirectional pulses may be further smothered by insertion of filters consisting of inductive and capacitive reactances interconnected to the output terminals of the rectifying system.

Space Charge Effect.—Not all of the electrons emitted by the cathode reach the plate. Some return to the cathode while

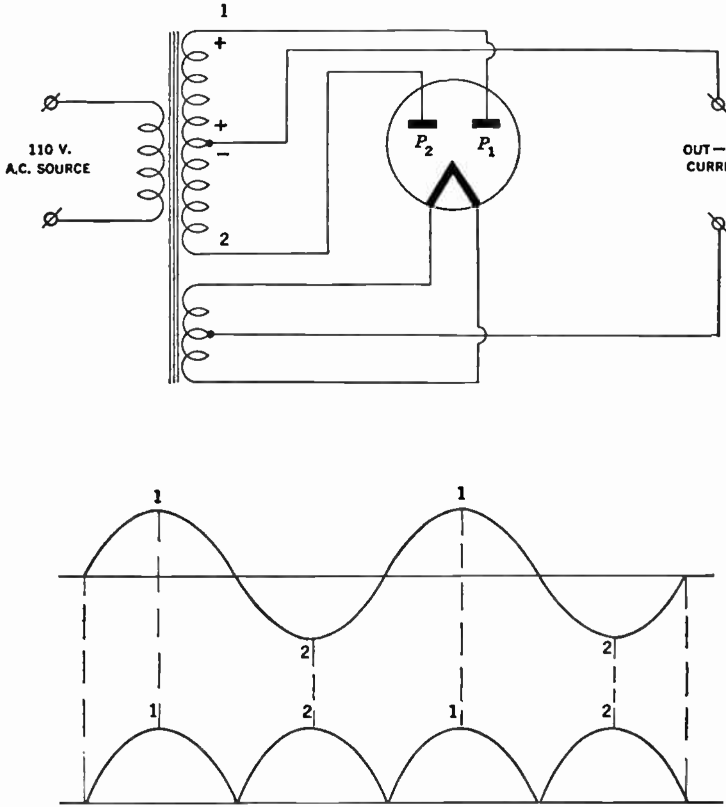


FIG. 12.—Connection diagram and depiction of the action of a full-wave rectifier tube.

others remain in the space between the cathode and plate for a brief period to form an effect known as *space-charge*. This charge has a repelling action on other electrons which leave the cathode surface and impedes their passage to the plate. The extent of this action and the amount of space-charge depend on the cathode temperature and the plate potential.

Plate voltage vs. Plate current relationship of a diode.—The higher the plate potential, the less is the tendency for electrons to remain in the space-charge region and repel others. This effect may be noted by applying increasingly higher plate voltages to a tube operating at a fixed heater or filament voltage. Under these conditions, the maximum number of available electrons is fixed, but increasingly higher plate voltages will as previously stated succeed in attracting a greater proportion of the free electrons.

Beyond a certain plate voltage, however, additional plate voltage has little effect in increasing the plate current. The reason is that all of the electrons emitted by the cathode are already being drawn to the plate. This maximum current is called *saturation current*, and because it is an indication of the total number of electrons emitted, it is also known as the *emission* current. See fig. 13.

Tubes are sometimes tested by measurement of their emission current. However, in this test it is generally not feasible to measure the full value of emission because this value would be sufficiently large to cause change in the tube's characteristics, or to damage the tube. For that reason, the test value of current in an emission test is less than the full emission current. However, this test value is larger than the maximum value which will be required from the cathode in the use of the tube.

The emission test, therefore, indicates whether the tube's cathode can supply a sufficiently large number of electrons for satisfactory operation of the tube.

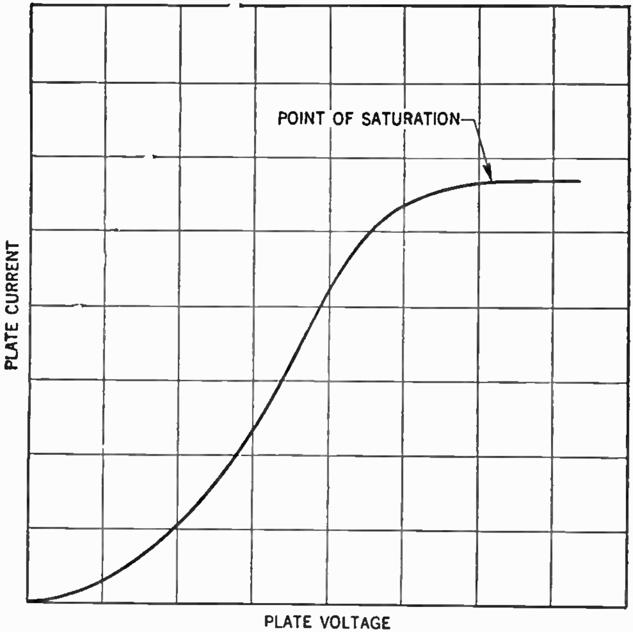


FIG. 13.—Characteristic curve of a diode.

Triodes.—The triode or three electrode tube is principally a two-electrode tube in which a third electrode, called the *grid*, is placed between the plate and the cathode. See fig. 14.

The grid consists usually of a mesh of fine wire extending the full length of the cathode. The spaces between the turns of the wire constituting the grid are comparatively large, so as not to impair the passage of the electrons from the cathode to the plate.

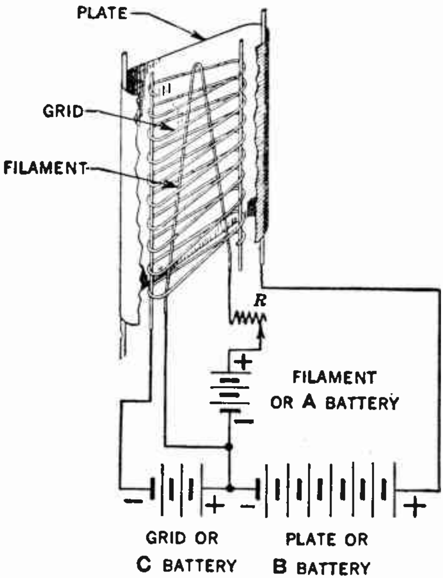


FIG. 14.—Schematic diagram showing triode connection to battery.

Grid Function.—The function of the grid is to control the plate current. By maintaining the grid at a negative potential, it will repel electrons and will in part, but not altogether, neutralize the positive or attractive force exerted upon them by the positive plate. Hence, a stream of electrons will flow from the grid to the plate, although smaller than it would be if the negative grid had not been present. Now if the grid is made less negative, it follows that its repelling effect will be reduced and consequently a larger current will flow through it to the plate.

Similarly if the grid be again made more negative its repelling force will increase and the current to the plate will correspondingly decrease. See fig. 15.

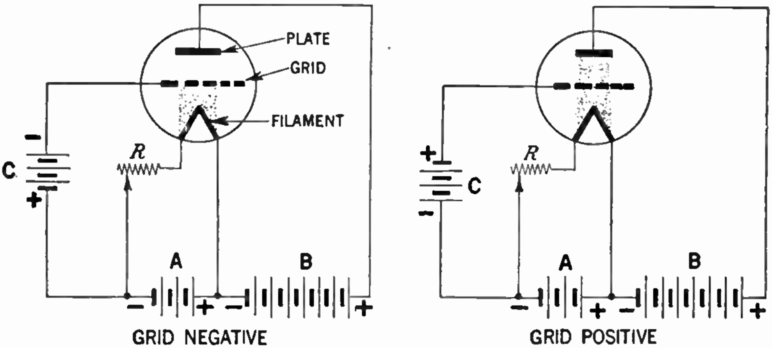


FIG. 15.—Illustrating the action of a grid in a triode vacuum tube.

From the above, it follows that when the potential of the grid be varied in accordance with some desired signal, the plate current will vary in a corresponding manner. Because the grid is assumed at all times to be at negative potential with respect to the cathode, it is evident that it can not collect electrons and so a small amount of energy will be sufficient to vary its potential in accordance with the input signal.

Capacitance Effect.—In a triode the grid plate and cathode form what is called an electro-static system, i.e., each electrode acts as a plate of a small condenser. The capacitances are those existing between grid and plate, plate and cathode, and grid and cathode. See fig. 16.

These capacitances are usually referred to as "Inter-electrode Capacitances." In this connection it may be mentioned that the capacitance between the grid and plate is of the utmost importance, because of the fact that in high-gain radio-frequency amplifier circuits, this capacitance may act to produce undesired coupling between the *input circuit*, the circuit between the grid and cathode, and the *output circuit*, the circuit between the plate and the cathode. The effect of this coupling may cause instability and unsatisfactory performance in the amplifier.

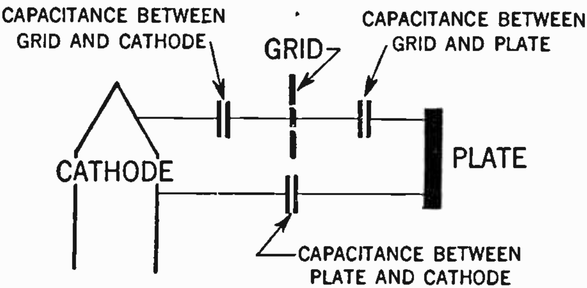


FIG. 16.—Diagram showing inter-electrode capacitances in a triode.

Tetrodes.—The undesirable capacitance between the grid and the plate in the triode can be decreased by inserting an additional electrode or *screen* between the grid and the plate as shown in fig. 17. With the addition of this fourth electrode the tube is accordingly referred to as a *tetrode*.

The Screen Function.—The position of the screen between the grid and the plate gives it the function of an electrostatic shield between them, thus reducing the capacitance between the two.

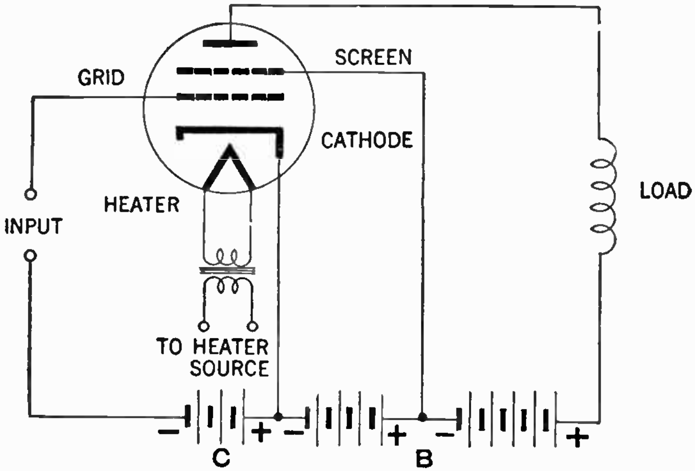


Fig. 17.—Connection of electrodes of a screen gride tube.

The effectiveness of this shielding action is further increased by inserting a by-pass condenser between the screen and the cathode. Therefore, by means of this screen and by-pass condenser, the grid to plate capacitance is very small.

The screen has another desirable effect in that it makes plate current almost independent of plate voltage over a certain range. The screen is operated at a positive voltage and therefore, attracts electrons from the cathode, but because of the comparatively large space between wires of the screen, most of the electrons drawn to the screen pass through it to the plate.

Hence, the screen supplies an electrostatic force pulling electrons from the cathode to the plate.

At the same time the screen shields the electrons between cathode and screen from the plate so that the plate exerts very little electrostatic force on electrons near the cathode. Therefore, plate current in a screen grid tube depends to a great degree on the screen voltage and very little on the plate voltage. This holds true only as long as the plate voltage is higher than the screen voltage.

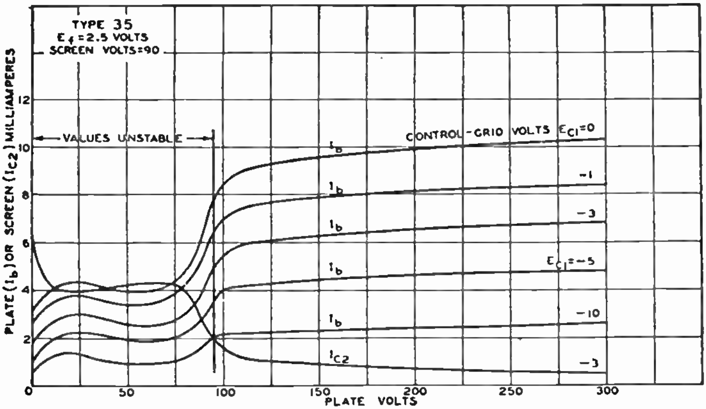


FIG. 18.—Average plate characteristics of a screen grid amplifier tube.

The fact that plate current in a screen grid tube is largely independent of plate voltage makes it possible to obtain much higher amplification with a tetrode than with a triode. The low grid to plate capacitance makes it possible to obtain this high amplification without plate-to-grid feed-back and resultant instability.

Pentodes.—It has previously been shown that when electrons strike the plate they may if moving at sufficient speed dislodge other electrons. This in the two and three electrode types does not cause any trouble since no other positive electrode than the plate is present to attract them.

These vagrant electrons therefore are eventually drawn back to the plate.

Emission from the plate caused by bombardment of the plate by electrons from the cathode is referred to as *Secondary Emission* on account of its effect being secondary to the original cathode emission.

In the case of the previously discussed screen grid or tetrode tube, the proximity of the positive screen to the plate offers a strong attraction to these secondary electrons, and more markedly so if the plate voltage be lower than the screen voltage. This results in lowering of the plate current and limits the permissible plate swing for tetrodes.

To overcome the effects of secondary emission a third grid, called the *suppressor grid* is inserted between the screen and plate. This grid, being connected directly to the cathode, repels the relatively low-velocity secondary electrons back to the plate without obstructing to any appreciable extent the regular plate-current flow. Larger undistorted outputs therefore can be secured from the *pentode* than from the *tetrode*.

Pentode-type screen-grid tubes are used as *radio-frequency voltage amplifiers*, and in addition can be used as *audio-frequency voltage amplifiers* to give high voltage gain per stage, since the pentode resembles the tetrode in having a high amplification factor. Pentode tubes also are suitable as audio-frequency power amplifiers, having greater plate efficiency than triodes and requiring less grid swing for maximum output. The latter quality can be indicated in another way by saying that the *power sensitivity*—ratio of power output to grid swing causing it, is higher. In audio power pentodes, the function of the screen grid is chiefly that of accelerating the electron flow rather than shielding, so that the grid often is called the *accelerator grid*. In radio frequency voltage amplifiers the suppressor grid, in eliminating the secondary emission, makes it possible to operate the tube with the plate voltage as low as the screen voltage, which cannot be done with tetrodes.

As audio-frequency power amplifier pentodes have inherently greater distortion (principally odd-harmonic distortion) than triodes. The output rating usually is based on a total distortion of 10%.

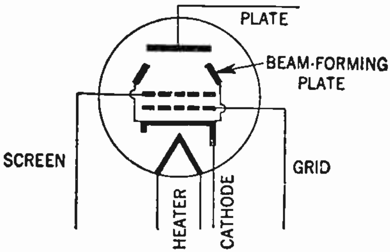


FIG. 19.—Conventional representation of beam power tube.

The Beam Power Tube.—In this tube a different method is used for suppressing secondary emission. The tube (See figs. 19 and 20) contains four electrodes, a cathode, grid, screen and plate respectively. The spacing between the electrodes is such that secondary emission from the plate is suppressed without the suppressor found in the pentode.

Due to this method of spacing the electrodes, electrons travelling to the plate slow down, when the plate voltage is low, the velocity being almost zero in a certain region between the screen and the plate. In this region the electrons form a stationary cloud—a space-charge. The effect of this space-charge is to repel secondary electrons emitted from the plate, and thus cause them to return to the plate, hence causing the suppression of *secondary emission.*

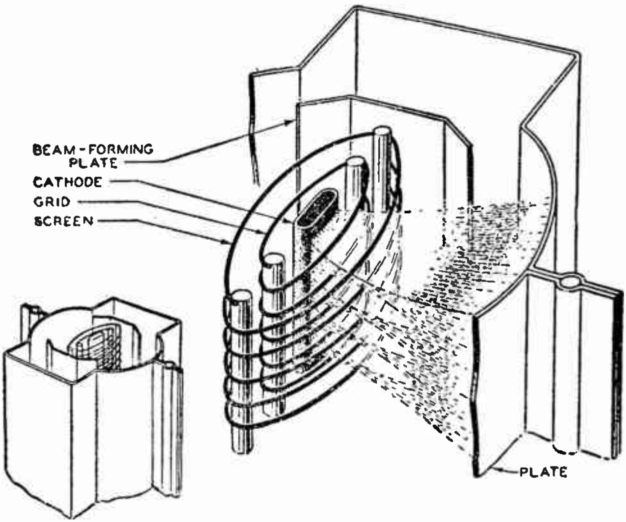


FIG. 20.—Internal structure of beam power tube. (Courtesy R.C.A. Mfg., Inc.)

An added advantage of the beam power tube is the low current drawn by the screen. The screen and the grid consists of spiral wires wound in such a way so that each turn of the screen is shaded from the cathode by a grid turn. On account of this alignment the screen and grid causes the electrons to travel in sheets between the turn of the screen so that very few of them flow to the screen. Because of the effective suppressor action provided by space charge and because of the low current drawn from the screen, the beam power tube has the advantage of high power output, high sensitivity and efficiency.

Multi-Purpose Tubes.—During the early stages of tube development and application, tubes were essentially of the so-called general purpose type, that is a *triode* was used as a radio-frequency amplifier, an intermediate frequency amplifier, an audio frequency amplifier, an oscillator or as a detector.

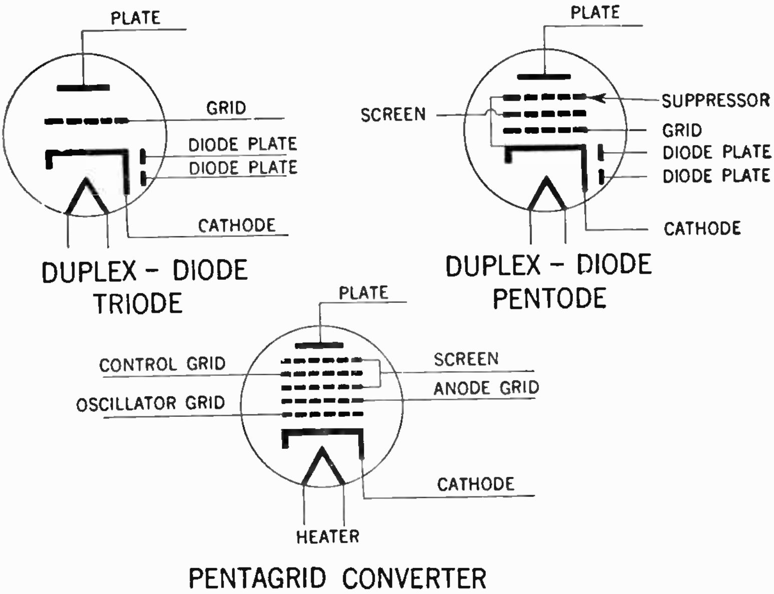
It is obvious that with this diversity of applications, this one type did not meet all requirements to the best advantage.

At present a great multiplicity of tube types have been developed to do special work in radio circuits. Among the simplest and most important in radio receiver circuits are the full-wave rectifiers, containing two separate diodes of the power type in one bulb, and twin-triodes consisting of two triodes in one bulb for class B audio amplification.

To add the functions of diode detection and automatic volume control to that of amplification, a number of types are made in which two small diode plates are placed near the cathode, but not in the amplifier-portion structure. These types are known as *duplex-diode triodes*, or *duplex-diode pentodes*, depending upon the type of amplifier section incorporated.

Another type is the *pentagrid converter*, a special tube working as both oscillator and first detector in superheterodyne receivers. There are five grids between cathode and plate in the pentagrid converter; the two inner grids serve as control grid and plate of a small oscillator triode, while the fourth grid is the detector control grid. The third and fifth grids are connected together to form a screen grid which shields the detector control grid from all other tube elements. The pentagrid converter eliminates the need for special coupling between the oscillator and detector circuits.

The convential diagram representation of these tubes are depicted in figs. 21 to 23. Another type of tube consists of a triode and pentode in one bulb, for use in cases where the oscillator and first detector are preferably separately coupled;



FIGS. 21 to 23.—Schematic representation of multi-purpose tubes.

while still another type is a pentode with a separate grid for connection to an external oscillator circuit. This "injection" grid provides a means for introducing the oscillator voltage into the detector circuit by electronic means.

Receiving screen-grid tetrodes and screen-grid pentodes for radio-frequency voltage amplification are made in two types. known as *sharp cut-off* and *variable-mu* or super-control types, In the sharp-cut off type the amplification factor is practically constant regardless of grid bias, while in the variable-mu type the amplification factor decreases as the negative bias is increased. The purpose of this design is to permit the tube to handle large signal voltages without distortion in circuits in which grid-bias control is used to vary the amplification, and to reduce interference from stations on frequencies near that of the desired station by preventing cross-modulation. Cross-modulation is modulation of the desired signal by an undesired one, and is practically the same thing as detection. The variable-mu type of tube is a poor detector in circuits for r.f. amplification, hence cross-modulation is reduced by its use.

CHAPTER 12

Transistor Fundamentals

The transistor, sometimes termed the "Mighty Midget" because of its minute size, is primarily a three electrode germanium crystal contact device, which when properly connected in a circuit will provide many of the services which until now have been delegated to the familiar vacuum tube.

The development of the transistor will undoubtedly make possible new types of electronic equipment which will use not only transistors, but also electron tubes, and other electronic components in increasing quantities.

During certain experiments in the Bell Telephone Laboratories, it was found that by placing point contacts of tungsten and phosphor bronze in close proximity (0.05 to 0.25 mm) on the specially prepared surface of a germanium block, interdependence of currents in the vicinity of the contacts can be utilized to obtain power amplification somewhat in excess of 20 decibels.

Transistor Theory.—A reasonable explanation of the mechanism of conduction in the region of contacts is possible in terms of statistical mechanics, but it is difficult to convey a plausible physical picture of the transmission of current.

According to the prevailing theories, there are two types of semi-conductors, the so called *n-type* involving the migration of electrons and the *p-type* in which permissible but unoccupied electronic *energy* levels or "holes" are propagated *through* the crystal *lattice* structure, and are equivalent to a flow of positive electricity in the opposite direction to the electron flow. The nature of the conduction is influenced by impurities in the material.

In the transistor the main body of the germanium is of the *n-type* with a thin surface layer of *p-type* germanium. It is thought that the current between the emitter contact and the main body of the germanium is conveyed by "holes" and that a large portion of these "carriers" are attracted to the collector.

The mobility of the carriers is dependent on temperature and the field strength. In practice, the finite mobility is equivalent to the transit time in a tube, and limits the response of the transistor, at the contact spacings previously noted, to frequencies well below 10 megacycles.

One type of germanium impurities consists of arsenic, antimony and phosphorus, which when added in minute amounts, result in an increase in the conductivity. Germanium having an excess of electrons due to the addition of such impurities is known as *n-type* germanium, that is, germanium having an excess of negative charges.

Conduction in germanium may also be increased by adding a second type of impurities such as aluminum, boron or indium, which impurities are known as the *p-type* and create a deficiency of electrons or *holes* resulting in a positive charge. This positive charge, or holes contribute to the conductivity of the crystal in much the same manner as electrons since they also move from atom to atom. As more *p-type* impurities are added, more holes are formed and the conductivity of the crystal is increased.

The main distinction between the two types of germanium is that the *n-type* has an excess of electrons while the *p-type* has an excess of holes. Both *n* and *p* types are used in transistors, and in certain types of transistors both exist in different parts of the same crystal.

There are presently two principal types of transistors in use, namely the *point-contact* and the *junction type*. The point-contact type having reached a more advanced stage of development will be treated in the first part of this Chapter.

Germanium Crystal Manufacture.—The heart of the transistor is the germanium crystal. Germanium is a semi-conductor, a metallic-like substance having conductivity greater than that of an insulator but less than that of a conductor. Its resistance in contrast to that of metals, decreases with an increase in temperature.

In the United States germanium is obtained most frequently as a by-product of zinc mining. In Great Britain it has also been obtained in considerable quantities from flue dust residue.

Manufacturers of germanium products receive this substance in the form of germanium dioxide powder. The conversion of the dioxide into crystals for use in transistors involves some of the most important and critical processes in the manufacture of germanium devices. The electrical characteristics of the transistor are dependent to a considerable degree upon the characteristics of the germanium. The control of transistor characteristics to acceptable tolerances depends upon the uniformity of the germanium.

The resistivity of germanium, an important factor in transistor operation, is dependent upon the presence in the germanium of minute quantities of certain impurities. If no impurities be present in the germanium crystal, no transistor action takes place. If, on the other hand, too many impurity atoms be present, the germanium becomes too conductive and transistor action is adversely affected.

The initial process in the conversion of germanium dioxide to the final crystals for transistor use is the reduction of the dioxide to a germanium metallic powder. This process is performed in a hydrogen atmosphere at a temperature of approximately 650° C. The powder is then melted at a temperature of approximately 960° C. and is formed into ingots.

After the ingots are formed, they may be subjected to one or more stages of purification. In one type of the purification process, the germanium ingot is placed in a furnace in an inert-gas atmosphere, is melted, and is then progressively cooled from one end to the other. During this cooling process, impurities present in the germanium tend to concentrate at each end of the ingot. The inner portion of the ingot, therefore, has a higher purity than the ends where the impurities are concentrated. The low-purity ends of the ingot may be cut off and the process repeated if additional purification is needed.

The germanium ingot formed by these purification techniques is poly-crystalline. Greater uniformity is obtained in a further process in which a single crystal is formed from this poly-crystalline ingot. In this process the poly-crystalline germanium is placed in a graphite pot and melted. A small single crystal of germanium is dipped into the surface of the melt, then withdrawn very slowly, pulling with it some molten germanium which solidifies on the crystal seed. The speed of withdrawal may be about a quarter of an inch per minute.

Point-Contact Transistors

Transistor Fabrication Process.—The details of construction of a point-contact transistor are given in fig. 1. This transistor consists essentially of two rectifying point electrodes which make contact with a small pellet of germanium. These electrodes are known as the *emitter* and the *collector*. A third electrode known as the *base*, is in low-resistance contact with the germanium crystal.

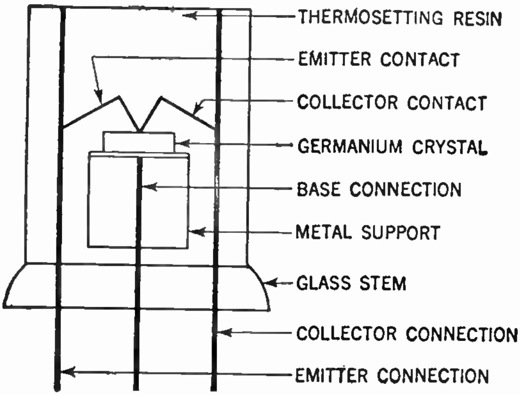


FIG. 1—Construction details of typical point-contact transistor.

The emitter, collector and base form the three electrical connections to this germanium crystal triode. The complete assembly is then embedded in a thermosetting plastic to provide ruggedness and freedom from atmospheric contaminants. The final process, and one of the most important in transistor fabrication is "electrical forming." In this process, relatively large surges of currents are passed through the collector to the base.

Point-Contact Rectification.—Prior to transistor development germanium has been known primarily for its use in point-contact diode rectifiers which have been available commercially for several years. These devices have achieved widespread use in many present day electronic applications. In a similar manner when the transistor point electrode makes contact with the germanium-crystal surface rectification of current is obtained.

When this contact occurs, a nonlinear relationship exists between a voltage applied to and the current flowing through the point of contact. A so-called "barrier" to the flow of current will be present or absent depending upon the polarity of the voltage applied to the metal point.

Thus, for example, if a metal point contacts the surface of an *n-type* germanium, the barrier will be absent and a large forward current will flow if the metal point is biased positively with respect to the crystal. If, on the other hand, the point is biased negatively with respect to the crystal, the barrier will be present and only a small reverse current will flow.

If the germanium is a *p-type*, the forward current will flow when the point is biased negatively with respect to the crystal. One explanation of this barrier is, that a very thin layer at the surface of the crystal acts as an insulating layer. If the germanium resistivity is too low, this insulating barrier at the surface does not exist because of the large number of current carriers present both in the interior and on the surface of the germanium and poor rectification results.

The foregoing transistor properties may best be observed by a reference to fig. 2 showing a basic amplifier circuit utilizing the *n-type* transistor. In this circuit the collector is biased negatively with respect to the base, while the emitter is positively biased.

If it be assumed at first that no voltage be applied to the emitter, the collector will draw a current of approximately 0.5 milliampere if a negative voltage of 25 volts be applied to the collector contact. Then, if a positive voltage be applied to the

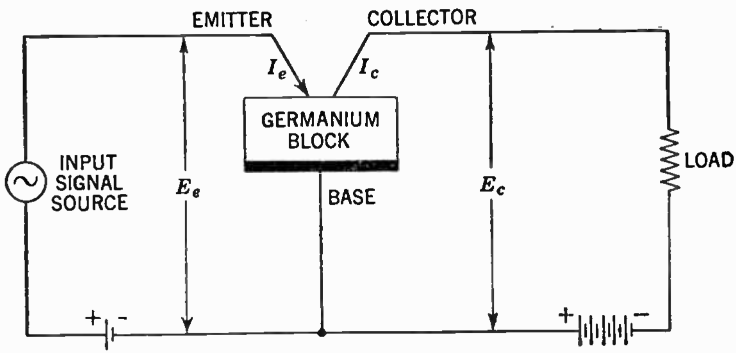


FIG. 2—Basic transistor circuit.

emitter contacts, electrons will be drawn into the emitter and a flow of holes from the emitter will be attracted to the negative field of the collector, thereby increasing the collector current appreciably.

Now, with both the emitter and collector drawing current, a small signal voltage is applied to the transistor as noted in fig. 2. As the applied voltage swings positive, the emitter current will increase thereby increasing the collector current by supplying additional holes. On the negative swing of the signal voltage, the collector current will decrease.

If the assumption be made that every unit of hole current which leaves the emitter reaches the collector, it follows that a small change in emitter current will result in an equivalent change in collector current, producing an amplification factor of *one*.

It should be noted that the transistor amplifies not only input current but also power. Because the emitter is biased in the forward direction, only a small impedance to the flow of current exists, therefore the input impedance of the transistor is fairly low, on the order of 500 ohms. The collector, on the other hand, is biased in the reverse direction and hence offers a higher impedance to the flow of current. The collector resistance comprises the greatest portion of the output impedance of the transistor.

The load resistance to provide a proper impedance match, must be fairly high on the order of 10,000 to 20,000 ohms. With the input signal applied to the transistor at a low impedance and the output taken from a high impedance, power amplification results.

In the *p-type* transistor, electrons are ejected from a negatively biased emitter and collected at a positively biased collector. In general, therefore, the *p-type* transistor has characteristics similar to the *n-type* unit, except that in operation, all battery polarities are reversed.

Point-Contact Transistor Characteristics.—The electrical characteristics of the point-contact transistor may be described by static characteristic curves having slopes equal to the open-circuit resistances.

Thus, for example, the input characteristic illustrated in fig. 3, is defined as the emitter voltage *vs.* the emitter current for several values of constant collector current. The slope of the curve taken at any point is defined as the open-circuit input resistance because the output circuit is an open circuit for alternating currents.

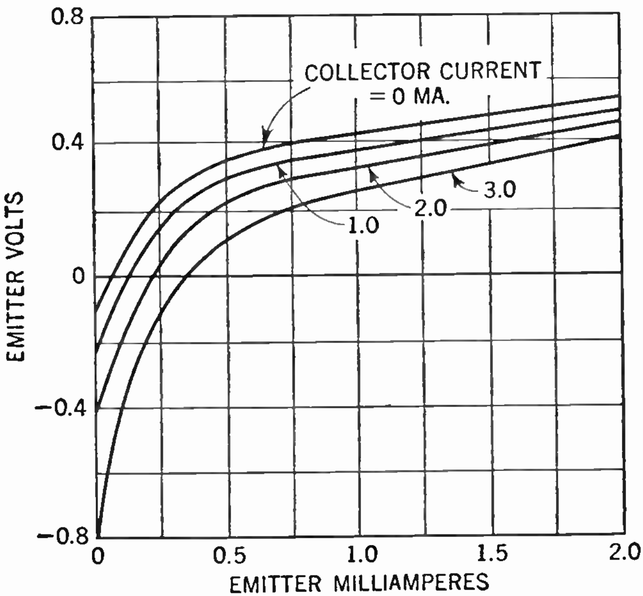


FIG. 3—Input characteristics of a point-contact transistor. (Courtesy Radio Corporation of America.)

The feedback characteristic is illustrated in fig. 4. The slope of this curve is the internal feedback resistance which is mutual to both input and output circuits. This resistance is a measure of the effect of collector current upon the voltage drop at the emitter point. It acts as a positive feedback element and if it becomes too large, the transistor may become unstable.

The output characteristic curve is given in fig. 5. The slope of this curve is the open-circuit output resistance. This resistance is approximately equal to the collector resistance or the *a.c.* impedance which exists at the collector contact.

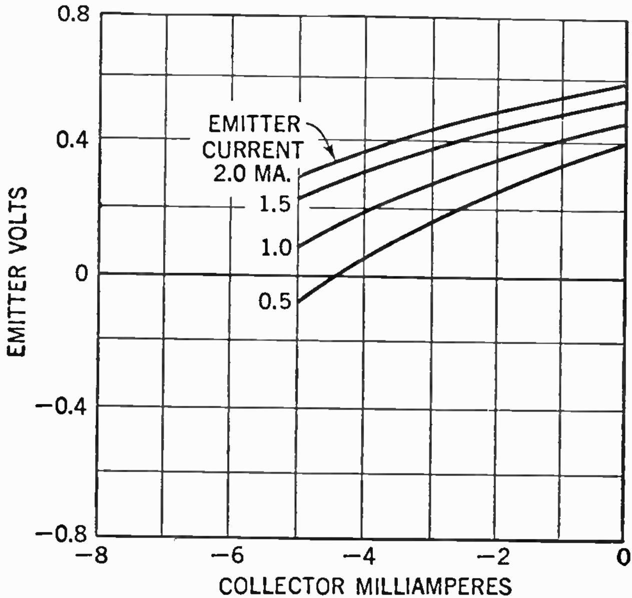


FIG. 4—Feedback characteristics of a point-contact transistor.

The current amplification factor which is a measure of the effect of the emitter current upon the collector current, may also be measured from the output characteristic. Along a line of constant collector voltage, a change in collector current for an increment of emitter current may be measured. The current amplification factor is equal to the change in collector current divided by the change in emitter current.

The output characteristic curve is similar to the curves of the plate family of electron tubes except that the voltages are plotted as a function of the currents for the transistor, while the currents are plotted as functions of the voltages for the vacuum tube.

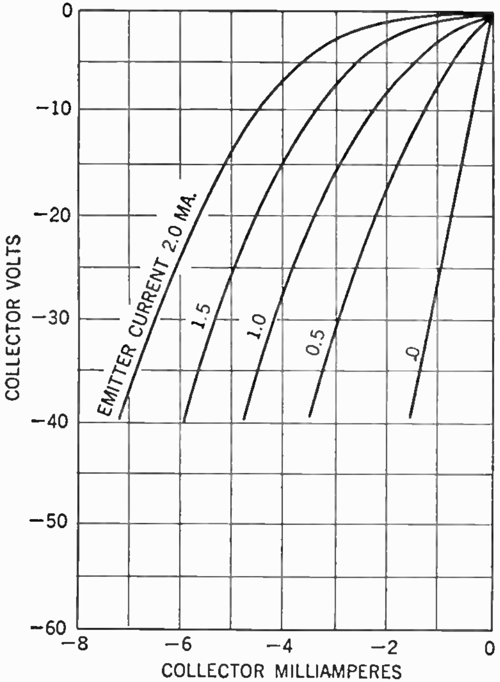


FIG. 5—Output characteristics of a point-contact transistor. (Courtesy Radio Corporation of America.)

Because a transistor may have a negative input resistance, it is possible to obtain two sets of currents for one set of voltages. This effect is shown in fig. 7 which curve gives the emitter voltage *vs.* the emitter current for a constant collector voltage.

As the emitter and collector currents increase, the voltage across the internal feedback resistance becomes larger. Since this voltage is negative with respect to the base and is in series with the applied emitter voltage, a point is reached where the

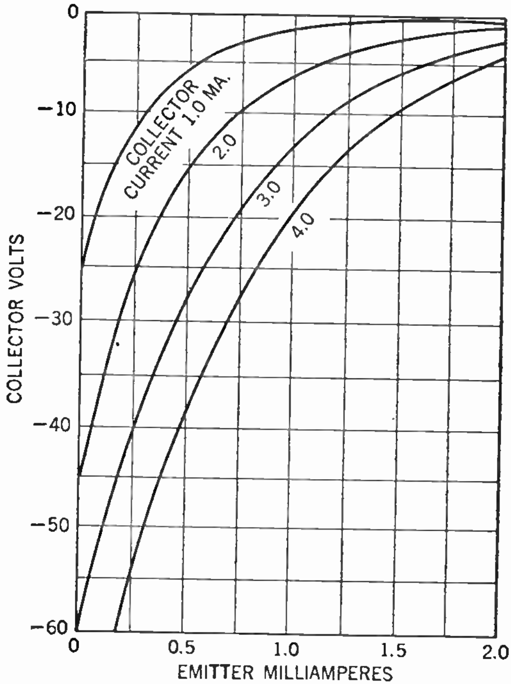


FIG. 6—Transfer characteristics of a point-contact transistor. (Courtesy Radio Corporation of America.)

total emitter voltage decreases with increased emitter current, resulting in a negative input resistance. There will also be different collector currents for each set values of emitter current.

Because there is only one set of voltages for a given set of currents, it is desirable to plot the voltages as a function of currents. It is also highly important that constant current rather than constant voltage sources be used. If fixed voltages were applied directly to the emitter and collector, any slight increase in collector current would tend to increase the emitter

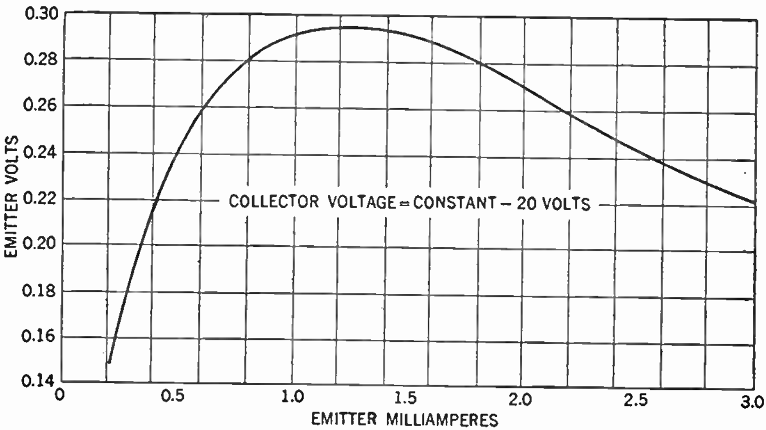


FIG. 7—Negative input-resistance characteristics of a point-contact transistor. (Courtesy Radio Corporation of America.)

current due to the feedback effect. This increase would in turn increase the collector current and considerable instability would result. In junction transistors, on the other hand, neither the negative input resistance nor the positive feedback exists. Therefore, constant voltage supplies may be used with no possibility of instability.

The transfer resistance is defined as the slope of the transfer characteristic curve, which is illustrated in fig. 6. This resistance is also equal to the product of the current amplification factor and the output resistance.

Some typical values of open-circuit resistances for a point-contact transistor are:

Input resistance,	300	ohms
Output resistance,	20,000	"
Feedback resistance,	120	"
Transfer resistance,	40,000	"

Because of feedback effects, the optimum input and output impedances for maximum gain in an amplifier circuit using this transistor, are slightly less than the open-circuit resistance values. An input impedance of 200 to 500 ohms and an output load impedance of 10,000 to 20,000 ohms, however, would result in a power gain of approximately 20 decibels, which is close to the maximum available gain.

It should be noted that the power gain of the transistor depends upon three major factors:

1. The gain varies almost directly with the ratio of output impedance to input impedance. This ratio may be on the order of 100 to 200 to 1 in point-contact transistors. In junction transistors the ratio may be on the order of 10,000 to 1.

2. The power gain varies as the square of the current amplification factor, which may be on the order of 2 or 3 for point-contact transistors and slightly less than one in junction transistors.

3. The positive feedback of the transistor accounts for several decibels in power gain. The amount of gain due to feedback depends upon the magnitude of the internal feedback resistance and current amplification.

Transistor Frequency Response.—The frequency response of the point-contact transistor is limited by the transit time of the holes or electrons; the transit time being the time it takes the holes or electrons to travel from the emitter to the collector. The transit time in seconds may be calculated approximately by the expression:

$$T = \frac{S^3}{\rho \mu I_e}$$

Where S is the contact spacing or the distance between the emitter and collector in centimeters, ρ is the resistivity of the germanium in the ohm-centimeters, μ is the mobility of the holes or electrons in centimeters squared per volt-second and I_e is the emitter current in amperes.

Since an improved frequency response results from a small transit time, it can be seen from the foregoing expression that the response can be improved by using germanium of high resistivity and small contact spacings. The mobility of the holes or electrons is the velocity with which they move through the germanium when an electric field is applied.

In the case of *n-type* germanium, holes travel from the emitter to the collector, whereas in the *p-type* germanium, electrons travel from the emitter to the collector.

The mobility of electrons is greater than that of the holes and hence the frequency response of *p-type* germanium is slightly better than that of the *n-type* for a similar contact spacing and resistivity.

The frequency response may be defined as the measure of change in current amplification with the increase in frequency. The current amplification factor of certain types of close-spaced point-contact transistors drops approximately 3 *db.* at 10 *mc.*

A 3 *db.* drop in gain has been chosen to define the cut-off frequency.

This method of measuring frequency response, however, defines only one parameter as a function of frequency. If the power gain of the device is measured as a function of frequency in an amplifier with a high-impedance load, the response of the transistor deteriorates more rapidly. A transistor having a 3 decibel drop in the current amplification factor at 10 megacycles may have a cut-off of voltage or power gain at 4 megacycles or less.

Frequency Response in Wide-Spaced Transistors.—Since the transit time of the electrons or holes increases as the point spacing increases in theory, the frequency response of the transistor varies inversely as the cube of the spacing.

Some interesting studies made of the *n-types* having wide spacings between contacts, show that such transistors have certain useful characteristics. It is noted, that if germanium having high resistivity be used, transistor power gain and current amplification are relatively independent of the point separation up to approximately 0.015 inch. As the spacings increase, however, the effect of the collector upon the emitter decreases, that is, the feedback resistance decreases.

This value of feedback resistance for the wide-spaced transistors is low enough to assure short-circuit stability while values of power gain as high as 23 *db.* are maintained and even though the frequency response limit varies inversely as the point spacing, the cut-off of the current amplification factor of the wide-spaced transistor is approximately 100 kilocycles because the resistivity of the germanium is higher than that used in narrow-spaced units. The other characteristics, except for the low internal feedback are similar to those of the close-spaced unit.

Transistor Power Capabilities.—The power capabilities of point-contact transistors are low which considerably limit the employment of such devices. Most point-contact transistors do not withstand a collector power dissipation greater than 200 milliwatts. If the efficiency of operation as a *class* "A" amplifier is assumed to be 30% only 60 milliwatts of power may be obtained from one stage of a transistor amplifier. A conservative figure for operation would be somewhere between 30 and 40 milliwatts.

There are however, many applications in which some benefit may be obtained from a device which operates at low power dissipations. Hence the greatest opportunities for the use of point-contact transistors lie in those applications where power output is of relatively little importance and where conservation of power is essential.

The limited power obtained in contact-point transistors is largely due to the thermal effect at the collector. Considerable heat is generated at this point of contact when a current is passed through it. Germanium is a fair conductor of heat and some of the heat is conducted away from the point of contact through the germanium crystal and away from the crystal by the metal support. If too large a value of current be passed, however, the germanium and adjacent parts are unable to carry the heat away rapidly enough.

If the collector point becomes too hot, the collector resistance decreases and a change occurs in the collector bias current and also in the voltage drop across the collector. In order not to damage the transistor, by too high a power dissipation the transistor must be designed for best possible heat conductivity away from the crystal. By increasing the size of the crystal support and by adding special cooling fins, the allowable power dissipation of the transistor may be increased to 500 milliwatts or more, thus increasing the power output of the transistor.

Transistor Life Considerations.—The life of the point-contact transistor is largely dependent upon electrical and physical considerations. The most obvious requirement for long life is that the transistor be physically very rugged.

The slightest shifting of the point contacts may result in large changes in transistor characteristics. The *RCA* method of improving the electrical and mechanical stability consists in an embedding process in which the transistor is embedded in a thermosetting plastic or resin and as a result of this embedding process the transistor may be subjected to severe impacts with no damage to its physical and electrical characteristics.

One of the most important causes of transistor failures is the attack of moisture and other chemical agents of the atmosphere upon the point-contact area of the transistor. Therefore, a transistor which is completely unprotected may fail in relatively high humidity in a few hours.

It has become necessary therefore, to prevent this moisture attack as much as possible by enclosing the point-contact area in waxes or resins having low moisture-absorption properties. When protected in this manner point-contact transistors have been subjected to continuous exposure at 95% relative humidity and immersion in water for periods of several months with practically no effect on transistor characteristics.

Under normal operating conditions transistors may be expected to survive with little change in characteristics for a considerable length of time. Predictions of point-contact transistor life of in excess of 70,000 hours either on the shelf or in continuous operation do not seem at all unlikely, if the transistors are operated within their ratings.

Exhaustive tests conducted by *RCA* engineers indicate that resin-embedded transistors also withstand temperatures lower than –70°C and higher than +100°C during storage with no apparent damage. Operation at the low values of temperatures is practical, but operation at high ambient temperatures is not feasible, since as the ambient temperature is increased, the temperature at the point of contact becomes too great and the collector resistance is reduced. Changes in other properties of the transistor such as the emitter resistance, transfer resistance and internal feedback resistance, may also occur. The net result of these changes is a loss of power gain, changes in bias conditions and possible permanent damage to the transistor.

Transistor Uniformity.—In order to complete successfully with other electronic devices, uniformity and reproducibility of its characteristics are essential.

The uniformity of transistors may be influenced to a large degree by the proper control of point spacing, point pressures and the fabricating techniques employed. The uniformity of the germanium itself, however, is probably the most important factor in obtaining reproducible transistor characteristics.

The art of germanium-crystal growing is rapidly progressing, and the uniformity of germanium has improved to the point where various transistor characteristics such as current amplification, power gain, feed-back resistance and input and output resistance have been controlled to within ± 25%. From the foregoing it follows that uniformity comparable to that of the electron tube seems entirely possible.

Junction Transistors

The junction transistor, generally known as the *p-n junction type*, has somewhat different characteristics from those of the point-contact design. In comparison with point-contact types, the junction transistor has lower noise, higher power gain, greater efficiency of operation and higher power-handling capabilities. As noted in table I, these improved characteristics are not obtained without some loss in frequency response.

	Point-Contact Type	Junction Type
Power Gain (Grounded base)	23 db	40 db
Current Amplification Factor	2.5	0.98
Noise Figure (db above thermal at 1000 cycles)	55 db	10 db
Minimum *d.c.* dissipation for satisfactory operation	5 to 15 mw.	0.6 microwatt
Efficiency, Class A operation	30%	49%
Frequency Cut-off (3 db down in current amplification factor)	10 mc.	1 mc.

TABLE I—Showing average value of several characteristics for two types of transistors.

Two types of junction transistors have been developed. The *n-p-n* junction transistor is composed of alternate *n*, *p* and *n* layers of germanium grown from a single crystal, as shown in fig. 8. The center layer of *p-type* germanium is very thin, its thickness may be as little as 0.001 inch.

Low-resistance contacts to the *n-areas* form the emitter and collector, whereas the low-resistance connection to the *p*-layer constitutes the base terminal.

The principle of operation of the junction transistor is somewhat different from that of the point-contact type in that the rectification takes place at the junction between the *p* and *n type* layers rather than at the point contacts.

In the point-contact transistor, holes or electrons drift from the emitter to the collector under influence of electric fields. In the *n-p-n* junction transistor, electrons diffuse through the *p-type* layer and are attracted to the collector. The center layer has an excess of holes, but if this layer be thin enough, most of the electrons entering the base region from the emitter will reach the collector region without recombining with the holes.

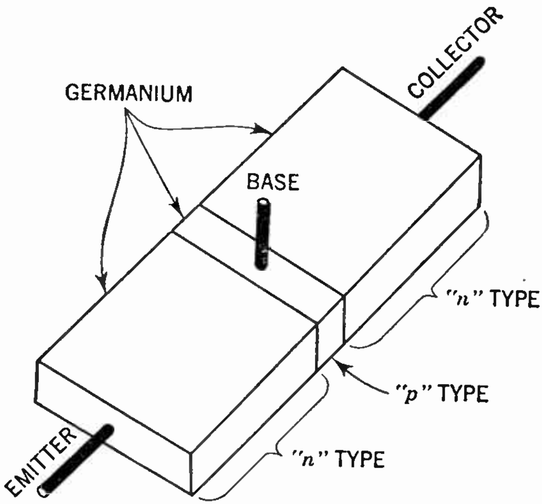


FIG. 8—Illustrating arrangement of n and p layers in an n-p-n type junction transistor.

In a junction transistor of this type, practically all the electrons leaving the emitter reach the collector, thus resulting in a current amplification of approximately one, but it cannot attain current amplification of greater than one unless more complex junctions are introduced. High power gains are obtained as a result of the very high impedance step-up between the input and output circuits.

Another junction type transistor known as the *p-n-p* type as illustrated in fig. 9, is formed by diffusing two *p-type* impurity metals on opposite faces of a piece of *n-type* germanium. The working principles in a transistor of this type depend upon the diffusion of atoms from the impurity metals into the germanium at high temperatures converting a portion of the *n-type* into *p-type* germanium, thus forming *p-n* junctions.

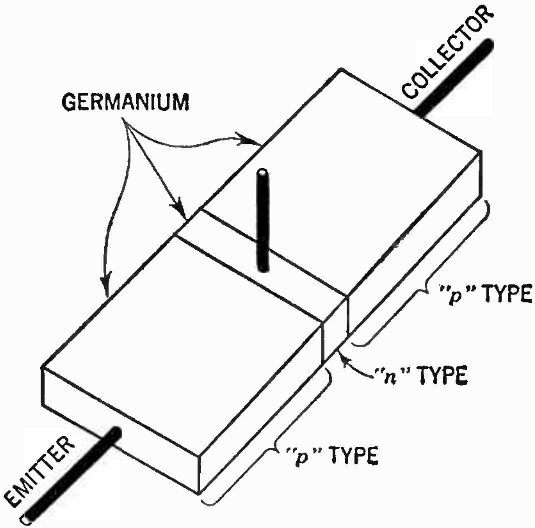


FIG. 9—Illustrating arrangement of p and n layers in a p-n-p type junction transistor.

In this type of transistor, the emitter is biased positively and the collector is biased negatively with respect to the base. Hole carriers are injected by the emitter and arrive at the collector, resulting in a current amplification factor of approximately one, as in the *n-p-n* transistor.

CHAPTER 13

Transistor Circuits

When considering the possible circuit applications for the two types of transistors, previously described, the limitations of both types must be recognized. Because of the fact that transistors are presently available at reasonable cost, they may advantageously be substituted for vacuum tubes in numerous circuits. This is particularly true where battery operation is desirable, since transistors in such circuits are much more efficient requiring no heater power and will operate with very low current, thus permitting standard flashlight cells to be used in a great many applications.

At the present time, the advantages of high gain, low noise and greater stability of the simple junction transistor can be utilized at frequencies up to several megacycles in applications such as *r.f.* and *i.f.* amplifiers of standard broadcast receivers. In addition, power outputs greater than one watt appear to be possible in oscillator and amplifier applications in the audio frequency and low frequency ranges. Another feature of the junction transistor is its ability to amplify and oscillate with microwatt power inputs.

The frequency response of the point-contact transistors, on the other hand, is somewhat higher than that of junction types.

As with junction types, point-contact types which are currently available can be made to oscillate and amplify over the broadcast frequency band.

When used as an amplifier, point-contact transistors have a relatively flat response over the entire broadcast band and beyond. Types now under development will operate at considerably higher frequencies. Feedback in these units have been reduced to values which make stable operation at radio frequencies practical.

The point-contact transistor, therefore, may also have considerable application in radio circuits and may be used in intermediate-frequency amplifiers, radio-frequency oscillators and other circuits not associated with the high power stages of *r.f.* systems. Point-contact transistors have been developed which are capable of oscillating at frequencies well over 100 megacycles.

When dealing with radio and other electronic circuits there are three fundamental functions involved. They are:

1. Detection
2. Amplification, and
3. Oscillation.

Until the invention of transistors, vacuum tubes have been employed to provide each of these functions. It is now possible to employ transistors in place of vacuum tubes to perform these operations.

Detection.—Detection is the process of recovering modulation from a signal. Any device that is "non-linear" that is, a device whose output is not exactly proportional to its input will act as a detector.

In radio communication systems, the transmitted intelligence is contained as modulation of an *r.f.* carrier frequency. To make use of this intelligence in its original form in the receiver, it must be separated from the carrier wave. The act or process of separation is termed *demodulation*, or *detection*.

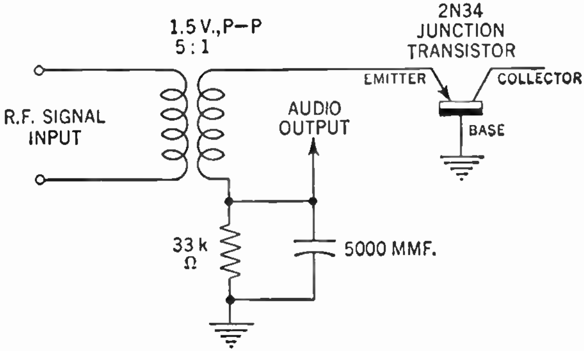


FIG. 1—Detector circuit using emitter-base connection.

Although there are numerous devices which have been employed to accomplish detection, there are only two that bear any resemblance to a transistor detector. These are the silicon or germanium crystal, and the vacuum tube diode, which are employed for the detection of A.M. radio transmission.

The reason for the successful use of each is the fact that they will conduct current only in one direction, that is, they are *non-linear devices*. A transistor, because of its construction, is also a non-linear device since it has two rectifying contacts, either one of which could be used with the base to form a detector.

Detector Circuits.—The transistor may be connected in various ways to obtain detection. Fig. 1 illustrates a circuit in which the transmitter is connected in such a manner that the emitter-base circuit is the rectifying section. Fig. 2 is similar to that shown in fig. 1 except that here the *collector-base* is used as the *rectifying* section. Fig. 3 shows an *emitter-collector* circuit.

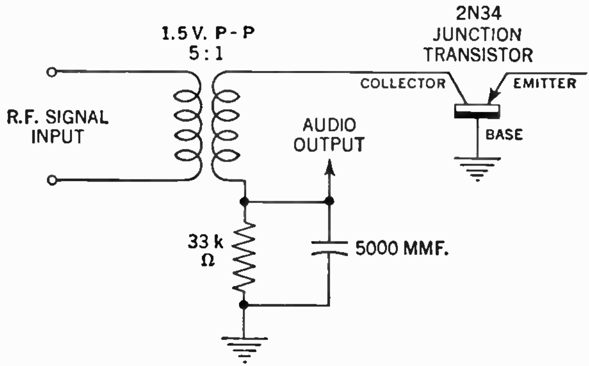


FIG. 2—Transistor detector with collector-base connection.

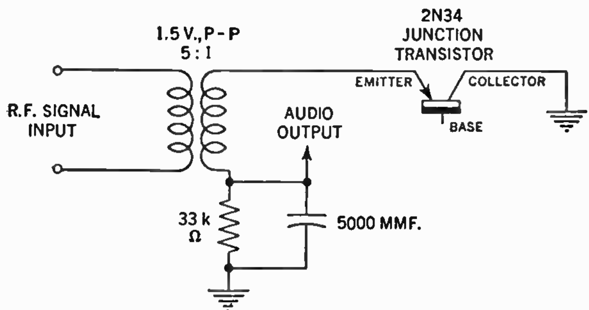


FIG. 3—Detector circuit with emitter-collector connection.

It should be noted however, that the foregoing detector circuits do not take full advantage of the latent transistor capabilities, since there is some amplification to be gained by merely completing the collector circuit as shown in fig. 4. Thus, by removing the detector load resistor and impressing the audio signal directly on the transistor in the form of current bias, a favorable detector circuit is obtained.

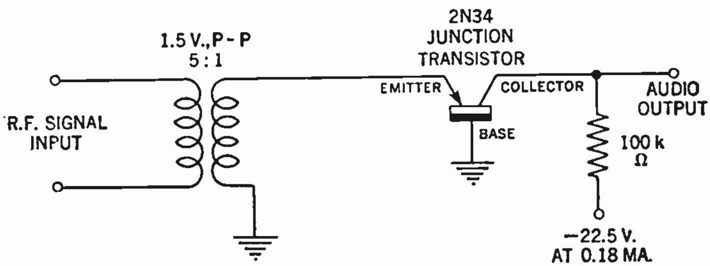


FIG. 4—Improved detector transistor circuit.

The circuit fig. 4, produces an undistorted output audio voltage several times the value of the output produced in fig. 1. From the foregoing it will be noted that it would be uneconomical in practice not to take advantage of the extra gain characteristics which is an inherent part of the transistor.

Amplification.—Transistor type amplifiers are utilized in the same manner as are radio vacuum tubes in a conventional amplification system. It should also be noted that in common with radio tube amplifiers, a variety of transistor amplifier circuits are possible, each with its own characteristics, to suit almost any desired requirement.

There are three possible ways in which a transistor can be connected for amplification, namely:

1. With a grounded base

2. With a grounded emitter, and

3. With a grounded collector.

The grounded base circuit employing a point contact transistor is perhaps the most difficult to incorporate in an amplifier because of its inherent instability. The collector current flowing through the internal base resistance develops a regenerative voltage which brings about an oscillatory tendency. Therefore, an amplifier constructed on this principle would be very unstable and in addition extremely critical with regard to transistor replacement.

The reason for this will become apparent when it be considered that the transistor base resistance is very high in the point-contact unit. This characteristic is determined by the size of the crystal and the resistivity of the germanium used in the manufacturing process, and although both of these factors can be reduced, the base resistance of the point-contact unit is still much larger than that of the junction unit.

The grounded-emitter circuit, on the other hand, provides an amplifier which is stable and in addition is not critical of variations between transistors of the same type.

As noted in fig. 5 the series resistor in the emitter circuit and the voltage divider which biases the base are both included in the circuit for stabilization of the operating point. This feature provides that fluctuation in battery voltage as well as ambient temperature variation will have only a minor effect over a wide range of operation.

To correct the low input impedance and relatively poor high frequency response, it has been found advantageous to drive the grounded emitter stages from a low impedance source.

This can best be performed by adding a grounded collector stage as shown in fig. 6. In this amplifier, the stabilizing network has been transformed to the grounded collector stage and since this stage operates at a lower current than the second stage, the power loss in the bleeder network is substantially reduced.

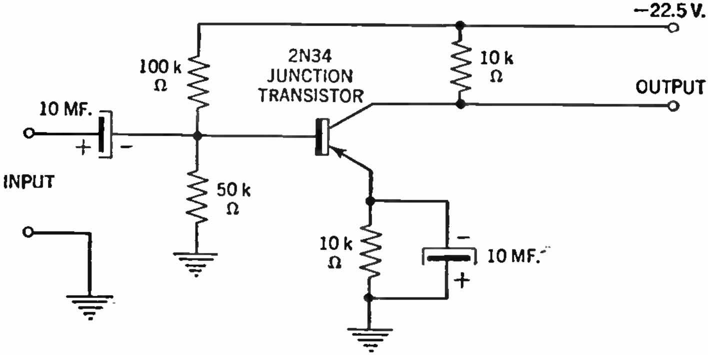


FIG. 5—Illustrating transistor amplifier with grounded-emitter.

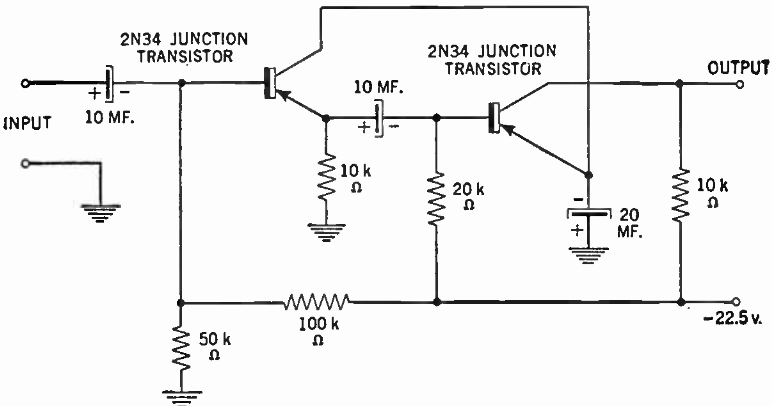


FIG. 6—Two stage transistor amplifier illustrating use of grounded-collector circuit.

In an amplifier circuit of this design, the first stage stabilizes the second by presenting a constant current source to the emitter of the second stage, and in addition the first stage provides an increase in power and voltage gain.

In most amplifier applications, the junction transistor is constantly proving its advantage over the point-contact type of transistor.

Oscillation.—It is a well known fact that if there be enough positive feedback in a vacuum tube amplifier circuit, self-sustaining oscillations will be set up. When an amplifier is arranged so that this condition exists it is called an oscillator.

A complete circuit is arranged in such a manner that the feedback circuit subtracts a portion of the energy from the output and returns it in the proper phase relationship to the input. This portion of the energy is then amplified, and a part of the voltage it develops in the output is returned to the input. When this cycle is continually repeated, the circuit is said to be oscillating.

Oscillator Circuits.—Since the point-contact transistor is basically a current amplifier, it can be arranged in a similar manner to produce oscillation.

By utilizing the negative resistance characteristics of the point-contact transistor, the oscillator will have current amplification, current feedback, and a tank circuit will produce maximum current.

Since the internal resistances of any transistor are fixed values, the only variables are the circuit impedances. There are three external circuit impedances any one of which can be manipulated to bring about oscillation. These are the base, emitter and collector impedances. Oscillation can be initiated by increasing the base impedance, decreasing the emitter impedance or by decreasing the collector impedance.

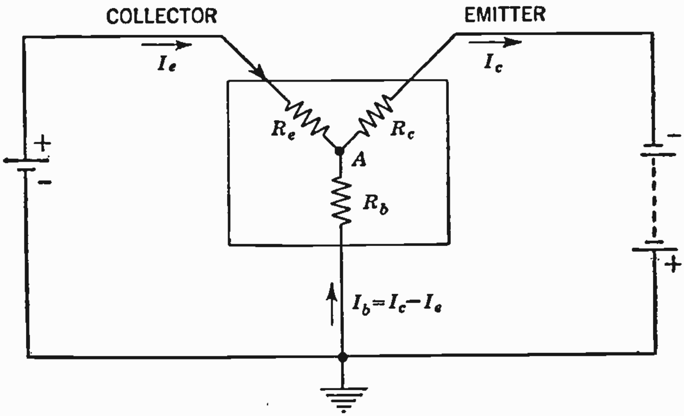


FIG. 7—Diagram showing current flow in an equivalent transistor circuit.

The effectiveness of the point-contact transistor as an oscillator is due partly to its built-in feedback circuit. As noted in fig. 7 the collector and the emitter have a common coupling impedance R_b in the base lead which feeds a part of the output back into the output circuit in the correct phase for oscillation. Only a small additional impedance is needed in the base arm to overcome the effects of the external components in the emitter and collector circuits.

With reference to fig. 7 it will be noted that emitter and collector currents flow in opposite directions in the base lead. Collector current I_c is larger than emitter current I_e, in point-contact resistors, so the resulting base current I_b constitute the difference in the two currents flowing in the same direction as the collector current. I_b flows through R_b to produce a voltage at a point (A) that is in phase with the emitter signal. It is in this manner that a positive feedback required for oscillation is obtained.

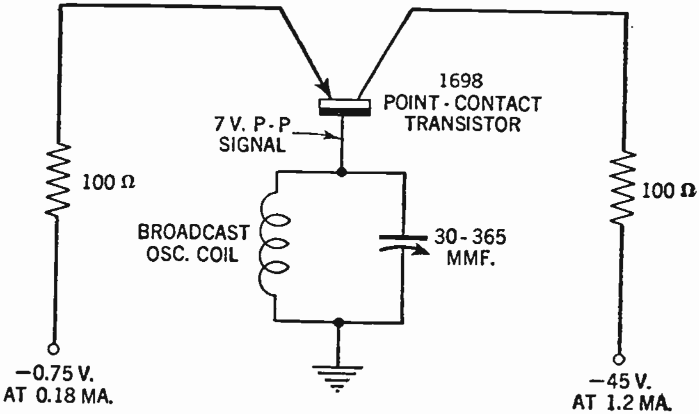


FIG. 8—Transistor oscillator circuit utilizing the principle of increased base impedance.

An increase in the base impedance can be achieved by inserting a parallel resonant circuit in the base outlet as shown in fig. 8. This provides a maximum of base impedance at resonance, and the circuit will oscillate at that frequency. A decrease in either the emitter or collector impedance can be obtained by connecting a series resonant circuit from the respective element to ground as indicated in figs. 9 and 10.

This will produce a minimum impedance and a condition of oscillation at resonance. The base resistor is required in figs. 8, 9 and 10, to maintain the base impedance at a high value and makes it necessary to reverse the normal polarity of the emitter bias supply in order to maintain the emitter just slightly positive with respect to the base.

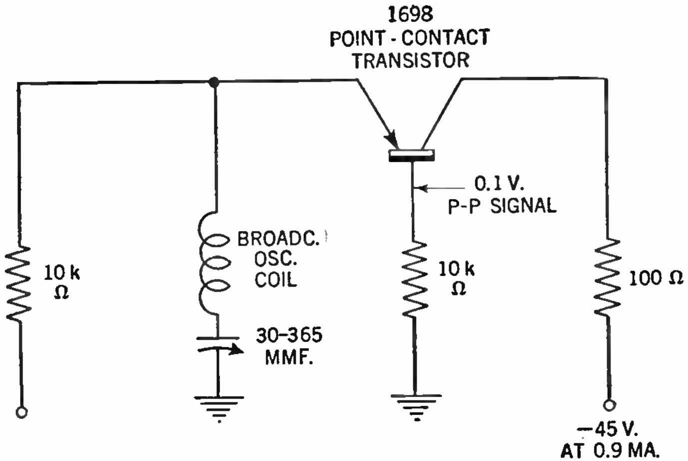


FIG. 9—Transistor oscillator circuit using a decrease in emitter impedance to produce oscillation.

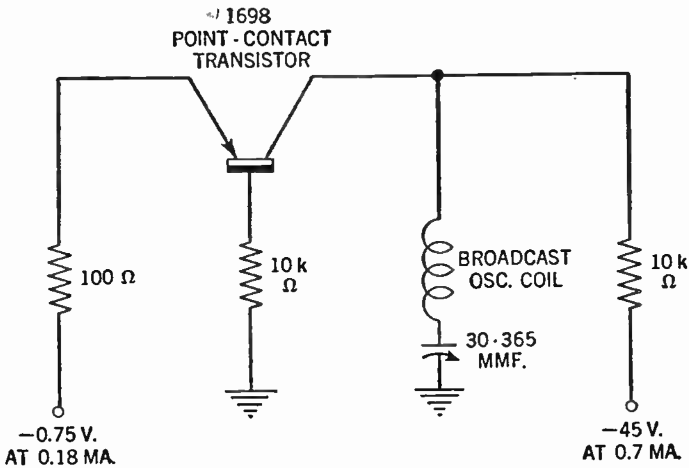


FIG. 10—Transistor oscillator circuit using the principle of decreased collector impedance.

It should be noted that the junction transistor will not oscillate in circuits figs. 8 to 10 simply because it is not a current amplifier, and the maximum current gain of a junction transistor is always less than unity. Therefore, it is necessary to employ this unit as a voltage amplifier and to use a voltage feedback circuit similar to that used with vacuum tubes. This can usually be accomplished by means of inductive coupling.

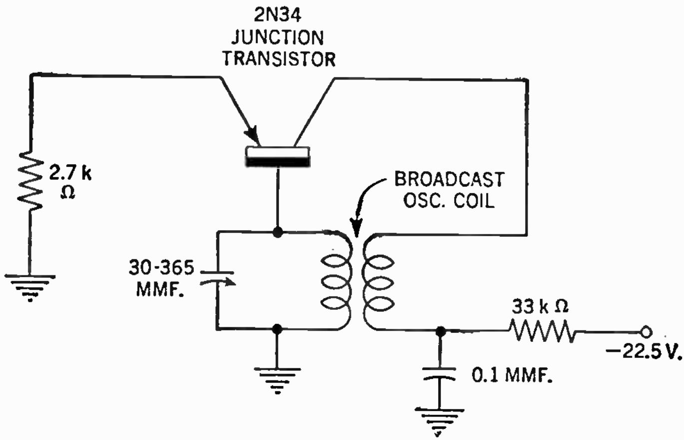


FIG. 11—Transistor oscillator incorporating voltage feedback in grounded base circuit.

The resulting circuits are somewhat similar to vacuum tube oscillators and two representative circuits are given in figs. 11 and 12.

Summing up it will be observed that the voltage feedback type of oscillator is not limited solely to the use of the junction transistor, but the point-contact unit can also be successfully employed.

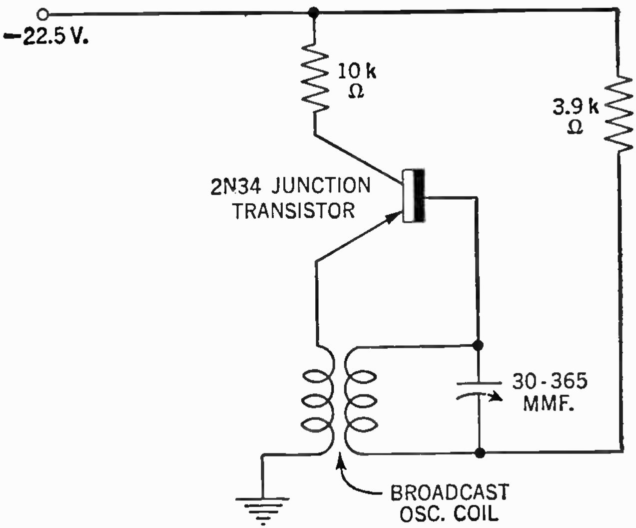


FIG. 12—Transistor oscillator utilizing the grounded emitter circuit and voltage feedback.

Transistor Code-Practice Oscillator.—The Code practice oscillator shown in fig. 13, is an example of a unit in which the favorable characteristics of a transistor is utilized. It should be noted that in a circuit of this sort only about a third of a milliampere is used, thus permitting flashlight cells to be employed.

Here the *CK*-722 junction transistor will oscillate readily at frequencies up to about one megacycle if an *r.f.* choke is connected in series with R_1. Thus it could be used as an *i.f.* test signal source, but it is not suitable for higher frequencies because of the relatively low cut-off frequency of junction transistors.

The circuit diagram fig. 13, shows the use of the conventional Colpitts circuits with the *CK*-722, *pnp* junction transistor. In comparing the transistor circuit with that utilizing a vacuum tube, it should be noted that the collector (pin #1 next to the red dot on the transistor) may be considered analogous to the plate, the base (pin #2 the center pin) to the grid and the emitter (pin #3) to the cathode.

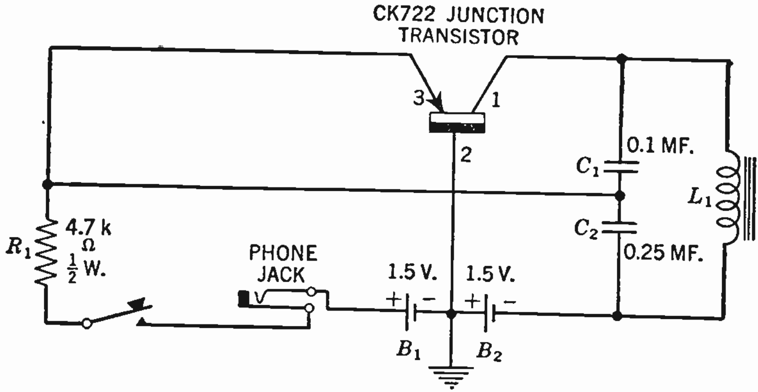


FIG. 13—Transistor audio oscillator circuit suitable for code practice. In the diagram L_1 represents a primary 500 ohm line-to-speaker transformer; C_1 and C_2 are paper condensers; B_1 and B_2 are flashlight cells.

Any magnetic phone's with an impedance of 1000 ohms or more may be used. Crystal phone's could be connected across C_2.

The primary (500 ohms side) of the small line-to-speaker transformer specified is about of the right inductance. If a different transformer be used it may be necessary to increase or decrease C_1 and C_2 to obtain a frequency of around 1,000 cycles. In this connection it should be noted that it is preferable to make C_2 larger than C_1, but again the ratio is not critical. R_1 may be increased to 22,000 ohms or more if less volume is desired in the headphones.

A similar circuit for single battery operation is shown in fig. 14. This oscillator will operate on a single dry cell, but two are required to give enough volume on the loudspeaker to be heard throughout the room. Headphones could be connected in series with R_1 as shown in fig. 13. The current from the two dry cells is only 0.7 milliampere, thus they will operate for a

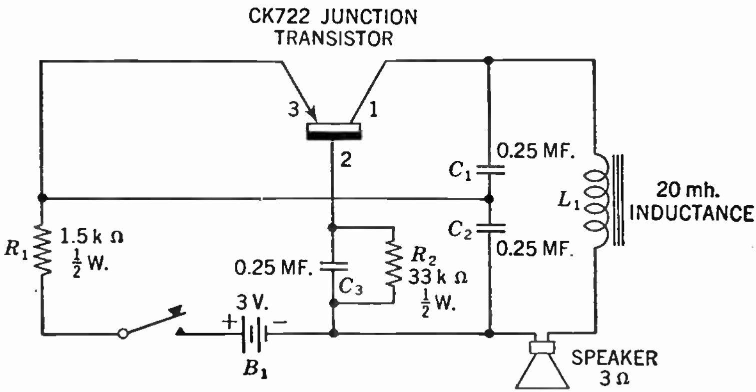


FIG. 14—Transistor audio oscillator circuit arranged for single battery operation. In the diagram C_1, C_2, and C_3 are paper condensers; B_1, one or two 1.5 volts flashlight cells.

considerable time. The dry cells could be replaced by a crystal, *r.f.* choke, and capacitor connected as shown in fig. 15 for operation as a complete self-powered keying monitor.

Transistor Keying Monitor.—The Code practice oscillator shown in fig. 13 may be adopted as a keying monitor when desired, by using one pole of a double-pole keying relay in place of the key and powering the emitter circuit from a keyed low-voltage circuit in the transmitter, or by obtaining the emitter current from rectified *r.f.* voltages.

Fig. 15 shows the modified circuit for the latter case. The emitter dry cell B_1, has been replaced by an *r.f.* choke, crystal rectifier and capacitor. Since the collector dry cell is retained, the circuit cannot be said to be entirely self powered.

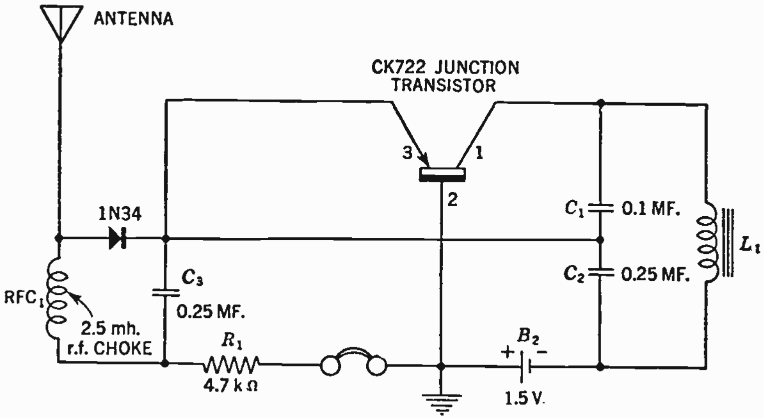


FIG. 15—Transistor keying monitor circuit. In the diagram L_1 represents a primary 500 ohm line-to-speaker transformer.

Transistor Phono Oscillator.—A circuit in which a single transistor will serve the double duty of audio amplifier and oscillator is shown in fig. 16. By means of a circuit arrangement of this type music and conversation can be broadcast over short distances.

As noted in fig. 16, the microphone is connected in the base circuit from the bias resistor R_2. This resistor, and also resistor R_1 must be by-passed with electrolytic condensors to prevent audio regeneration. Since R_1 must be bypassed for audio, the *r.f.* feedback must be prevented from going to ground also. The *RFC* choke prevents this.

Resistor R_4 prevents a periodic blocking of the *r.f.* oscillator by the voltage developed across R_1 and C_3. It should be noted that approximately 200 ohms prevents instability for all transistors, but in most instances 100 ohms will prove satisfactory.

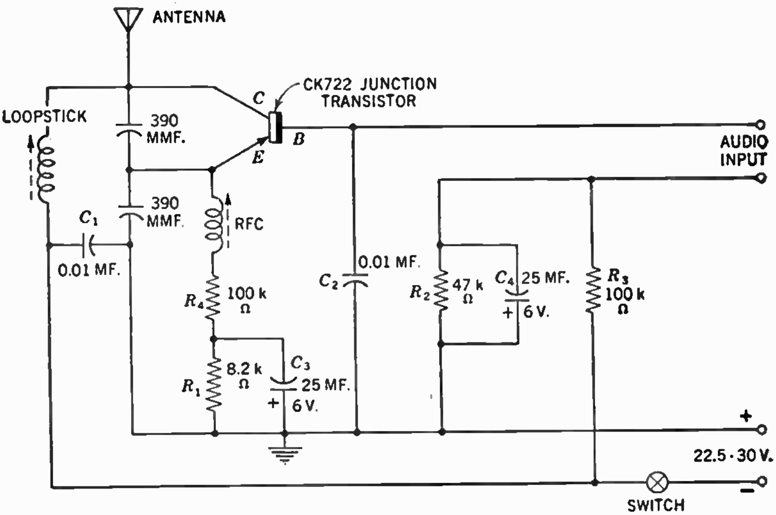


FIG. 16—Transistor phono oscillator circuit. In the diagram the 390 MMF capacitors are of the ceramic type; C_1 and C_2 are paper, whereas C_3 and C_4 are of the electrolytic type. The tuning coil and choke are both cut-down Ferri-Loopstick units.

The lowest value that prevents motor-boating of the carriers is the most desirable since high values of R_4 reduces audio gain. Because of the voltage drop in the stabilizing resistors it is necessary to use a voltage source of up to 30 volts which voltage does not exceed the transistor ratings. Thirty volts of course gives the greatest power output, but the circuit oscillates down to 15 volts, subject to variations in individual transistors.

To test the circuit assembly, a tap or sound into an earphone should produce sound when the unit is placed a few feet from a radio receiver. There will be feedback squeak if the microphone be too close to the speaker of the radio. It should be noted that the earphones give a fairly good impedance match to the transistor input, but it overloads and distorts easily on loud sounds. A three inch speaker connected through an output transformer to the oscillator makes a greatly improved microphone. Carbon microphones which are desirable for this purpose must have a coupling transformer of the filament type connected as indicated in fig. 17.

An extra stage of audio amplification may be added to the oscillator, connected as indicated in fig. 18. As noted, the amplifier is connected directly to the audio input terminals of the oscillator. Although the range of the oscillator is limited because of low power, the unit will readily transmit signals from room to room, and with exception of the transistor itself, standard low-cost components are used throughout.

Recent transistor developments include higher gain, lower noise, and greater stability. Transistors of the future may possibly be grouped or combined without the need for transformers or coupling components. Grouping is possible because crystals may be of the *n* or *p* type and thus complement each other.

A circuit designed at the *Bell Telephone Laboratories* and shown in fig. 19, is of the *bi-stable* type. Here, *npn* and *pnp* junction types transistors are paired. The circuit components consists of the circuit load R_1 and resistors R_2 and R_3, the latter of which may about 100 ohms aid in providing a trigger action. Ordinarily a trigger effect is associated with point-contact types

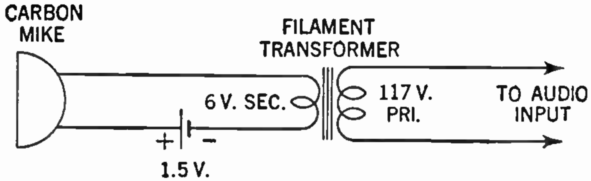


FIG. 17—Circuit for carbon mike output.

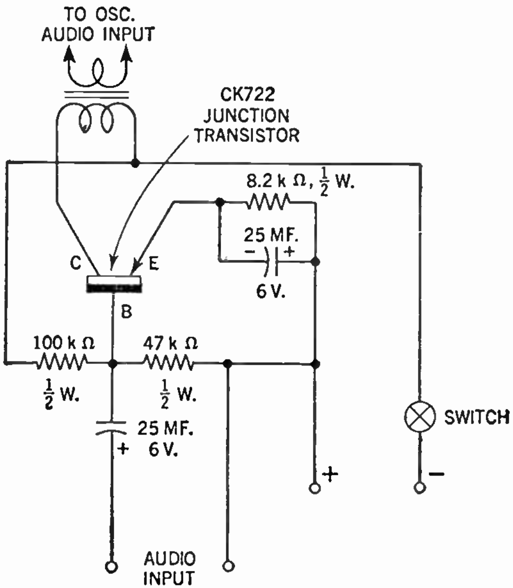


FIG. 18—Audio amplifier transistor circuit for phono oscillator shown in fig. 16. The 25 MF. capacitors are of the electrolytic type. The plate-to-line transformer primary impedance should be 10,000 to 25,000 ohms, with a secondary impedance of 200 to 500 ohms, primary current 3 to 1.5 ma.

of transistors only, until it was found that the same result may be obtained with the less expensive junction types.

When the applied positive signal is low, current through load resistor R_1 is small and the voltage drop across R_2 and R_3 is nearly zero. Since this drop determines the emitter bias for each transistor, each works near cutoff.

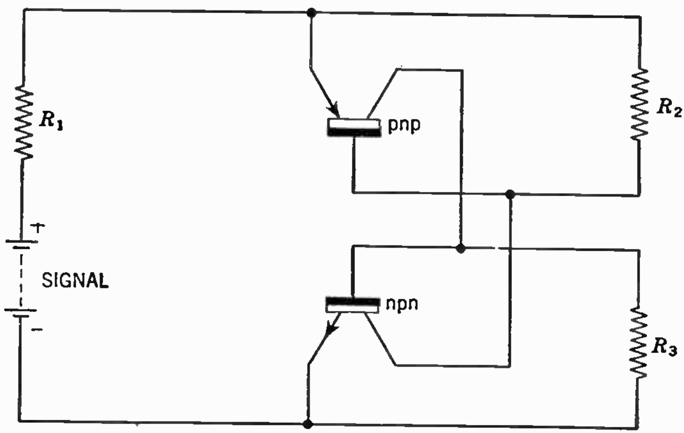


FIG. 19—Illustrating a bi-stable circuit with paired transistors.

When the positive input voltage is increased, more current flows through the circuit since resistors R_2 and R_3 produce a greater bias between emitter and base of each semi-conductor. The bias is always in the forward direction for each transistor. Additional bias results in more collector current, and in turn, the emitter bias is increased still further. Soon each transistor current reaches its saturation value where it remains, and the load current through R_1 is maximum. The trigger returns to low conduction when the input voltage is lowered to near zero.

The crystal pair shown in fig. 19, is equivalent to a single transistor with a current gain of $A/1\text{-}A$ where A is the gain of each individual unit. Thus, for example, if each has a gain of 0.9 then the equivalent transistor has a total gain of 9.

Another somewhat similar transistor circuit also developed at the *Bell Telephone Laboratories* is shown in fig. 20. Again, an *npn* and *pnp* are arranged in pairs to obtain special effects. The result is a circuit that can handle relatively large amounts of power.

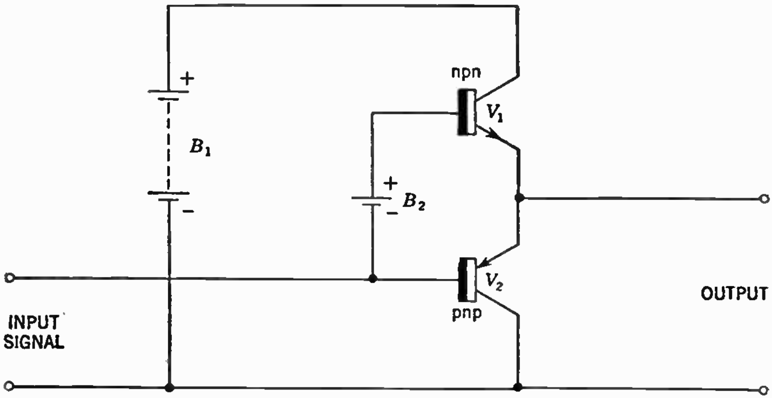


FIG. 20—Illustrating a transistor amplifier circuit with paired transistors.

As noted the two transistors V_1 and V_2 form a voltage divider across battery B_1. Auxiliary battery B_2 biases each transistor in the forward direction, that is, toward lower impedance.

When the input signal is zero, the transistors conduct equally. The output voltage is one-half of B_1. Electrons flow out of the collector of V_1, equal in amount to the holes drawn from the collector of V_2. The same number of electrons are injected into the emitter of V_1 as holes injected into the emitter of V_2. Thus there is no need for a direct return path for each element.

When the input goes positive, each base receives the positive potential and the conductivity of V_1 increases. At the same time V_2 decreases in conductivity. The output voltage is decreased during this time.

During the other half-cycle this process reverses and the output voltage rises. Each transistor contributes toward the power input, yet the circuit needs no transformers, capacitors or resistors.

CHAPTER 14

Radio Receivers

Generally any electrical circuit used in connection with radio reception is a radio receiving circuit.

The basic receiving circuits are as follows:

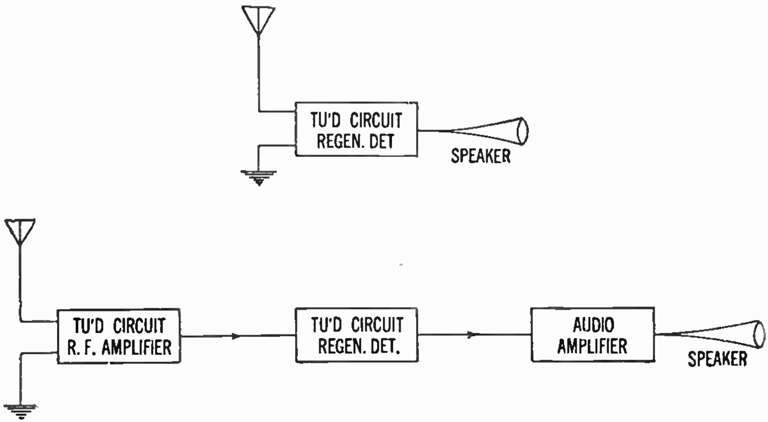
1. Regenerative
2. Tuned radio frequency regenerative
3. Super-heterodyne
4. Super-regenerative
5. Super-infra regenerative

The two last circuits are classified as short wave receivers.

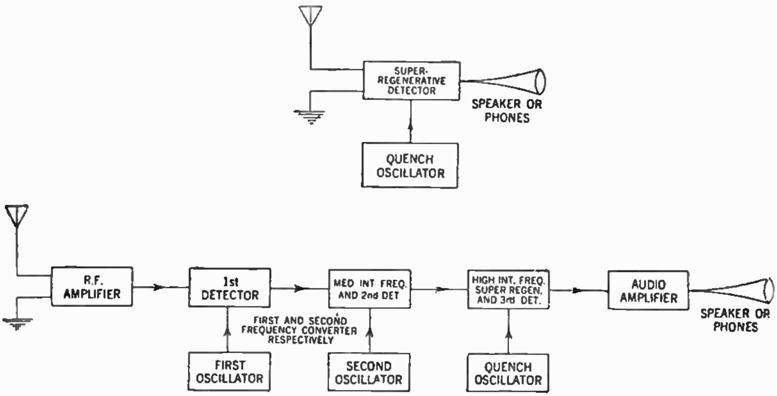
General Receiver Performance Characteristics.—The receiver performance may be divided into three groups namely:

1. Selectivity
2. Sensitivity
3. Fidelity and stability

The three groups are inter-dependent with selectivity the most important factor.



FIGS. 1 and 2—Block diagrams showing essential units of a regenerative and a tuned radio frequency regenerative circuit respectively.



FIGS. 3 and 4—Block diagrams showing essential units of a super-regenerative and a super-infra regenerative circuit respectively.

By definition, *selectivity* of a receiver is its ability to discriminate between signals of various frequencies. The *sensitivity* of a receiver is the minimum radio frequency voltage input required to give a certain specified output. The *fidelity* is that proportionate response through the audio frequency range, required for a given type of receiver.

A receiver's *stability* is identified by its ability to maintain its output constant over a period of time with constant *signal* input.

Receiver Selectivity.—As aforementioned the selectivity is that characteristic which makes it possible to determine how well a set will tune out one signal and tune in another.

Measurements of Selectivity.—The selectivity is determined with the aid of a radio frequency oscillator by means of which it is possible to impress known *r.f.* potential on the input of a radio receiver.

There are various methods of carrying out this test, although the one generally used is to impress a small potential on the input of the set and note the output, and then to vary gradually the frequency of the *r.f.* oscillator, and at the same time adjust the potential supplied to the receiver so as to maintain the same output.

In this manner a set of figures will be obtained, indicating how the output of the set falls off at either side of the frequency to which it is tuned. Generally it is true that the more rapidly it falls off the better is the selectivity of the receiver.

However, as previously noted, the receiver's selectivity is closely allied with its fidelity, for generally if making the selectivity too great, the side-bands are suppressed and the high frequencies are partially suppressed. A typical selectivity curve is shown in fig. 5.

Such curves may be made up at various points throughout the broadcast band, and the variations in a receiver's selectivity thereby determined.

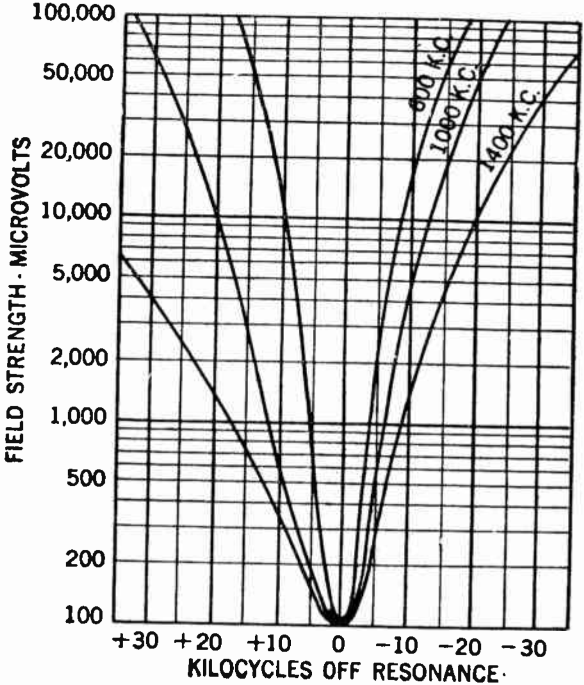


FIG. 5—A typical radio receiver selectivity curve.

Receiver Sensitivity.—The sensitivity of a receiver is not simply a matter of amplification, but is fundamentally limited by what is known as "the noise level" in that only signals that are audible above the prevailing noise background at the output are useful.

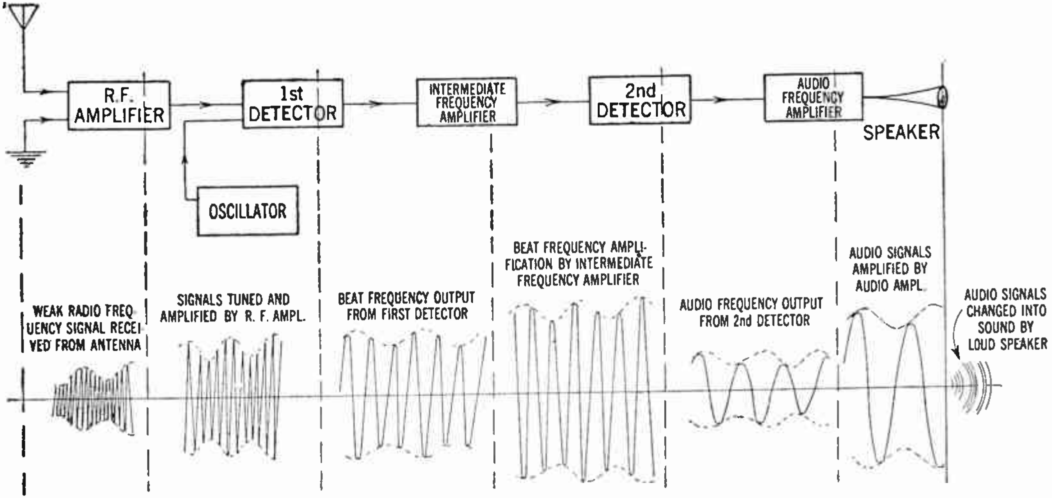


FIG. 6—Combination diagram showing arrangement of the different units of a typical super-heterodyne receiver with wave chart indicating how the radio signals are modified by each unit, that is, how the inaudible signals first picked up by the antenna undergo successive changes en route to the loud speaker.

In order to obtain a common basis facilitating the study and measurement of this characteristic, the term "noise equivalent" is used, which simply means the effective sensitivity of a receiver in terms of its own noise level.

Measurements of Sensitivity.—In connection with sensitivity measurements, a certain receiver is often expressed as having a sensitivity of so many micro-volts per meter. Just what this expression implies may best be conveyed by a description of what the term means.

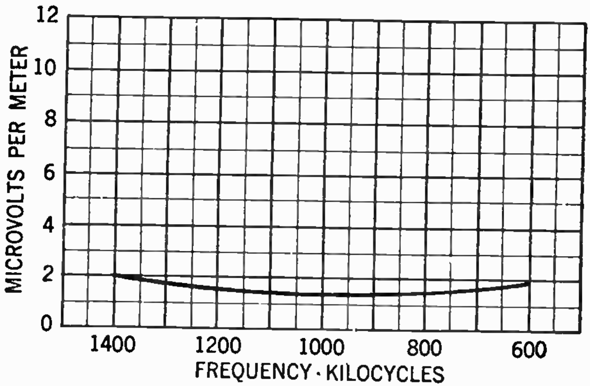


FIG. 7—Typical radio receiver, sensitivity characteristics.

The sensitivity measurements are generally accomplished in the following manner: The receiver is set up and a resistor is connected across the *a.f.* output of the set. The resistor should be of such value so as to give maximum power output per volt on the grid of the power tube. In most cases the resistor will have a value equal to twice the plate resistance of the output tube, which may easily be obtained from the tube performance chart.

The next procedure is to apply to an artificial antenna a known *r.f.* voltage modulated 30% at 400 cycles and to increase the *r.f.* input voltage until 50 milli-watts of audio-frequency power is developed across the output resistance.

The magnitude of the input *r.f.* voltage required to produce this output by dividing by the effective height of the artificial antenna, which is usually four meters is then determined.

Thus, finally the micro-volts per meter input required to produce the standard output of 50 milli-watts is obtained.

If it be assumed that the described method is utilized in determining the sensitivity of a certain receiver, it is simply necessary to give the micro-volts per meter input for standard output in order to define completely the sensitivity of the receiver in question.

It can therefore be said for example, that a certain receiver has a sensitivity of 10 micro-volts per meter. This means that if a 30% modulated *r.f.* signal is impressed across the input, then 50 milli-watts of power will be developed in the output at 400 cycles.

With the constant improvement in *r.f.* amplifier circuits, receiving sets at present are much more sensitive and it is not uncommon to find receivers having a sensitivity in the order of 3 to 5 micro-volts per meter or higher.

Fidelity.—Fidelity is the term being used to indicate the accuracy of reproduction, at the output of a radio receiver, of the modulation impressed on the *r.f.* signal applied to the input of the set under test.

This is generally determined by setting up the receiver to be tested and impressing on its input an *r.f.* signal modulated at 30%, the input signal having a value such that the normal output is obtained.

Next the frequency of the modulating signal is varied (the modulation being held constant) over the entire audio frequency band and the output power at each frequency is noted.

From the data so obtained, a curve can be charted showing how the audio-frequency output power from the set varies with the frequency applied.

Such curves are run at various radio frequencies for example at 600, 1000 and 1500 *k.c.* in the broadcast band, so that the variation of fidelity can be determined.

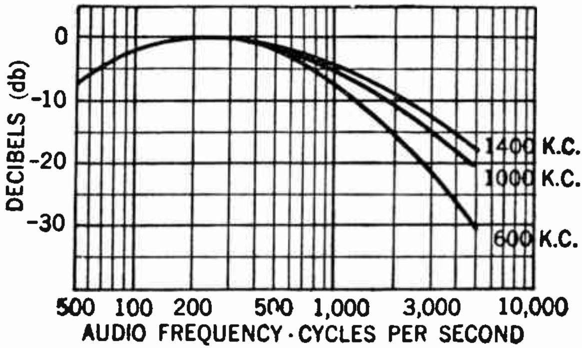


FIG. 8—Typical radio receiver, fidelity characteristics.

In this manner it is possible to obtain information regarding the characteristics of the *r.f.* amplifier system. It is obvious that if the system tunes too sharply at some point in the broadcast band, the side-bands will be suppressed partially and this will show up on the curve which is plotted as a falling off in response at the higher audio frequencies.

When making a test of this type, it is essential that the source of the audio frequency voltage used to modulate the *r.f.* input signal be quite pure (free from harmonics). Generally the total harmonic output from the audio frequency oscillator should not be allowed to exceed 5%.

Amplifier Classification.—There are four recognized classes of amplifier service. This classification depends primarily on the fraction of the input cycle during which the plate current is expected to flow under rated full-load conditions.

The term cut-off bias used in the following definitions is the value of grid bias at which plate current is of some very small value.

Class "A" Amplifiers.—A class A amplifier is one in which the grid bias and alternating grid voltages are such that the plate current in a specific tube flows at all times.

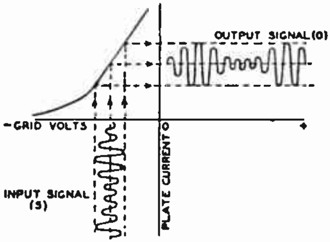


FIG. 9—A graphic illustration of method of amplification showing, by means of grid-voltage vs. plate-current characteristics, the effect of an input signal "S" applied to the grid of the tube. "O" is the resulting amplified plate-current variation.

Class A amplifiers of the voltage type find their application in reproducing grid voltage variations across an impedance or a resistance in the plate circuit. These variations are essentially of the same form as the input signal voltage impressed on the grid, but of increased amplitude. See fig. 9. This is accomplished by operating the tube at a suitable grid bias so that the applied grid-input voltage produces plate-current variations proportional to the plate swings. Since the voltage variation obtained in the plate circuit is much larger than that required to swing the grid amplification of the signal is obtained.

Class A amplifiers of the power type find their chief application as output amplifiers in audio systems, operating loud speakers in radio receivers and public address systems, where relatively large amounts of power are required.

For above applications, large output power is of much greater importance than high voltage amplification. Therefore gain possibilities are sacrificed in the design of power tubes to obtain this greater power handling capability.

Class "AB" Amplifiers.—A class AB amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciable more than one-half but less than the entire cycle.

Class "B" Amplifiers.—A class B amplifier is an amplifier in which the grid bias is approximately equal to the cut-off value so that the plate current is approximately equal to zero when no exciting grid voltage is applied, and so that the plate current in a specific tube flows for approximately one-half of each cycle when an alternating grid voltage is applied.

Class B amplifiers of the power type employs two tubes connected in push-pull, so biased that the plate current is almost zero when no signal voltage is applied to the grids (see figs. 10 and 11). Because of this low value of no signal plate current, class B amplification has the same advantage as class AB, in that large power out-put can be obtained without excessive plate dissipation. The difference between class B and class AB is that, in class B, plate current is cut off for a larger portion of the negative grid swing.

Class C Amplifiers.—A class C amplifier is an amplifier in which the grid bias is appreciably greater than the cut-off value so that the plate current in each tube is zero when no alternating

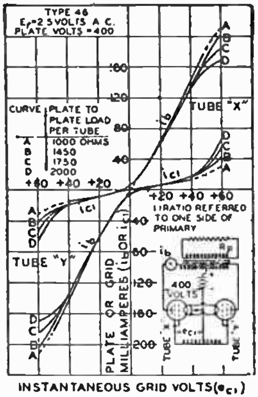


FIG. 10—Illustrates operation of tubes in class "B" circuit.

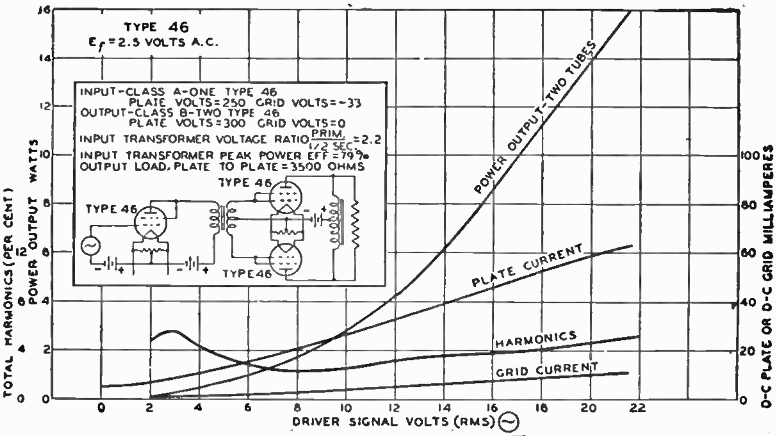


FIG. 11—Illustrates typical class "B" characteristics. An amplifier of this type generates considerable second and other harmonics. The efficiency of an amplifier of this type is higher than the previously discussed class A amplifier.

grid voltage is applied, and so that plate current flows in a tube for appreciably less than one-half of each cycle when an alternating grid voltage is applied.

Radio Frequency Amplifiers.—Radio frequency amplification is utilized to increase the volume of the weak radio frequency signals received from the antenna, and occurs before the radio frequency signals arrive at the detector circuit of the receiver.

There are three general methods for coupling the tube of one stage of radio frequency amplification to the next stage namely:

1. Resistance coupled
2. Impedance coupled
3. Transformer coupled.

Resistance-coupled Radio Frequency Amplifier.—In this type of amplifier (see fig. 12) a high resistance is being utilized for the interstage coupling.

The advantage with this type when used as an audio amplifier is that on account of its simplicity it is economical to build, in addition, the amplification can be made very uniform over a rather wide frequency range. It is these characteristics which have made it useful in television devices.

The function of the blocking condenser is to prevent the plate potential of one stage being impressed on the grid of the next stage.

These blocking condensers, being series condensers, would trap electrons between the grid and the adjacent condenser plate, were it not for the high resistance leakage path provided for their return to the filament circuit.

Impedance Coupled Amplifiers.—The method of connection for inductive coupling (also known as choke coil coupling), is shown in fig. 13. The impedances X_1 and X_2 are in the form of auto-transformers; R_1 and R_2 are grid leaks ranging in value of between one-quarter and one-half megohms; C_1 and C_2 are the usual blocking condensers of about one microfarad capacity each.

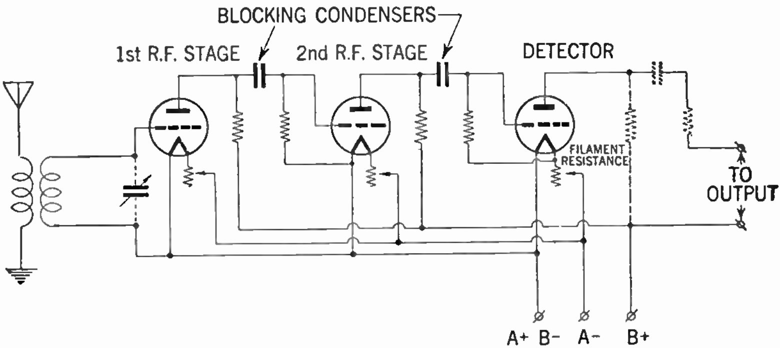


FIG. 12—Typical two stage resistance coupled radio frequency amplifier.

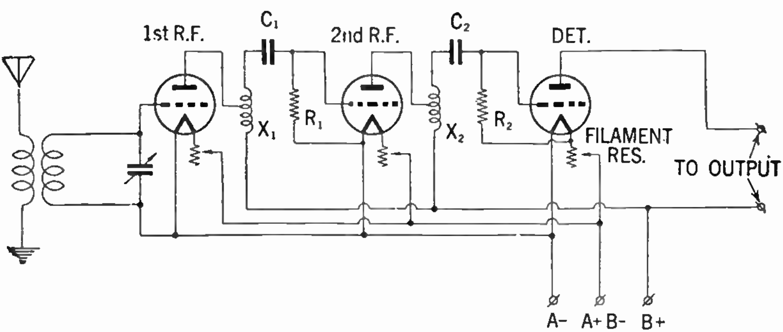


FIG. 13—Two stage impedance coupled radio frequency amplifier.

Transformer Coupled Amplifiers.—In this method the air-core transformers with a one to one transformer ratio, are most commonly used.

However, on very long wavelengths it has been found advantageous to use step-up ratio transformers, by having a greater number of secondary than primary turns.

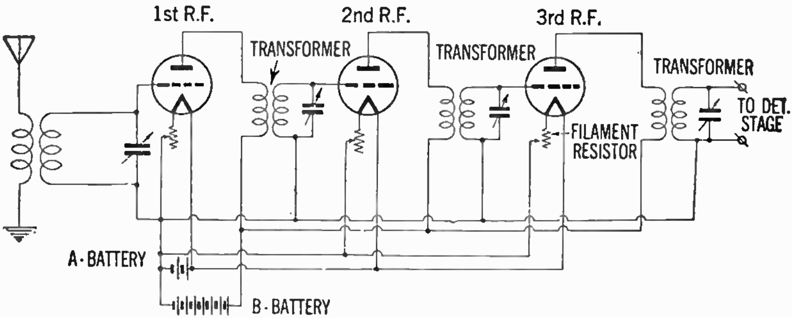


FIG. 14—Three stage radio frequency amplifier circuit.

In the transformer coupled circuit shown in fig. 14, the filaments are connected in parallel across the common "A" battery with a variable rheostat to adjust the filament current. A "B" battery is used to supply all the plate potentials, and a "C" battery (when necessary) to supply all grid biases.

Push-pull Amplifiers.—This type of amplifier is frequently used in receiving sets for supplying more power to the loud speaker than is ordinarily obtainable from one or two stage audio amplifiers.

Another advantage with this type of amplifier is that it eliminates any distortion which may exist in ordinary amplifiers due to the non-linear characteristics of the tube.

It will be found by observing circuit, fig. 15, that this is a balanced circuit, i.e. the cathode returns are made to the mid-point of the input and output devices.

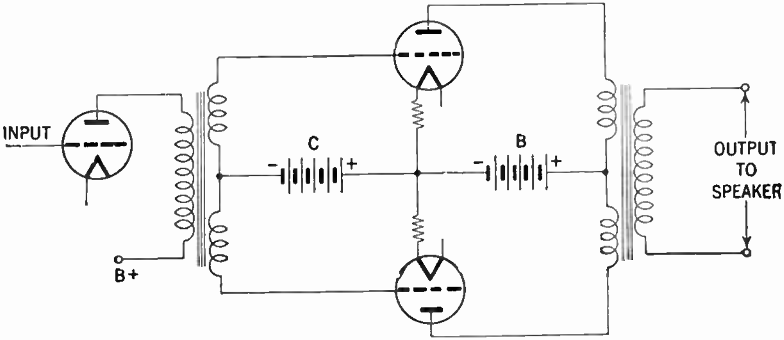


FIG. 15—Push-pull amplifier circuit. This type of amplification requires two identical tubes in each stage. The grids of the tubes are not connected together, as in the case of parallel operation, but are connected to opposite ends of a mid-tapped transformer secondary. The mid tap is used as a common connection for making connection to the negative bias voltage of the grids.

An *a.c.* current flowing through the primary winding of the input transformer will cause an *a.c.* potential to be induced in the secondary, since the ends of the winding will be at exactly opposite voltage with respect to the cathode connection. Hence it will be found that the grid of one tube is swung positive at the same instant that the grid of the other will be negative. From this it follows that the plate current in one tube is increasing, while the plate current of the other tube is decreasing. It is from this characteristic that the name "*push-pull*" has been derived.

Although ordinary amplifier tubes can be utilized in this type of amplifier, it is often desirable to use special power tubes which give a high amplification factor.

How Selectivity of a Receiver Is Affected by the Number of Radio Frequency Stages.—As previously explained the selectivity of a receiver is defined as its ability to discriminate between signals of various frequencies. However, this ability among other factors is affected by the number of stages of which the receiver is composed as well as the selectivity of each individual stage.

The influence of the number of stages upon the selectivity may best be understood by referring to fig. 16 which represents the selectivity characteristics of several radio frequency stages.

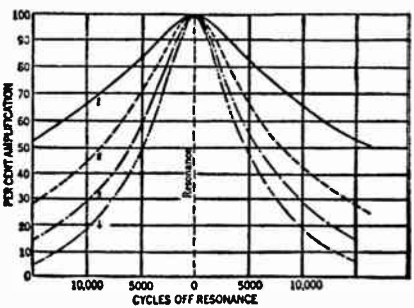


FIG. 16—Illustrates how the several stages of *r.f.* amplification increases the selectivity of a receiver by reducing the strength of undesired signals.

Curve 1 represents the selectivity of one single *r.f.* stage. At a point 5,000 cycles of resonance the circuit gives 84% of amplification at resonance and at 10,000 cycles off resonance the amplification has dropped to only 66% of the resonance amplification.

Assuming that instead of having only one *r.f.* stage that other stages be added having exactly the same characteristics as that of the first, the selective action as that represented by curve 2, will be obtained.

If now at a certain point off resonance, the first stage reduced the amplification factor to 84% then the second stage would reduce the amplification to 84% of what came through the first stage.

With reference to the chart at a point 5,000 cycles off resonance, the four stages would introduce a final amplification of only 49% of the resonant frequency.

Analyzing the result further, at a point 5,000 cycles off resonance the first stage is 84%; that of the second stage 84×84 or 70%; that of the third stage 84×84×84 or 59%, and finally the amplification of the fourth stage 84×84×84×84 or only a little better than 49%.

However, since a radio signal includes modulation frequencies up to 5,000 cycles off resonance, it is evident that a radio frequency amplifier having four stages would cause considerable side band suppression with consequent signal distortion.

Regenerative Circuits and Control Methods.—The term regenerative is applied to any detector circuit in which a coupling is provided between the plate and oscillatory grid circuit. The tube performs simultaneously the function of a detector and an oscillator.

A typical regenerative circuit is shown in fig. 17. The various methods for control of regeneration in receivers are known as potentiometers, ticklers, reversed capacity, etc. Figs. 18 and 19 shows two ways in which regeneration may be controlled by means of a screen grid detector. In fig. 18 the regeneration control is a variable condenser having a maximum capacity of 100 or 150 $\mu\mu$ *fd*. It acts as a variable by-pass between the low-potential end of the tickler coil and the cathode of the tube. If the by-pass capacity is too small the tube will not oscillate, while increasing the capacity will cause oscillations to start at a certain critical value of capacity.

This method of regeneration control is very smooth in operation, causes relatively little detuning of the received signal and, since the voltage on the screen-grid of the tube is fixed, permits the detector to be worked at its most sensitive point.

The sensitivity of a screen-grid detector depends a great deal upon maintaining the screen-grid voltage in the vicinity of 30 volts.

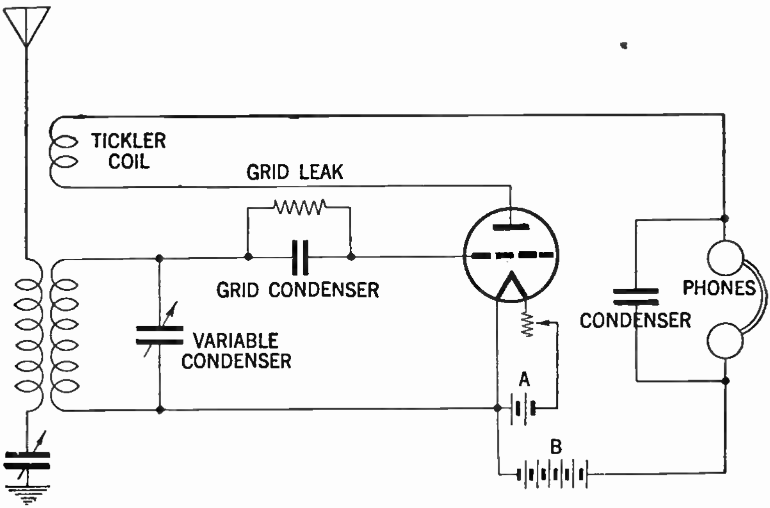
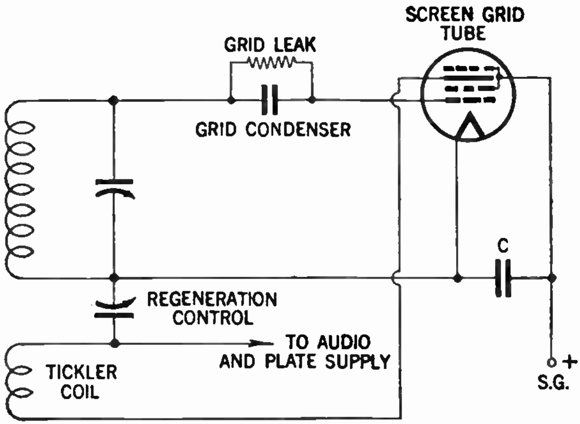
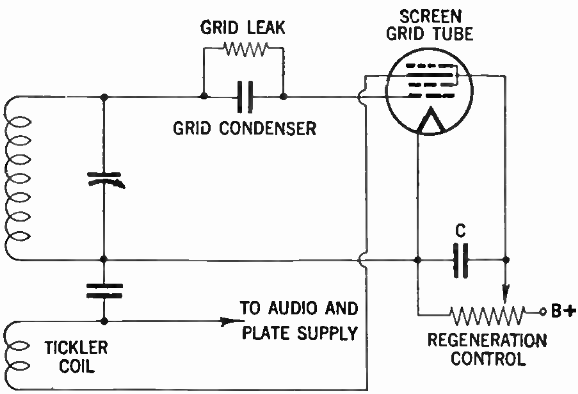


FIG. 17—Regenerative circuit. The scheme of combining a detector circuit with a separate oscillator circuit is called *heterodyning* and oscillators built exclusively for this purpose are called *heterodynes.* A circuit such as this is known as a *regenerative circuit,* and this term is applied to any detector circuit in which a coupling is provided between the plate and the oscillatory grid circuit.

In fig. 19 regeneration is controlled by varying the mutual conductance of the detector tube through varying its screen-grid voltage. The regeneration control is usually a voltage





FIGS. 18 and 19—Showing two methods for control of regeneration in radio receivers.

divider—or so-called "potentiometer"—with a total resistance of 50,000 ohms or more. This circuit causes more detuning of the signal than that in fig. 18 and the resistor is likely to cause some noise unless by-passed by a large capacity (about 1 μ *fd.*) at *C*. In fig. 18 condenser *C* may be .5 μ *fd.* or larger. With circuit, fig. 19, it is necessary to adjust the number of turns on the tickler coil to make the tube just start oscillating with about 30 volts on the screen grid if maximum sensitivity is desired.

Both the methods shown in figs. 18 and 19 may be applied to three-electrode detectors, although these tubes have been largely superseded as detectors by the more sensitive screen grid tubes. To use the method shown in fig. 19, the regeneration control resistor should be placed in series with the plate of the tube and it need not be used as a voltage-divider, but simply as a series variable resistor. It can also be used as a series resistor when controlling a screen-grid tube. Another type of regeneration control, more suitable for lower radio frequencies, uses a variable resistance across the feed-back portion of the *r.f.* circuit.

Conversion of a High Radio Frequency to a Low Radio Frequency.—This method is based on the simple electrical principle that when the energy of two different frequencies is combined in a suitable detector, there is produced a third frequency (termed the beat note or intermediate frequency) which is equal to the difference between the two first frequencies.

Thus if an amplifier is designed for 130 kilocycles and it is desired to receive a broadcast signal of 1,500 *k.c.* all that is needed, is to supply a locally-generated frequency either 130 *k.c.* higher or 130 *k.c.* lower than the received broadcast signal of 1,500 *k.c.*

The combination of the received broadcast signal and the locally-generated signal gives the beat note or intermediate frequency equal to the difference bteween them or 130 *k.c.*

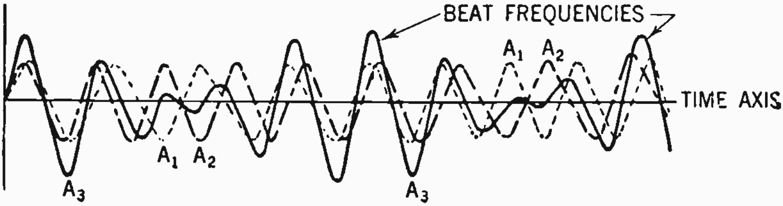


FIG. 20—Illustrates how beat frequencies are generated. With reference to curve A_1 and A_2, it may readily be observed how the frequencies are alternately in and out of phase with each other. The frequency with which these component curves are in phase with each other is equal to the difference between the frequencies of the two component currents, i.e. the frequency f_1 minus frequency f_2 equals frequency f_3. When the two frequencies f_1 and f_2 are the same, they are said to be adjusted to zero beat.

Detection.—It has been previously explained that *r.f.* amplification in a receiving set takes place before the radio signals arrival to the detector circuit. The function of the detector is to de-modulate the *r.f.* wave before it reaches the *audio* stage.

In the receiver it is desired to reproduce the original *a.f.* modulating wave, from the modulated *r.f.* wave, i.e. it is desired to de-modulate the *r.f.* wave.

The stage in the receiver in which this function is performed is often called the **demodulator** or **detector stage.** There are three detector circuits in general use, namely:

1. The diode detector
2. The grid-bias detector
3. The grid-leak detector.

A typical diode detector circuit is shown in fig. 21.

The action of this circuit when a modulated *r.f.* wave is applied is illustrated by fig. 22. The *r.f.* voltage applied to the circuit is shown in light line, the output voltage across the condenser *C* is shown in heavy line. Between points *a* and *b* on the first positive half-cycle of the applied *r.f.* voltage, the condenser *C* charges up to the peak value of the *r.f.* voltage.

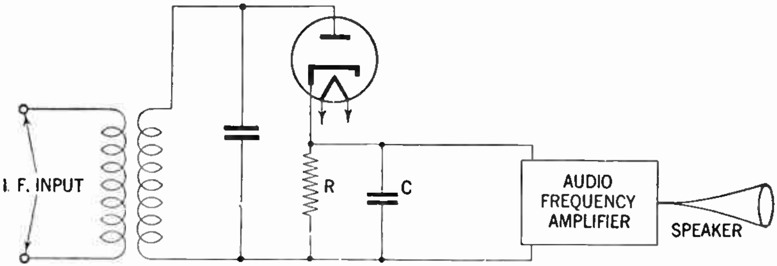


FIG. 21—Diode detector circuit.

Then as the applied *r.f.* voltage falls away from its peak value, the condenser holds the cathode at a potential more positive than the voltage applied to the anode. The condenser thus temporarily cuts off current through the diode. While the diode current is cut off, the condenser discharges from *b* to *c*, through the diode load resistor *R*. When the *r.f.* voltage on the anode rises high enough to exceed the potential at which the condenser holds the cathode, current flows again and the condenser charges up to the peak value of the second positive half-cycle at *d*. In this way, the voltage across the condenser follows the peak value of the applied *r.f.* voltage and thus reproduces the *a.f.* modulation.

The curve for voltage across the condenser, as shown in fig. 22 is somewhat jagged. However, this jaggedness, which represents an *r.f.* component in the voltage across the condenser, is exaggerated in the illustration. In an actual circuit the *r.f.* component of the voltage across the condenser is negligible. Hence, when the voltage across the condenser is amplified, the output of the amplifier reproduces the speech or music originating at the transmitting station.

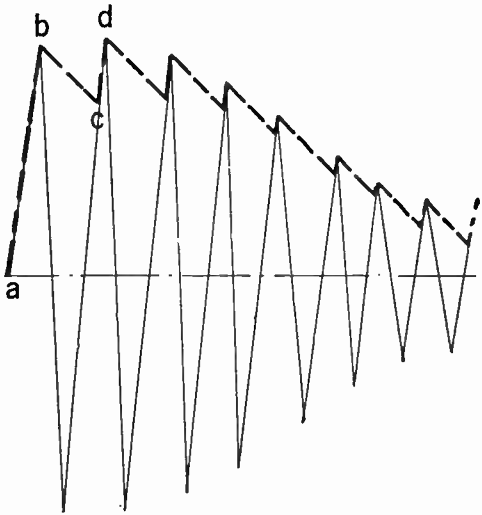


FIG. 22—Diode detector characteristics.

The diode method of detection has the advantage over other methods that it produces less distortion. The reason is that its dynamic characteristic can be made more linear than that of other detectors. It has the disadvantages that it does not amplify the signal, and that it draws current from the input circuit and therefore reduces the selectivity of the input circuit. However, because the diode method of detection produces less distortion and because it permits the use of simple *a.v.c.* circuits without the necessity for an additional voltage supply, the diode method of detection is most widely used in broadcast receivers.

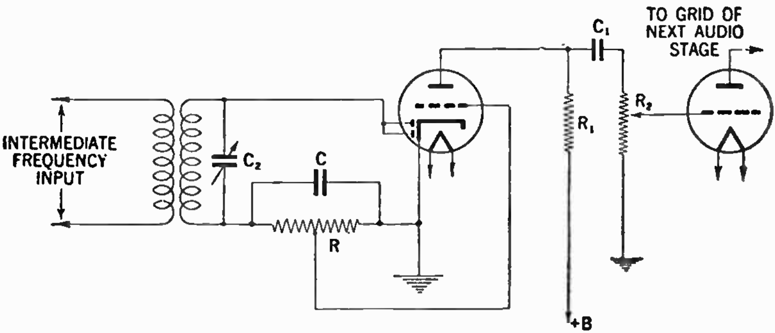


FIG. 23—Diode-biased detector circuit.

Another diode detector circuit, called a diode-biased circuit, is shown in fig. 23. In this circuit, the triode grid is connected directly to a tap on the diode load resistor. When an *r.f.* signal voltage is applied to the diode, the *d.c.* voltage at the tap supplies bias to the triode grid. When the *r.f.* signal is modulated, the *a.f.* voltage at the tap is applied to the grid and is amplified by the triode. The advantage of this circuit over the self biased arrangement shown in fig. 24 is that the diode-biased circuit does not employ a condenser between the grid and the diode load resistor, and consequently does not produce as much distortion of a signal having a high percentage of modulation.

However, there are restrictions on the use of the diode-biased circuit. Because the bias voltage on the triode depends on the average amplitude of the *r.f.* voltage applied to the diode, the average amplitude of the voltage applied to the diode should be constant for all values of signal strength at the antenna. Otherwise there will be different values of bias on the triode grid for different signal strengths and the triode will produce distortion.

This restriction means, in practice, that the receiver should have a separate-channel automatic volume control system. With such an *a.v.c.* system, the average amplitude of the signal voltage applied to the diode can be held within very close limits for all values of signal strength at the antenna.

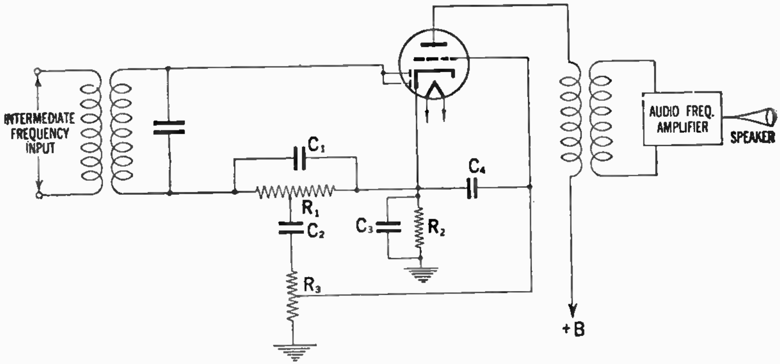


FIG. 24—A typical diode-detector circuit using a duplex-diode tube is shown above. In this circuit R_1 is the diode load resistor. A portion of the *a.f.* voltage developed across this resistor is applied to the triode grid through the volume control R_3. In a typical circuit, resistor R_1 may be tapped so that five-sixths of the total *a.f.* voltage across R_1 is applied to the volume control. This tapped connection reduces the voltage output of the detector circuit, but also reduces audio distortion and improves the *r.f.* filtering. *D.c.* bias voltage for the triode section is provided by the cathode-bias resistor R_2 and the audio by-pass condenser C_3. The function of condenser C_2 is to block the *d.c.* bias voltage of the cathode from the grid. The function of condesner C_4 is to by-pass any *r.f.* voltage on the grid to cathode. A duplex-diode pentode may also be used in this circuit. With a pentode, the *a.f.* output should be resistance-coupled rather than transformer-coupled.

The tube used in a diode-biased circuit should be one which operates at a fairly large value of bias voltage. The variations in bias voltage are then a small percentage of the total bias and hence produce small distortion. Tubes taking a fairly large bias voltage are types such as the 6R7 or 85 having a medium-mu triode.

Tube types having a high-mu triode or a pentode should not be used in a diode biased circuit. Since there is no bias applied to the diode-biased triode when no *r.f.* voltage is applied to the diode, sufficient resistance should be included in the plate circuit of the triode to limit its zero-bias plate current to a safe value.

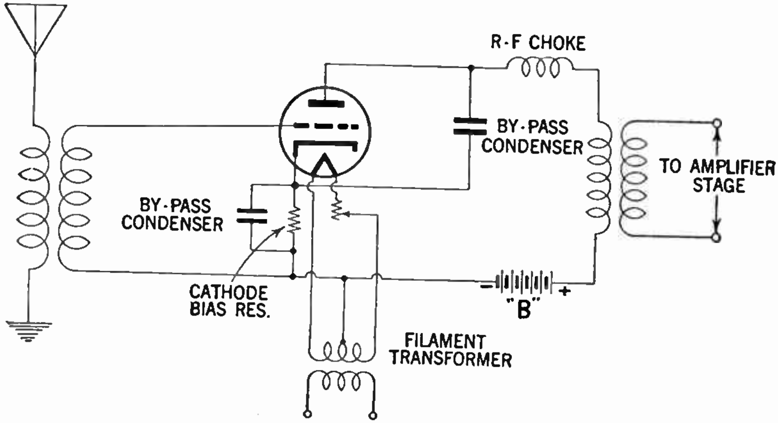


FIG. 25—Grid-biased detector circuit.

A grid-bias detector circuit is shown in fig. 25. In this circuit, the grid is biased almost to cut-off, i.e. operated so that the plate current with zero signal is practically zero. The bias voltage can be obtained from a cathode-bias resistor, a "C" battery, or a bleeder tap. Because of the high negative bias, only the positive half cycles of the *r.f.* signal are amplified by the tube. The signal is therefore detected in the plate circuit.

The advantages of this method of detection are that it amplifies the signal, besides detecting it, and that it does not draw current from the input circuit and therefore does not lower the selectivity of the input circuit.

The grid-leak and condenser method, shown in fig. 26 is somewhat more sensitive than the grid bias method and gives its best results on weak signals. In this circuit, there is no negative *d.c.* bias voltage applied to the grid. Hence, on the positive half-cycles of the *r.f.* signal, current flows from grid to cathode. The grid and cathode thus act as a diode detector, with the grid-leak resistor as the diode load resistor and the grid condenser as the *r.f.* by-pass condenser.

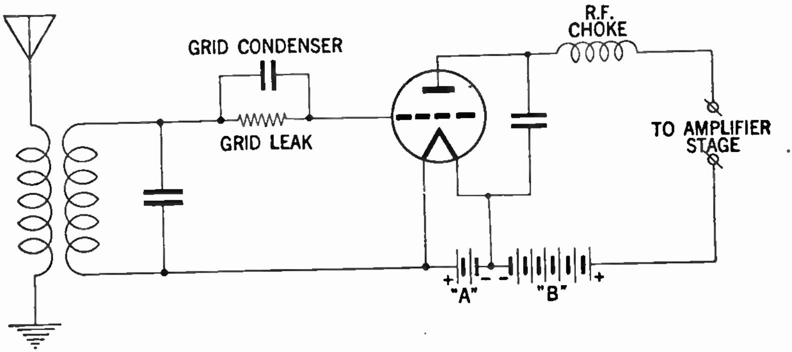


FIG. 26—Detector circuit grid-leak and condenser method.

The voltage across the condenser then reproduces the *a.f.* modulation in the same manner as has been explained for the diode detector. This voltage appears between the grid and cathode and is therefore amplified in the plate circuit. The output voltage thus reproduces the original *a.f.* signal.

In this detector circuit, the use of a high resistance grid leak increases selectivity and sensitivity. However, improved *a.f.* response and stability are obtained with lower values of grid-leak resistance. This detector circuit has the advantage that it amplifies the signal, but has the disadvantage that it draws current from the input circuit and therefore lowers the selectivity of the input circuit.

Tuned Radio Frequency Circuits.—The word *tuned* in this connection simply means that the circuit is brought into resonance with the desired signal. A tuned *r.f.* circuit is one in which

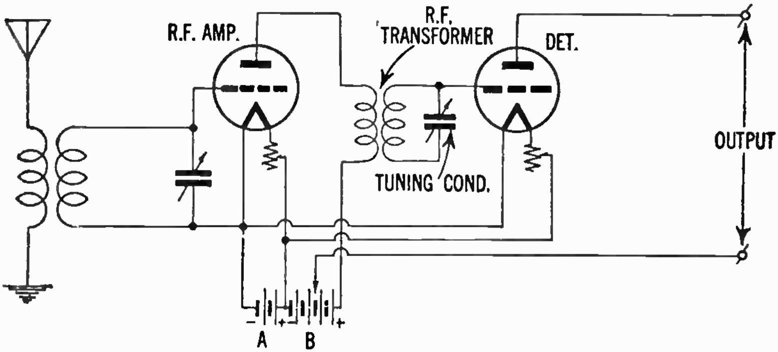


FIG. 27—Diagram illustrating principle of tuned radio frequency. The usual method of tuning is by means of a variable condenser in parallel with the secondary of the radio frequency transformer. A potentiometer is used to control oscillations, as the greatest amplification is obtained when the circuits are operated just at the point before self oscillation starts.

the radio frequency amplifier circuits may be tuned to the desired wave lengths by adjusting the inductance or the capacity or both, although the usual method of tuning is by means of a variable condenser in parallel with the secondary of the radio frequency transformer. (For theory of tuning see page 165.)

Reflex Circuits.—The reflex circuit principle is only one of several circuits developed, whose aim it was to extract the maximum use of a tube or a group of tubes, i.e. to reduce the number of tubes required in a multi-stage receiver.

The use of this circuit, however, with the versatility and relative inexpensiveness of the modern vacuum tube has become largely obsolete except in locations where space and weight of a receiver is at a premium—for example, in connection with portables, airplane, and automobile receivers.

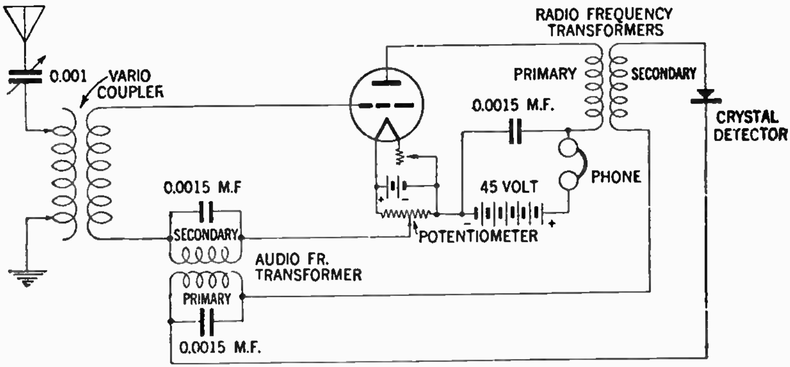


FIG. 28—Diagram showing typical reflex circuit.

In this circuit the vacuum tubes are made to perform the double duties of both radio and audio frequency amplifiers.

The incoming radio frequency signal is amplified at radio frequency, rectified by a detector, and then amplified at audio frequency using the same tube, or if so desired the circuit values can be chosen so that the stage can function as a radio frequency and intermediate frequency amplifier.

It can readily be understood that to construct a stage which will first amplify the signal at the *i.f.* and then further amplify the signal after it has been rectified and converted into an audio frequency, requires a very careful choice of circuit constants, because not only must the circuit elements give the proper load at both audio and intermediate frequencies but filters must also be inserted to separate the frequencies so as to prevent feedback. A typical reflex circuit using one tube and a crystal detector is shown in fig. 28.

Intermediate Frequency Amplifiers.—The function of the intermediate frequency amplifier in a super-heterodyne receiver is to convert the *r.f.* signal to an intermediate frequency.

To obtain this change in frequency, a frequency-converting device consisting of an oscillator and a frequency mixer is commonly employed.

In a circuit of this type two potentials of different frequency namely the radio frequency voltage and the potential generated by the oscillator are applied to the input of the frequency mixer.

The aforementioned potentials beat, or heterodyne with the mixer tube to produce a plate current having in addition to the frequencies of the input potential, numerous sum and difference frequencies.

Generally the output circuit of the mixer stage is provided with a tuned circuit adjusted to select only one beat frequency—that frequency which is equal to the difference between the impressed signal frequency and the oscillator frequency.

It is this selected output frequency which is known as the *intermediate frequency* or in abbreviated form *i.f.*

The output frequency of the mixer tube is kept constant for all signal frequency values by tuning the oscillator to the proper frequency. Methods of frequency conversion for super-heterodyne receivers are as follows:

The first method widely employed before the availability of tubes especially designed for this purpose utilizes as mixer tube either a triode, a tetrode or a pentode. In this method the oscillator and signal potential are applied to the same grid. The coupling between the oscillator and mixer circuits is obtained by means of inductance or capacitance.

A second method employs a tube which is especially designed for this type of service and is known as the *pentagrid converter* tube.

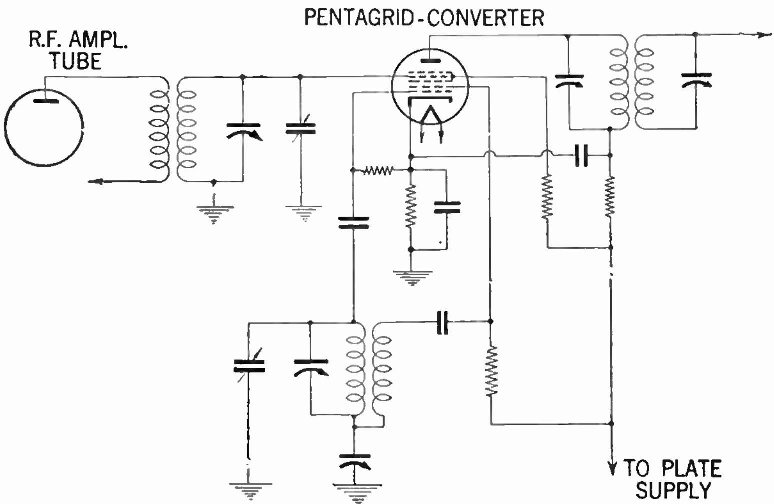


FIG. 29—Pentagrid converter tube employed as an oscillator mixer in a super-heterodyne receiver circuit.

In this tube the oscillator and frequency mixer are combined, and the coupling between the oscillator and mixer circuit is obtained by means of the electron stream within the tube. For the arrangement of elements in a pentagrid converter see page 249.

A third method employs a tube designed for short-wave reception, and is identified as the pentagrid mixer. It has two independent control grids, and is used with a separate oscillator tube.

In this tube the *r.f.* signal potential is applied to one of the control grids and oscillator potential to the other.

Audio Frequency Amplifiers.—An audio frequency amplifier is employed to increase the volume of the signals after leaving the detector tube, but before the signal is passed into the loud speaker.

There are three general methods of audio amplifier couplings whereby the tube of one stage of audio frequency amplifier may be connected to the following stage, identified as:

1. Resistance coupled
2. Impedance coupled
3. Transformer coupled.

Resistance Coupled Audio Frequency Amplifier.—Here, as in previously discussed *r.f.a.* a resistance is employed in the interstage coupling, as shown in fig. 30.

The function of the blocking condenser *C*, is that of insulating the grid of the tube from the high positive potential of the plate supply. In order to prevent the grid from the tendency of accumulating a negative charge, a high resistance leakage path is introduced through grid R_2, the size of which depends upon the value of the grid to filament resistance of the tube.

When a signal potential is received from the detector, a current is generated through coupling resistor R_1, in the plate circuit of the primary tube, these voltage variations lowered by the blocking condenser *C*, are impressed upon the input circuit of the second tube. Finally the grid voltage variations applied to the secondary tube causes corresponding variations of the plate potentials which are impressed on the input circuit of the final stage.

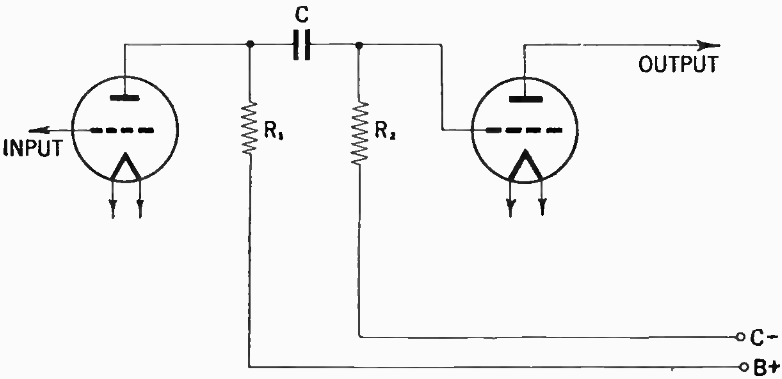


FIG. 30—Interstage coupling in a *resistance coupled* audio frequency amplifier.

Resistance coupling of the audio-frequency stages offer the advantages of good response at low audio frequencies. However, this increases the possibility of trouble from a common plate voltage supply. This is on account of the fact that the by-pass condensers are ineffective at very low audio-frequencies and hence the common voltage supply acts as coupling between the stages. This gives rise to oscillations which are known as motor-boating and may be prevented as suggested on page 320.

Impedance Coupled Audio Amplifiers.—The impedance coupled audio amplifier is similar to the resistance coupled amplifier just described except that in place of the resistance an inductance consisting of a coil of wire wound on a laminated steel core, is utilized.

This type of coupling is also known as choke coil coupling or choke coil amplification. The voltage amplification obtained in this type is, as in the case of the resistance coupled amplifier, due to the amplification of the tube employed.

The effect of the blocking condenser is similar as that described for the resistance coupled amplifier.

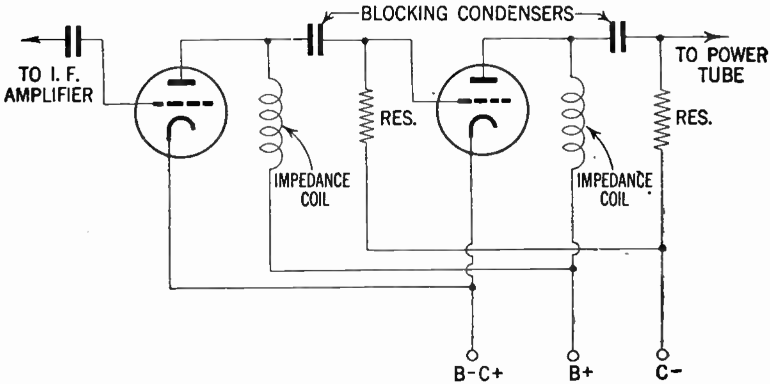


FIG. 31—Inter-stage coupling in an impedance coupled *audio frequency* amplifier.

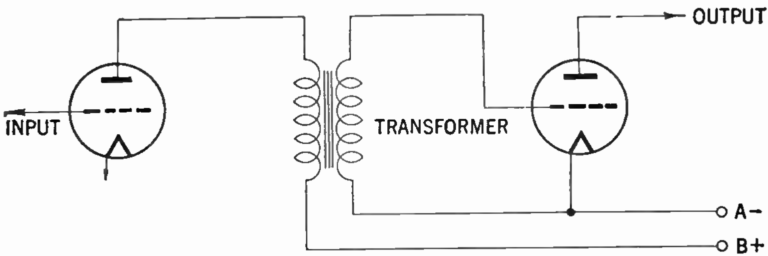


FIG. 32—Method of inter-stage connection of *transformer coupled* audio ferquency amplifier.

Transformer Coupled Audio Amplifier.—In the transformer amplifier shown in fig. 32, the coupling is made by means of a transformer consisting of two windings—one primary and one secondary.

This type of coupling used extensively in early radio receivers has now largely disappeared on account of a number of disadvantages as compared with previous mentioned types.

The voltage gain received in this type is largely defeated due to the fact that it is not linear for all frequencies.

The frequency distortion is caused largely by the distributed capacity existing between the windings of the transformer.

An additional form of distortion known as harmonic distortion is caused by saturation of the iron core in the transformer.

Tuning Indication.—Tuning indication in modern receivers is usually accomplished by the employment of an electronic device identified as the electron-ray tube.

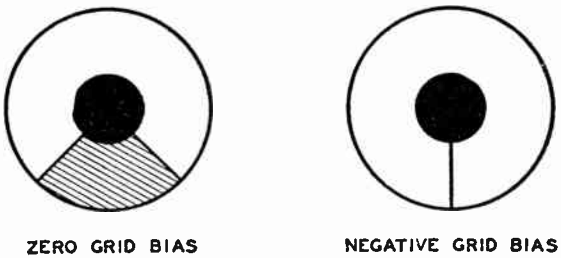


FIG. 33—Electron pattern on the 6E5 target for various grid bias.

The choice between the two types known as the 6E5 and 6G5 for a receiver depends largely on the receiver's automatic volume control characteristics. The 6E5 for example has a sharp cut-off triode which closes the shadow angle on a comparatively small value of *a.v.c.* potential, whereas the 6G5 has a remote cut-off triode which closes the shadow angle on a larger value of *a.v.c.* potential.

In both types the triode is mounted in an evacuated glass enclosure with a fluorescent target in a dome as shown in fig. 34. The target is operated at a positive potential and hence attracts electrons from the cathode.

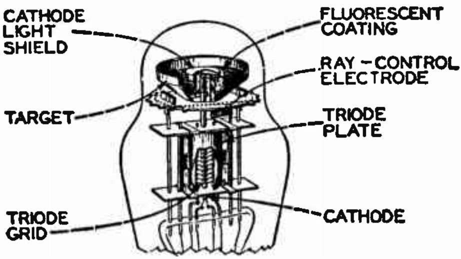


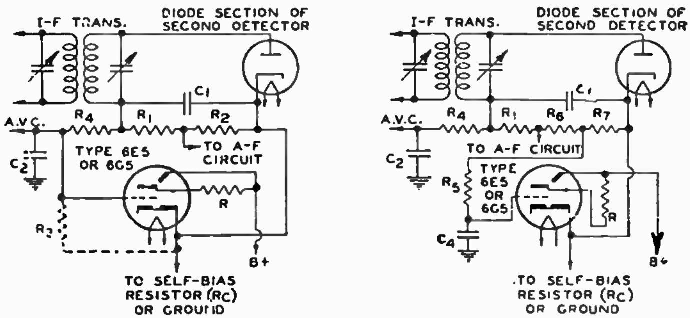
FIG. 34—Internal construction of electron ray indicator tube. (Courtesy R.C.A. Mfg. Co. Inc.)

When the electrons strike the target they produce a glow in the fluorescent coating on the target, which appears as a ring of light when the electrons are flowing over the whole circumference.

The extent of this glow pattern depends upon the grid voltage of the tube, and hence will give an indication on the amount of departure from the condition of resonance or sharpness of tuning.

The tubes may be connected for indicator service as depicted in figs. 35 and 36.

When the receiver reaches a condition of resonance during timing, the automatic control voltage is at maximum, and since this maximum voltage is applied to the grid of the triode, it acts to decrease the triode plate current, and decrease the shadow angle to a minimum, which gives an indication that the set is tuned exactly on the desired station.



FIGS. 35 and 36—Typical tuning indicator circuits. When the strongest carrier received produces sufficient *a.v.c.* voltage to exceed the cut-off bias value of 8 volts, the shadow area of fluorescent traget will overlap. In order to overcome this effect resistor R_3 should be connected, as shown, between the triode unit grid and cathode in order to reduce the control voltage. The value of this resistance may best be determined by applying a strong signal and then adjust R_3 until the shadow angle is nearly zero. (Courtesy R.C.A. Inc.)

$R = \begin{cases} 1.0 \text{ megohm for } B+ = 250 \text{ volts} \\ 0.5 \text{ megohm for } B+ = 100 \text{ volts} \end{cases}$

$R_1 = 0.05$ megohm *rf* (filter)
$R_2 = 0.2$ megohm
$R_3 =$ determined by test
$R_4 =$ *a.v.c.* filter resistor
$R_5 = R_4$
$R_6 + R_7 = 0.2$ megohm
$C_1 = 100$ to 200 $\mu\mu f$
$C_2 =$ *A.v.c.* filter condenser
$C_3 = 0.05$ to 1.0 μf
$C_4 = C_2$

"Motor Boating" of Amplifiers.—Generally this term is derived from the erratic action of a receiving set in giving out a "put-put" sound somewhat resembling that of a motor used in propelling a boat. This is usually caused by inter-action coupling between stages, due to common coupling in the plate-supply unit.

To remedy this situation a circuit known as an "anti-motor-boating" has been found to give good results.

To add a circuit of this kind to any existing receiver it is simply necessary to connect the resistance *R*, in series with the lead connecting between the *B*+ detector terminal on the receiver and the *B*+ terminal on the detector terminal on the power unit.

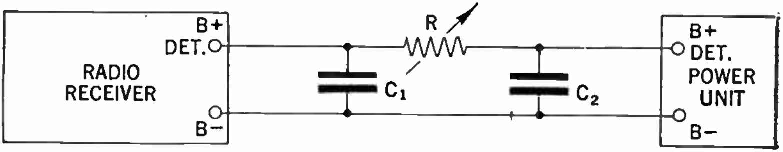


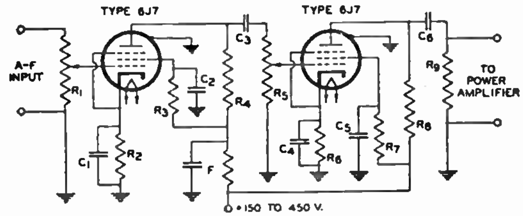
FIG. 37—A method whereby "motor boating" may be eliminated, by means of condensers and resistor connected between the receiver and "B" power supply unit as shown.

Condensers C_1 and C_2 each having a value of 2.0 mfd. are connected between the *B*+ and *B*− as illustrated. It is preferable to locate the resistance at a point close to the receiver rather than near the power unit.

The value of the resistance depends to some extent upon the characteristics of the receiver and the power unit. In some amplifiers a value of 10,000 ohms have been found to be satisfactory whereas in others a resistance of 50,000 to 100,000 ohms has been required to prevent "motor-boating" although in most cases a resistance of 50,000 ohms has been found satisfactory.

A non-motor boating resistance coupled amplifier using two type 6J7 tubes with a voltage gain of 9,000, using circuits values as indicated, is shown in fig. 38.

Various Methods of Obtaining Grid Bias.—The grid bias may generally be defined as the direct potential applied to the grid of a vacuum tube, to influence its operation by making it negative with respect to the filament or the cathode.



C_1, C_4 = 8 μf, LOW VOLTAGE
C_2, C_5 = 0.08 μf, VOLTAGE RATING AS HIGH AS VOLTAGE SUPPLY
C_3, C_6 = 0.008 μf, VOLTAGE RATING AS HIGH AS VOLTAGE SUPPLY
R_1 = VOLUME-CONTROL POTENTIOMETER
R_2, R_6 = 800 OHMS, 0.1 WATT
R_3, R_7, R_9 = 500000 OHMS, 0.5 WATT
R_4, R_8 = 100000 OHMS, 0.1 WATT
R_5 = 500000-OHM VOLUME-CONTROL POTENTIOMETER GANGED WITH R_1
F = DECOUPLING FILTER

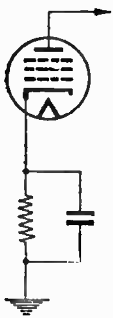
FIG. 38—Schematic circuit diagram of "Non-motor boating" resistance coupled amplifier. (**Courtesy R.C.A. Mfg. Co. Inc.**)

Among the numerous methods of obtaining bias voltage for amplifier tubes, the simplest and most direct way is to connect the "C" battery in series with the grid return lead of each tube.

However, because of a rather popular aversion to the use of batteries, to mention nothing of its cost, this classical scheme is ruled out. The next method in order of simplicity is the use of a self-bias resistor, properly by-passed, as shown in fig. 39. This method is familiar to all set builders and experimenters, and therefore requires little comment. The only disadvantage is the high cost of resistors and by-pass condensers, especially when there are numerous tubes in the set.

A number of other bias circuits are available which have the advantages of simplicity, low cost and reliability. These schemes make use of the fact that the total *B* drain of the set returns to the power transformer through the minus *B*, lead of the set. Fig. 40 shows one of the circuits. A single tapped resistor is used to obtain the *C*, bias voltages for all the tubes. When using this circuit, the cathodes of all tubes are grounded.

Experimenters and set builders will appreciate how much this means in cleaning up the wiring around a tube socket.



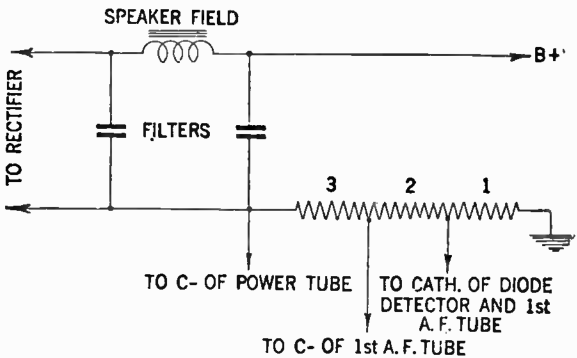


FIG. 39—Showing how grid bias may be obtained by the use of self biased by-passed resistor.

FIG. 40—Illustrating a simple and convenient grid bias scheme.

Finding Resistor's Value.—The proper value of this resistor is easy to determine. With reference to fig. 40 add up the plate and screen currents of all the tubes in the set (this value can be obtained from a tube chart) and divide the total into the value of grid bias of the output tube.

For example, if the sum of all the plate and screen currents is, say, 70 milliamperes (0.07 ampere); the grid bias of the output tube is, say 12.5 volts. The value of the entire resistor is then 12.5 divided by 0.07 or approximately 180 ohms. This resistor is divided into three parts: Part 1, is simply the value of the bias on the *r.f.* and *i.f.* tubes divided by 0.07; part 2, is the value of the bias on the first audio tube divided by 0.07, etc.

If trouble be encountered with this calculation, then find the value of the entire resistor and determine the position of the taps by trial and error; the same answer will be obtained either way.

Using Speaker Field.—Another convenient bias circuit is to make use of the voltage drop across the speaker field when it is connected in the negative leg of the filter. This circuit is shown in fig. 41. In this circuit, all cathodes are connected directly to chassis. The proper position of the taps is best calculated, because *R* should be about 0.5 megohm and accurate readings cannot be obtained on ordinary volt-meters with such high resistors in the circuit.

In a typical case, *E* is 100 volts. R_1 is 3 times 500,000 divided by 100, or 15,000 ohms. R_2 is 1.2 times 500,000 divided by 100 or 6,000 ohms; in a similar manner R_1 plus R_2 plus R_3 is determined.

In circuit fig. 43 is another typical device which is used with much success. In this circuit, the *a.v.c.* resistors are used to form a voltage divider with another resistor R_3. The theory of the circuit is as follows: A bias voltage *E*, is developed across resistor R_4 in a manner similar to that described for circuit fig. 1. This voltage is impressed across R_1, R_2 and R_3 in series. It is the fraction of *E*, that is developed across R_1 plus R_2 that supplies bias for the *r-f* and *i-f* tubes. The entire voltage *E*

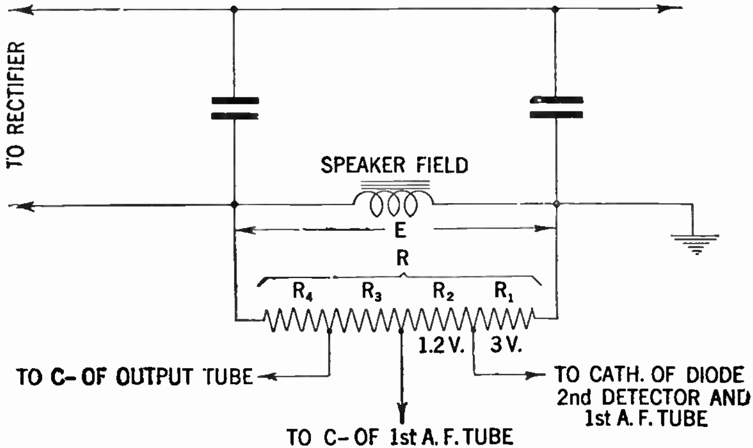
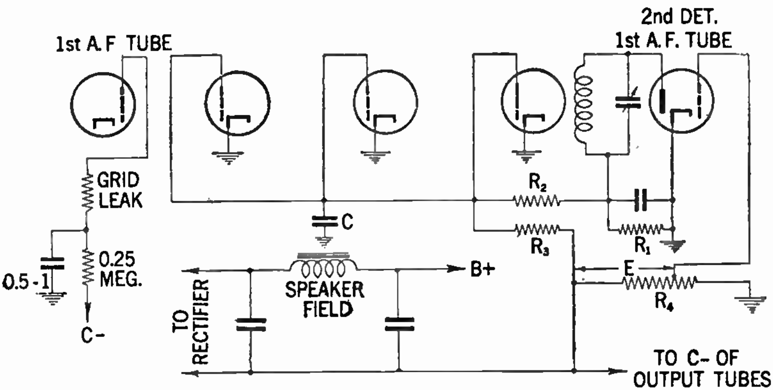


FIG. 41—Method of obtaining grid bias by utilizing voltage drop across speaker field coil.



FIGS. 42 and 43—Grid bias method when receiver is equipped with automatic volume control.

supplies bias for the output tube; the first *a-f* tube obtains bias from a tap on R_4. The merit of this circuit lies in the fact that any hum on R_4 is filtered from the grids of *r-f* and *i-f* tubes by the *a.v.c.* condenser *C*, which is normally in the circuit.

The circuits shown here are fundamental types and there are many deviations from them. This circuit is relatively new and is being adopted by an increasing number of manufacturers for reasons of economy.

Only one precaution need be taken. Should hum develop, simply insert a decoupling resistor in the grid lead of the first audio tube, as shown in fig. 42.

***R.M.S.* (Root mean-square) and Peak Voltage Relations in an Alternating Current.**—In order that a clear conception may be had regarding the exact meaning of the above terms, the definitions are as follows:

1. **The *R.M.S.* (Root mean-square) Value** sometimes identified as effective voltage is that part of an alternating current which has the same heating effect as a direct current of the same potential, and it is for this reason that the *r.m.s.* value of an alternating voltage is termed the effective value.

2. **The Peak Value** of an alternating voltage is the maximum value to which the voltage rises during any part of the cycle. The shape of ordinary *a.c.* voltages are such that the potential is proportional to the sine of an angle, hence the often heard expression of the term "sine curve" shown in fig. 44.

When the voltage has such a form the peak voltage is equal to the $\sqrt{2}$ times the *r.m.s.* value or if the peak voltage is known divide this voltage by the $\sqrt{2}$ to obtain the *r.m.s.* or effective value.

Example.—*What is the effective or (r.m.s.) value of an oscillating grid voltage whose peak values are 7 and 22 volts negative, and what is the grid bias?*

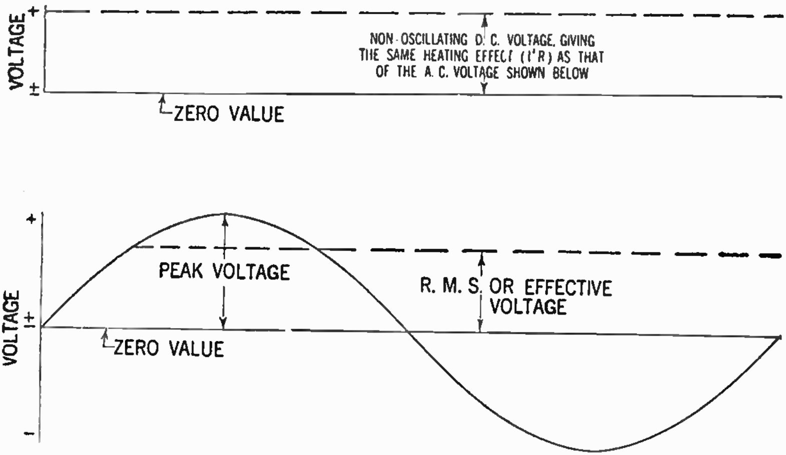


FIG. 44—Illustrating comparative values of *r.m.s.* and peak voltage in an alternating current.

Solution.—Since the extreme values of voltage variation are -7 and -22 volts, the total amount of grid "swing" will be their difference or 15 volts, while the amplitude of an oscillation will be half of this or 7.5 volts. Now the *r.m.s.* value is always $\frac{1}{1.41}$ or 0.707 of the corresponding amplitude; hence the *r.m.s.* value of the grid voltage oscillations will be $0.707 \times 7.5 =$ 5.3 volts approximately. The grid bias point or mean potential of the grid will obviously lie half-way between the extreme peaks of potential attained in the cycle; it will therefore be ½ (7+22) or 14.5 volts negative.

Example.—*If a 2 volt battery supplies 0.85 watt to a filament circuit, what is the current drain?*

Solution.—For the solution of this problem, it is necessary to re-write the equation $W = I \times E$ in the equivalant from $I = \frac{W}{E}$ in which as usual E and I are in volts and amperes, while W is expressed in watts. In the above example therefore—

$$I = \frac{0.85}{2} = 0.425 \text{ ampere}$$

Example.—*It is desired to use 75% of the possible voltage amplification of a triode in a resistance coupled audio frequency stage. If the μ and a.c. resistance of the tube are 22 and 18,000 Ω with 100 volts on the plate, what resistance load is necessary in the anode circuit?*

Solution.—For the purpose of this question, ignore entirely the frequency distortion which is inevitably introduced into the resistance capacity audio frequency coupling, by reason of the inter-electrode capacitance of the tube, and the coupling condenser, and assume simply that amplification is uniform over all frequencies. As a working approximation over a wide frequency band, the actual voltage amplification obtained from a single stage is given by the well known formula:

$$\text{stage gain} = \frac{\mu \times R}{R + Ro}$$

where μ and *Ro* are the amplification factor and anode *a.c.* resistance of the tube, and *R*, is the external load in the anode circuit. In this case, the voltage gain over the stage is 75% of μ.

Hence, $\frac{\mu \times R}{R+Ro}=\mu\frac{75}{100}$

equating and substituting, it follows that,

$$\frac{R}{R+18{,}000}=\frac{75}{100} \text{ or } R=54{,}000 \text{ ohms.}$$

Example.—*If the anode resistance in the preceding example is connected directly to the output of an eliminator supplying current at 300 volts, what is the average current taken by the audio frequency tube?*

Solution.—Since the anode voltage of the audio frequency tube is specified as 100 volts, the voltage drop across the anode resistance will be the difference between 300 and 100 or 200 volts. The average current passing will therefore be—

$$I=\frac{E}{R}=\frac{200}{54{,}000} \text{ or } 3.7\ M.A.$$

CHAPTER 15

Receiver Construction

Tools.—It cannot be denied that a commercial factory built receiver from the standpoint of appearance can be made much neater than most amateur built sets. This is due in most cases to the lack of necessary tools for handling the modern type of construction, found in ready built sets.

It is undoubtedly true that with a few well-chosen tools, an otherwise time consuming piece of work may be turned out neat appearing, satisfactory and reliable from every point of view.

Within certain limits it is true that the greater the variety of tools the better the job will be done, and it is also true that a great many difficult pieces of equipment have been built by only a minimum number of hand tools.

A list of tools commonly required by the amateur are as follows:

1 Hacksaw (12 in. blades).
1 Pr. slip-joint pliers (6 in.).
1 Pr. longnose pliers (6 in.).
1 Pr. diagonal cutting pliers (6 in.).
1 Ball pein hammer (1 lb. head).
1 Bench vise (4 in. jaws).

1 Round bastard file (coarse, ½ in. or more diam.).
1 Flat file (12 in. very coarse for fast cutting).
1 Taper reamer (1 in.) for brace.
1 Taper reamer (½ in.) for brace.
1 Center punch.
1 Electric soldering iron (100 watts, small pointed tip).
1 Heavy knife
1 Circle cutter (adjustable) for brace.
1 Screw driver bit for brace.
1 Countersink for brace.
1 Carpenter's ratchet brace.
1 Hand drill (2 speed).
1 Yardstick or other straight edge.
1 Carpenter's plane (8 to 12 in.).
1 Combination square (12 in.).
1 Pr. wing dividers (8 in.).
1 Long shank screw driver with screw holding clip (¼ in. blade).
1 Screw driver (6 in. to 7 in. ¼ in. blade).
1 Screw driver (4 in. to 5 in. ⅛ in. blade).
1 Scratch awl or ice pick.
1 Cold chisel (½ in.)
1 Wood chisel (½ in.).
1 Pr. tin shears (10 in.).
1 Set small stamped steel open end wrenches.
Several small "C" clamps.
Drills; particularly ⅜ in., ¼ in., 3/16 in. and Nos. 18, 21, 28, 29, 33, 42 and 50.
Solder (rosin core).
1 Combination oil stone for sharpening tools
Sandpaper and emery cloth (several grades).
Steel wool.
Soldering paste (non-corroding).

Method of Bending and Cutting Sheet Metal.—The cutting of sheet metal is generally performed with a hacksaw, following a marked outline on the panel to be cut, after which the rough edge is trimmed down to measurement with a suitable file.

A dependable steel square should be used in marking out the various lines to be cut, otherwise the assembly will be out of alignment when put together.

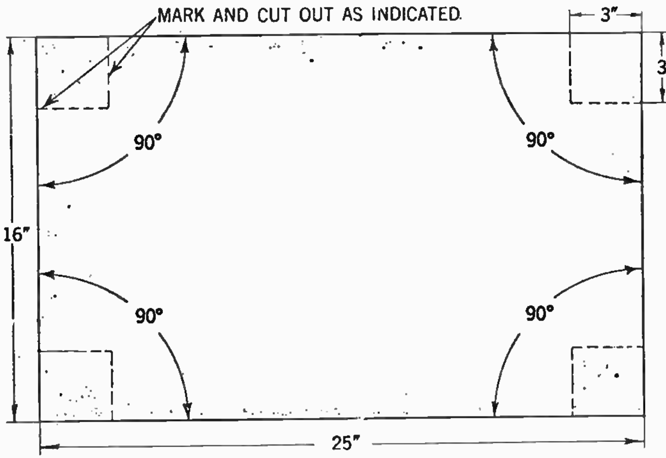


FIG. 1—Showing method of laying out metal to be developed into a radio receiver chassis. The dimensions shown are typical only, and should not be considered as standard for any particular job.

As a final finishing of the edges it is recommended that a long piece of emery cloth or sandpaper be placed on a flat surface, on which the edge of the metal be run back and forth.

In bending a piece of metal the sheet may be scratched as deeply as permissible (without weakening the strength of the piece) after which it is put in a vise and bent to the desired form. Sometimes a pair of iron bars or angles of the same length or longer than the width of the sheet, will facilitate the bending process.

Laying Out the Apparatus.—A general practice of good workmanship is to lay out the component parts, on a sheet of heavy paper upon which the exact outline of the panel or chassis has been made. The parts are generally moved around until a satisfactory arrangement has been obtained. The centers and size of the various holes are then laid out on the paper, after which the

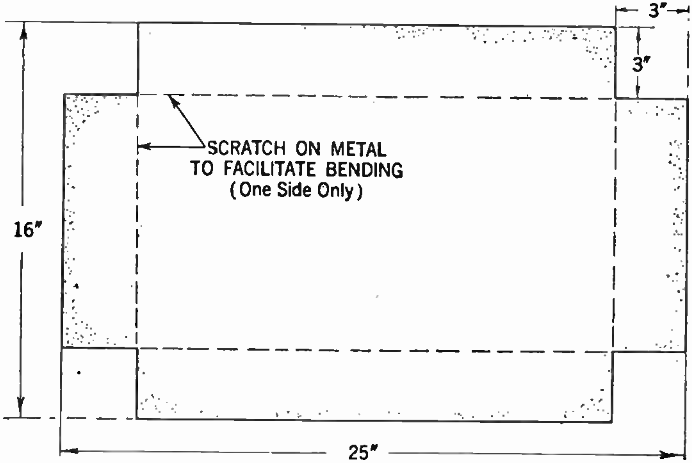


FIG. 2—After corners has been removed and the drilling and cutting completed, the projecting sides of the metal is bent down 90° to form the chassis as shown in fig. 4.

paper is transferred to the panel and properly fastened by gummed paper or adhesive tape. Only after this has been done may the center of the holes be punched through the paper. This general procedure has been found to save a great many valuable panels, and is in the long run, a method of time and money saving.

When measurements are made it is well to observe with great care that the necessary accuracy be obtained, otherwise unnecessary filing and trimming will be required which may finally make an unsatisfactory assembly.

Generally it can be said that holes larger than ⅛ or $\frac{3}{16}$ in. should be drilled with a small drill and then enlarged successively until the wanted size is obtained.

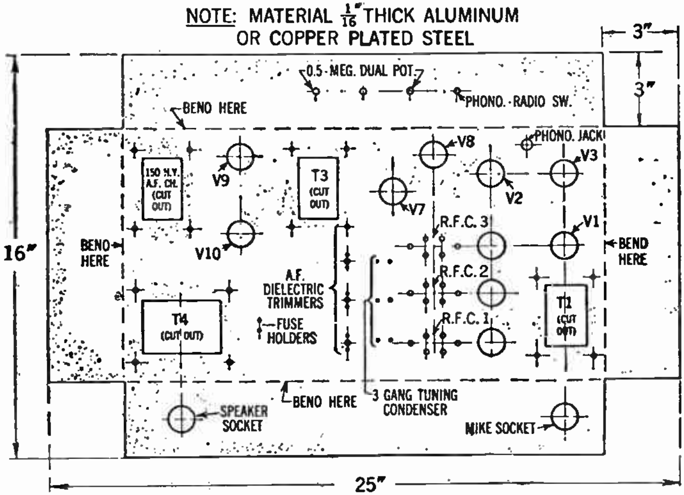


FIG. 3—Example of a typical chassis size and drilling layout, showing location of parts.

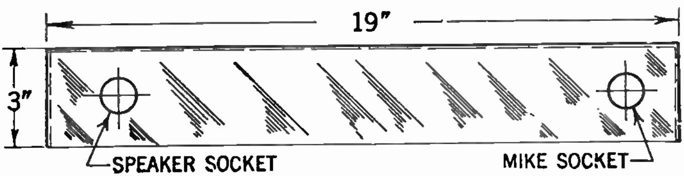


FIG. 4—Side view of final development of chassis.

For holes larger than ¼ in. a taper reamer should be used if possible. When holes of 1 in. diameter or larger are to be drilled, a hole cutter sometimes identified as a fly-cutter is necessary. If such a tool is not available, it may be cut out by drilling a series of small holes as close together as possible, as shown in fig. 5.

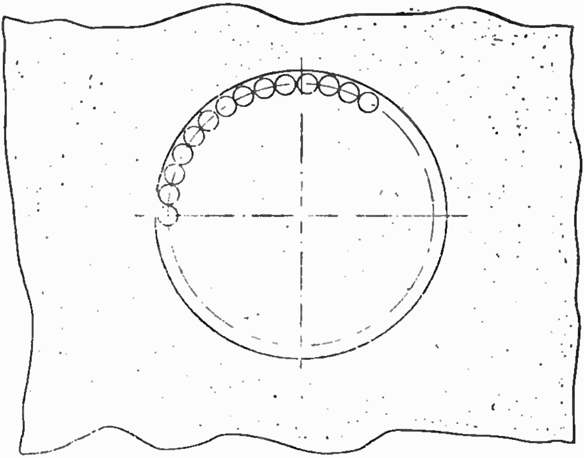


FIG. 5—Method of drilling large diameter holes. After drilling is being completed the remaining corners are removed by a round file of suitable size.

Tapping of Holes.—After the holes are drilled to measurement and before they are tapped, it is well to refer to the table showing the tap sizes to be used for the various standard sizes of machine screws.

Certain metals, notably aluminum, are difficult to tap, hence care should be observed not to break the tap and as a precaution the tap should be kept at right angle to the metal surface, and reversed whenever necessary, and machine oil should always be used.

Soldering.—Before proceeding to the actual construction it may be well to observe the importance of soldering.

In soldering it is important that the solder and the joint be kept at similar and sufficient temperatures. A good soldering joint is made when the heat applied to the solder is sufficient to melt the solder when it comes into contact with the wire forming the joint. Soldering paste of the non-corroding type is recommended, and should be used sparingly, because of the fact that an excessive amount of solder will spread over the adjacent wire insulation causing leakages and breakdowns.

Finally the tip of the soldering iron should be kept at the correct temperature as well as clean and well heated.

Wiring.—The importance of wiring in radio receiver construction should not be underestimated. The old geometrical axiom that a straight line is the shortest distance between two points should not be taken **too seriously** when wiring a radio receiver, if a satisfactory performance is to be expected.

Although there are no specific rules guiding the performance of this task, many skillful constructors wire a receiver in the following order:

1. In case of *a.c.* supply all filaments or heater connections are wired with a pair of twisted wires. They should be placed wherever possible in the angles formed by the top of the chassis separately away from the other circuits.

2. All grid and plate connections are run as directly and with as short leads as possible from the tube socket or cap to the indicated terminal (preferably to the condenser in a tuned circuit) but should be spaced from or run at right angles to other circuit elements.

3. The plate and grid return circuit with their various filter elements are placed in a neat orderly way in place.

Guiding Principles.—Whenever possible, a single common ground point should be used for each stage. By-pass condensers should be placed as close to the socket terminal or by-passed element as possible. Choke coils should be placed so that their fields do not mutually interact, and as much spacing between the parts in adjacent stages should be provided as the construction permits.

When ordinary push-back wire is used for plate and grid connection in short-wave receivers, it should be kept away from the chassis or other parts, since the insulation at high frequency is apt to cause leakage. Spaghetti or varnished cambric insulation is generally satisfactory at ordinary radio frequencies.

Important Information.—The one important factor to keep in mind when wiring a receiver is that damaging reactions between the stages due to stray coupling between the various circuit elements should be avoided, hence too much dependency should not be placed on ordinary forms of insulation, in keeping the elusive high frequency current in boundaries geometrically formed by the wire.

Also the resistance introduced by one single improperly soldered connection may ruin the performance of an otherwise perfect receiver.

CHAPTER 16

Control Systems

AUTOMATIC FREQUENCY CONTROL (A. F. C.)

In the early kinds of radio sets the receiver control had to be operated manually by the turning of one or more volume control knobs. In modern receivers however, automatic frequency control has been incorporated to make this constant manipulation of the volume control knobs unnecessary.

The action of the automatic frequency control circuits in superheterodyne receivers is such that any mis-tuning by the listener or any frequency drift in the set after it has been properly tuned is automatically corrected by the incoming signal itself.

The requirement for an automatic frequency control circuit are:

1. A *d.c.* detector operated through an *i.f.* frequency discriminator network, and

2. An oscillator frequency control circuit.

How the Discriminator-Detector Circuit Works.—The discriminator-detector network as the name implies, discriminates between applied intermediate frequencies which are too low and those which are too high, and produces a corresponding direct current or voltage whose polarity depends upon the direction of frequency departure from a prescribed intermediate frequency. This *d.c.* voltage is applied to a control element which in turn causes a shift in frequency of the local oscillator such as to bring the *i.f.* signal to very nearly the correct intermediate frequency. Since production of the *d.c.* voltage is due to departure from the resonant or center frequency of the *i.f.* system, obviously the correction cannot be strictly complete; but in the system described a correction ratio of more than 100 to 1 is feasible.

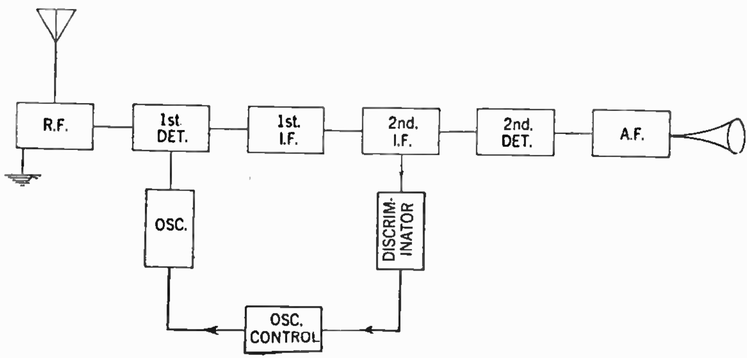


FIG. 1—Conventional block diagram of an automatic radio frequency control circuit.

In other words, when the dial of the receiver is mis-tuned 100 *k.c.* for the received signal, the automatic correction may be made to bring the actual *i.f.* signal frequency to only 100 cycles off resonance in the *i.f.* system. Of course that is easily sufficient.

The Frequency Discriminator.—A method for obtaining differential *d.c.* potentials (or currents) whose magnitude and polarity are determined by the amount and the sign, respectively, of the difference between an applied frequency and the true intermediate frequency is described herewith. Side circuits tuned above and below the center frequency are not used.

The action depends upon the fact that a 90° phase difference exists between the primary and secondary potentials of a double-tuned, loosely-coupled transformer when the resonant frequency is applied and that this phase angle varies as the applied frequency varies. Thus if the primary and secondary voltages are added vectorially, the absolute magnitude of the resultant vector will be greater on one side of resonance then on the other.

The vector sum of the primary and secondary voltages may be physically realized by connecting the two parallel tuned, coupled circuits in tandem, applying the input potentials to one circuit and taking the output across both circuits in series. In this manner, an action similar to that of a side circuit is produced even though the primary and secondary are both tuned to the center frequency.

The potentials at either end of a secondary winding with respect to a center tap on that winding are 180° out of phase. Therefore, if the center tap, rather than one end, of the secondary is connected to the primary, two potentials may be realized, one maximizing above and one maximizing below the center frequency. See fig. 2.

If a transformer is connected in this manner and the resonant frequency is applied to the primary the two resulting output potentials will be equal in magnitude. If these are then applied to two separate, like detectors and the resulting *d.c.* voltages are added in opposition, the sum will be equal to zero. If, however, the applied frequency departs from responance, the sum of their outputs will be some real value whose polarity will depend upon the sign of the frequency departure.

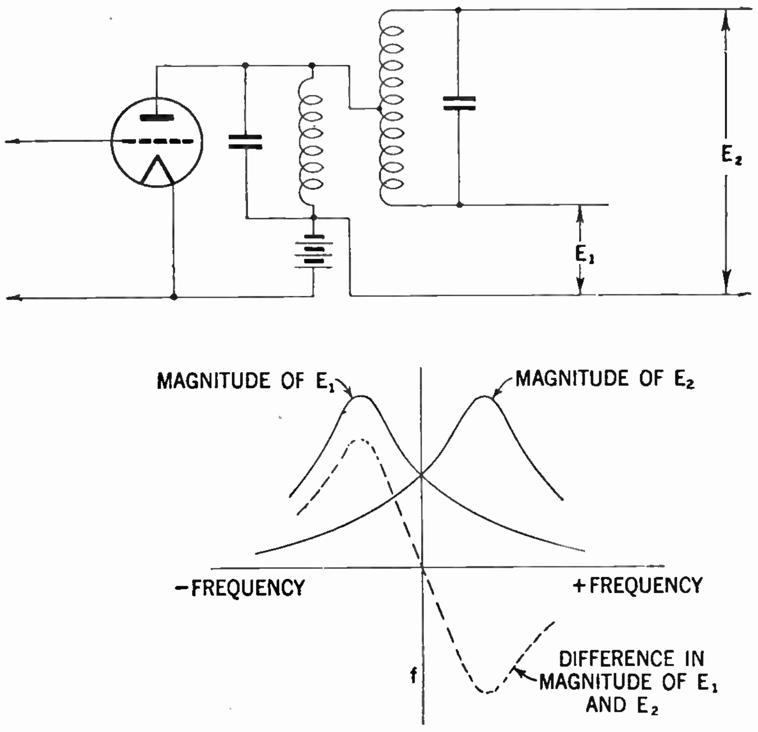


FIG. 2—Diagram and plotted curves illustrating how the potentials at either end of secondary are 180° out of phase.

Referring to fig. 3, the action is as follows: If the resonant or center frequency is applied to the grid of the amplifier tube, equal amplified voltages will exist between the point *A* and ground and between the point *B* and ground. These are rectified by the diodes and direct currents will flow in the resistors R_1 and R_2 in opposite directions with respect to ground. Thus, the net *d.c.* potential produced by the two *IR* drops between *E*, and ground is equal to zero. If, however, the applied frequency departs from resonance the potentials across the diodes will be unequal in magnitude, unequal *IR* drops will be produced in the two resistors and a *d.c.* potential will exist between *E* and ground, the polarity of which will depend upon the sign of the frequency departure.

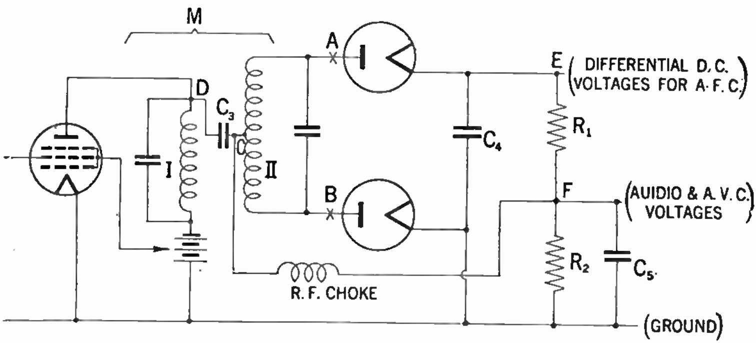


FIG. 3—Automatic radio frequency control detector diagram.

If a carrier at the resonant frequency with normal intensity modulation, but without frequency modulation, is applied to the system, the *a.f.* as well as the *d.c.* voltages across R_1 and R_2 will be equal and opposed. Therefore at resonance there will be no *a.f.* potentials between *E* and ground, and as far as audio components are concerned, the system acts exactly as though point *E*, were grounded with the outputs of the two diodes acting in parallel. Actually if C_4 is sufficiently large to have negligible reactance at the lowest modulating frequency, this is the case. Then the point *F*, becomes a potent source of audio voltages to supply the *a.f.* amplifier system and no other audio detector is necessary.

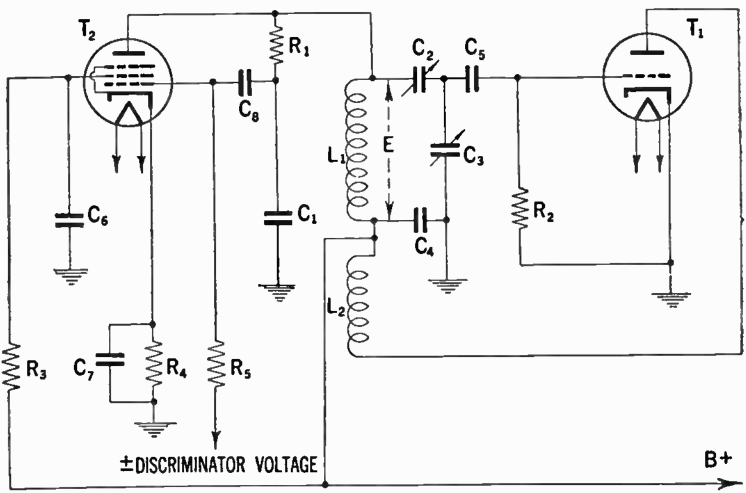


FIG. 4—Typical control circuit diagram.

It can be seen that the *d.c.* potential between ground and the point *F*, will have the proper polarity to be used for *avc* action, and that this potential will bear the same ratio to the developed audio voltages as is found in the conventional diode detector *avc* system. The fact that it maximizes at one side of resonance is of no significance if automatic frequency control is used. When the *afc* is cut out of circuit (manually) point *E*, is grounded. This causes the *d.c.* potential at *F*, to maximize on resonance.

The Control Circuit.—A circuit which will convert *d.c.* discriminator voltages into changes in oscillator frequency is shown in fig. 4. In this figure T_1 is the oscillator tube and T_2 the control tube. The combination of R_1 and C_1 connected across the oscillator tank circuit produces a voltage on the grid of the control tube 90° out of phase with that existing across the tank circuit. Variations in grid bias of the control tube (obtained from the discriminator) vary the plate current of that tube. This plate current is 90° out of phase with the tank circuit voltage and therefore the control tube acts like a reactance in shunt to the tank circuit. The magnitude of the reactance and therefore the oscillatory frequency are varied by the control tube grid bias.

With the circuit shown in fig. 4 the control tube is equivalent to an inductance in parallel with the tuned circuit. An increase in mutual conductance of the control tube produces a decrease in the magnitude of this equivalent inductance and consequently an increase in the oscillator frequency.

Control Tube.—The amount of control is proportional to G_m, but is also affected by the control grid voltage for this G_m, since a high value of bias permits R_1 or C_1 to be smaller for a given oscillatory voltage. Consequently maximum control is proportional to the product of G_m and E_c. Sensitivity of control is however, another important requirement, since it is desired that the frequency change be as large as possible for a given change in bias. This means the control tube should be of the short cut-off type. Further requirements are high r_p, linear change of G_m with bias, and for economy, low plate and screen currents.

All of these requirements are best met by the short cut-off, *r.f.* pentodes such as 57, 77, 6C6 and 6J7. By proper choice of R_1 and C_1 the maximum amount of frequency correction can be adjusted to suit required conditions.

The frequency control readily obtainable by this circuit is of the order of 9.5% of the oscillator frequency in the broadcast band and 1.5% in the region of 10 megacycles.

In a receiver it has been found that a discriminator sensitivity of 100 volts per *k.c.* and a control sensitivity of 7 *k.c.* per volt can be easily obtained, so that an overall control ratio of 700 to 1 results. A tuning misadjustment of 7 *k.c.* will therefore result in only a 10 cycle shift of the intermediate frequency.

The use of *afc* on the short-wave bands has the very much needed advantage of making the tuning operation easier. The tuning control has to be moved only until the frequency is close enough to resonance that the discriminator will develop sufficient voltage to bias the control tube the amount required for the departure from resonance. Short-wave stations are thus spread out on the dial, making them easier to locate and easier to hold.

In the broadcast band this characteristic would have the disadvantage that the receiver would appear to laymen to be broad in tuning in comparison with receivers without *afc*. This apparent disadvantage can be eliminated by combining the *afc* switch with the tuning mechanism so that the *afc* automtically becomes inoperative during the tuning operation.

PUSH BUTTON TUNING SYSTEMS

Push-Button Station Selectors.—Push button station selectors is primarily an arrangement whereby the process of tuning has been greatly simplified. It is thus possible by means of a mechanical arrangement to choose a selected number of stations each one of which may be tuned in by the method of some control to a pre-determined position.

It is only recently however, that these systems have achieved the measure of popularity that it undoubtedly deserves, and this is probably because of the technical difficulties involved in producing a receiver which has the same capabilities as any ordinary set—the problem being not only to incorporate this additional device, but of maintaining it consistently in operation.

These early difficulties, however, have been largely overcome, primarily by the employment of apparatus of a higher standard of quality than was previously possible, and also due to a better understanding of the problems involved.

Various Systems in Use.—There are many push-button tuning systems in use as well as many different methods of control. Perhaps most common, however, is that of a series of push buttons (one for each station) located on the receiver itself, although sometimes these buttons may be duplicated, one set being mounted on the receiver, and the other at the end of an extension cable of suitable length.

Typical Extension Cable System.—A typical system of this kind is incorporated in the current line of General Electric receivers.

In this system remote tuning and volume control is accomplished by extending the push-button tuning circuits by means of a cable to the remote control box.

Changes in the volume level are effected through the use of a motor on the volume control shaft as shown in fig. 5. A reversible motor is employed and controlled by two switches on the remote control box.

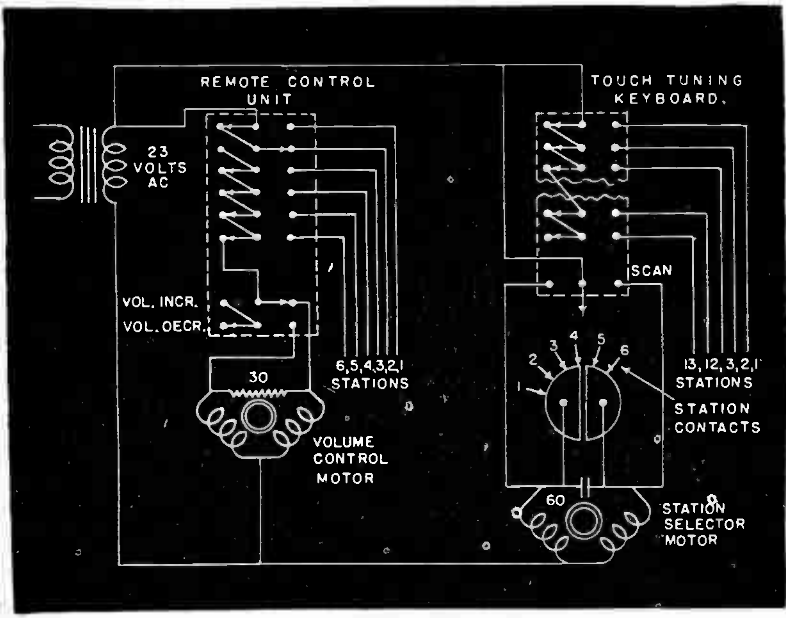


FIG. 5—Schematic wiring diagram of a General Electric push button remote control system.

The station selector consists of the usual electric motor mechanism with a split stator winding. On account of the split stator winding arrangement, the device is *homing*, i.e., goes directly to the selected station.

The capacity of the remote tuning system makes thirteen stations available at the remote control box. The arrangement is such that when the button is depressed for any one of the thirteen stations, the power is automatically turned on to the set.

The remote control keys are non-latching in order to avoid any interference with the buttons on the receiver. At present only six of the stations have been extended for the remote control, which is attached to the set by means of a plug on the rear of the set.

To avoid the possibility of keeping the tuning motor running, by pressing two buttons simultaneously, single pole-double throw switches are utilized at both the receiver as well as at the remote control station.

The power to the volume control motor is supplied from the same transformer which supplies the tuning motor.

It is possible to change the volume of the receiver only after the station button at the remote control station has been released on account of the interlocking feature.

Finally a scan switch for rapid manual tuning from one of the bands to another is provided on the receiver. This switch is of the double throw type, normally open, which permits directive operation of the motor.

Again, instead of the usual push-button system a similar effect may be obtained by a mechanism similar to that of the well-known automatic telephone, and as a matter of fact it is perfectly possible to utilize standard telephone parts in the design of such a tuning control system.

Another remote control system in which the previously discussed control cable is being eliminated, and in which the tuning is accomplished by means of tuning pulses oscillations emanating from a dial, is described on page 346.

How the System Works.—Electrically these various systems divide themselves into two main classes, namely:

1. Those in which a large number of pre-set switch selected condensers are used.

2. Those in which an ordinary variable condenser is provided for tuning but can be remotely controlled by means of an electric motor.

Considering the former the basis for a tuned circuit is given in fig. 6.

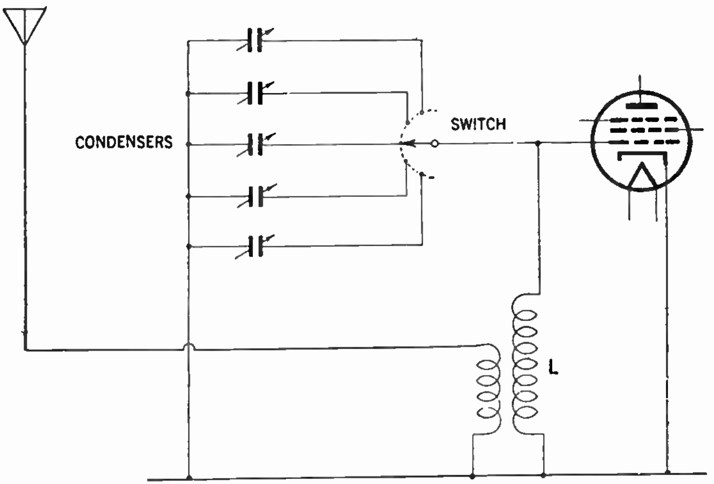


FIG. 6—Schematic diagram showing general principles of simple tuning circuits. In this system a separate pre-set condenser is provided for each station and selected by a switch, as shown.

It may be observed that instead of a variable condenser for tuning the coil *L*, a number of pre-set condensers are provided and the one desired can be selected by means of the switch shown.

It is obvious that each tuned circuit in the receiver must be provided with a similar bank of condensers and switches. With the system under discussion, the switch is set to the first position, and one station is tuned in on the opposite condensers; the switch is then set to the next position and another station is tuned in and so on.

For every station required, it is necessary to provide an extra condenser and switch contact for each tuned circuit.

This particular system has been commonly employed in the past in simple types of receivers. The system has a great merit especially where only two or three stations are required on account of its simplicity.

It is obvious, however, that if a dozen or more stations are required, it begins to be complicated by virtue of the large number of condensers required. There is also a further drawback when it is applied to a selective receiver such as a super-heterodyne, and this drawback is that it may not prove stable enough for satisfactory operation.

Where the circuits are flatly tuned as in the case of the local station receiver, small changes in tuning capacities and the input capacities of tubes have very little effect upon the performance of the receiver, but where the set is selective, then these changes do command quite a large effect.

In a super-heterodyne the oscillator is the critical circuit, and it is common experience with ordinary receivers that the tuning drift somewhat, for perhaps a quarter of an hour or so after switching on.

Where systems of this kind are used, therefore, great care must be taken to maintain stability, and the oscillator circuit must itself be designed to this end.

In addition, the layout of components must be carefully chosen so that their temperature remains as nearly as possible constant and the condensers themselves often have to be of special types, with unusually high stability of capacity.

Motor Tuning.—In this type of remote control tuning systems, the use of a standard type receiver with a gang condenser is utilized.

For the purpose of control the tuning condensers are driven through a chain of gears from a small electric motor of the

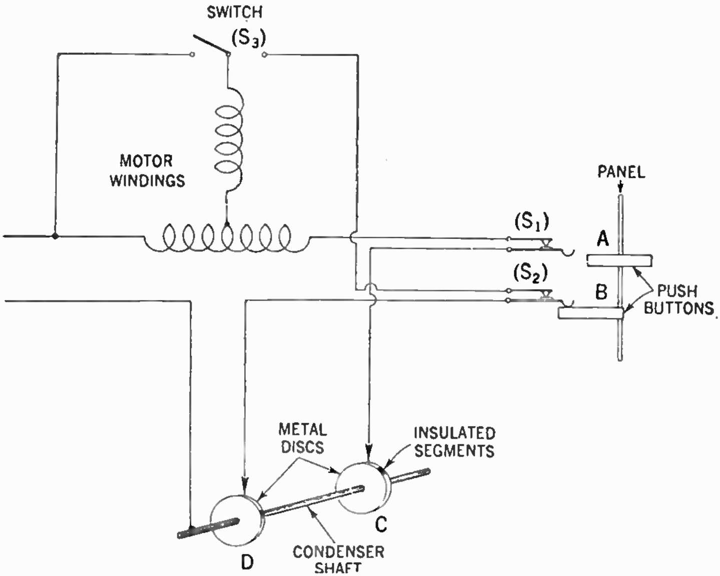


FIG. 7—Diagram illustrating a typical push button control system. The tuning condenser is driven by an electric motor which is controlled by press buttons.

reversible type. This motor usually operates from a 24 volt supply and the method of operation may readily be understood with reference to fig. 7 but there will be one disc for every station required and at the remote control there will be one push button for every disc.

It will be noted that of the two push buttons shown, *A* will be out while *B* is pushed in, so that the contacts of S_2 are closed. The circuit is then completed through the ring *D*, and the motor revolves turning the variable condenser and also the disc *D*.

When the insulated segment comes opposite the contact the circuit is broken and the motor stops. The receiver is then tuned to the desired station, for the initial set-up, the discs have been so aligned on the condenser shaft that the insulated segments in every case correspond to the condenser position for the wanted station.

This is a comparatively easy matter and it could for example be imagined that each disc is being held on by its own set screw to the shaft.

To set up any one disc for a particular station, one would tune in that station manually in the usual manner and then twist the disc so that the insulated segment comes opposite the contact and then tighten up the set screw.

It will be seen that upon pressing a button the condenser may start moving away from the desired station instead of towards it. When this happens the condenser goes on moving to minimum or maximum as the case may be, and then trips the automatic reversing switch S_3 and comes back to the desired station.

With some of the latest systems this reversing switch is unnecessary, for means are included to insure that the motor always start off with the correct direction of rotation.

It is clear, however, that a system of the kind under discussion would by itself hardly be satisfactory since it would not be possible to guarantee sufficiently accurate tuning for a selective receiver. It is, therefore, that this system is almost invariably associated with an *A.F.C.* system which most usually takes the form as shown on page 342 . Such *A.F.C.* circuits properly arranged, will give very good control and take out quite large changes in tuning of the medium and long-wave bands, but in general they are not directly applicable to short-wave reception although naturally they can be employed in a double super-heterodyne.

The disadvantage of *A.F.C.* is that it increases the cost of the receiver, because it increases the number of tubes, and the initial adjustments of the circuit involved is fairly critical. It is therefore generally only found in the more expensive types of receivers. In the less expensive sets it is less often included and a good performance is then secured by paying great attention to stability.

Mechanical Accessories.—It is not within the scope of this discussion to go deeply into mechanics of the actual control circuits because they vary so widely and generally do not effect the principles of operation.

The use of systems which may be known variably as push-button or dial tuning is not confined to remote control, and in some cases these controls are mounted instead of on the ordinary tuning dial, on the receiver itself.

They are then often very much simpler and one arrangement consists merely of mounting a telephone type of disc with the usual finger holes on the shaft of the gang condenser.

Again in another system the condenser shaft carries a number of heart-shaped discs, one for each station. One operating key is provided for each disc, and its pressure moves the cams around in the manner shown in fig. 8.

Still another system has a series of control bars mounted on the condenser shaft. One such bar with its actuating lever is shown in fig. 9.

The lever presses against the rounded portion of the bar and so rotates the condenser shaft, until it reaches the flat part.

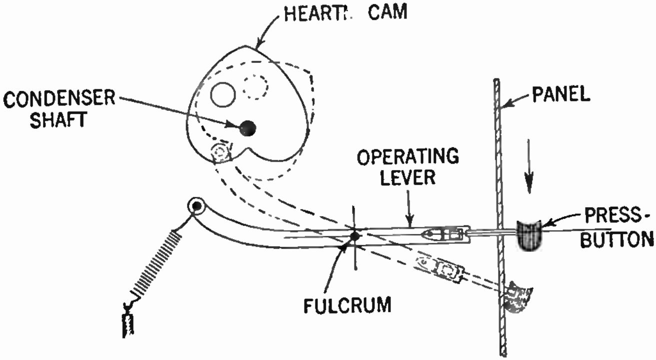


FIG. 8—Principles of control in which the tuning condenser is rotated by the pressure of a lever against a heart cam.

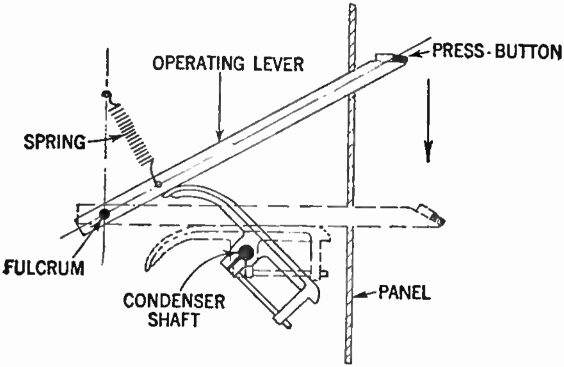


FIG. 9—Method of condenser control by lever system. When pressing the lever it contacts the rounded portion of control bar and so turns the condenser until the flat position is parallel with the lever.

Method of Inter-station Noise Elimination in Automatic Control Systems.—In modern super-heterodyne receivers the potential amplification is very high, hence the tuning problem would be very difficult if an automatic volume control were not included in the receiver.

It is however a well known fact that all *a.v.c.* systems are designed to regulate the gain of the receiver only while a signal is being received; therefore between stations the sensitivity rises to a maximum.

This means, of course, a great increase in the background noise between stations and unless there be a noise suppression auxiliary provided in the receiver to limit this audible noise it often becomes objectionable, especially in locations where there is a large amount of man-made static.

Several schemes have been advanced to solve the interstation noise problem in the *a.v.c.* equipped receiver. Perhaps the simplest one is to provide an adjustable bias on the *i.f.* tube (in addition to the *a.v.c.*) so that the receiver's maximum sensitivity may be manually decreased below the noise level. This undoubtedly settles the noise problem, but it may, through excessive adjustment, reduce the receiver's sensitivity to such an extent that weak stations, which might otherwise be received fairly well, will be skipped by unnoticed. Then, too, if this manual sensitivity control has to be continually retarded and advanced in an effort to locate weak stations, it loses much of its effectiveness as far as noise is concerned.

Another idea for checking inter-station noise and one which has found greater favor among set designers and experimenters than that outlined previously, is the utilization of a vacuum tube as a carrier controlled relay to block the audio amplifier when no signal is being received. This system is very efficient as a noise suppressor.

It is fully automatic in action once the circuit has been properly adjusted. However, while some radio men have successfully installed it in existing receivers, it is generally most effective when included in the original design of the set since it is quite critical in its voltage requirements.

In analyzing the nature of this between-station noise, it has been found that most of it occurs in the high audio frequency spectrum; thus, if the high frequency response of the receiver is checked by a tone control, the intensity of the noise will be greatly reduced. However, the degree of high note suppression needed to limit inter-station noise is much greater than can be tolerated where good fidelity of tone is desired from a local station.

For this reason on the usual radio which is equipped with a manual tone control, it is necessary to adjust the control frequently to meet existing conditions. By adding a tube to the diode detector circuit as shown in fig. 10 this tone control action may be effected automatically in the *a.v.c.* equipped receiver. It is an idea that has been successfully used for noise suppression purposes in several of the larger super-heterodynes, and due to its simplicity it can be easily adapted to any receiver using *a.v.c.* A worthy feature of the system is that it will decrease noise without reducing the overall sensitivity.

This automatic tone control must operate in conjunction with a diode type detector. The left half of the accompanying diagram shows the fundamental diode second detector and *a.v.c.* rectifier circuit found in the majority of modern superheterodynes. Although the tube shown is a 6H6, it may also be the diode portion of a diode-triode or diode-pentode tube; and in some older model receivers, it may even be a triode connected as a diode.

If the associated parts of the detector circuit consisting of resistors R_1, R_2 and R_3 and condensers C_1 be arranged as shown,

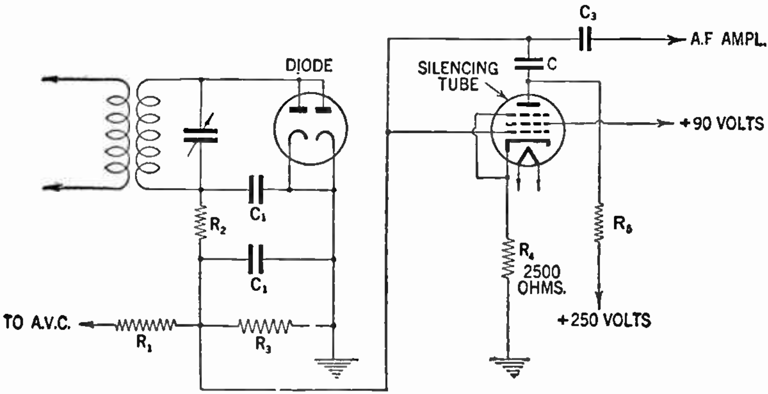


FIG. 10—Automatic tone control circuit.

they need not be disturbed when adding the tone control tube to the receiver. However, if R_3 is a volume control potentiometer, it must be removed and used instead in the grid circuit of the first audio tube to control the input to the grid of this tube. The original fixed resistor in the audio grid circuit may then be shifted to the R_3 position if it be .25 to .5 megohms in value.

In some sets, R_2 may be replaced by an *r.f.* choke or it may be omitted altogether without affecting the performance of the circuit. The experimenter may also find that some receivers divide the functions of *a.v.c.* and detection, using separate diode sections or tubes for each purpose. In this case, connect the tone control tube to the detector diode circuit and disregard the separate *a.v.c.* system.

CHAPTER 17

Loud Speakers

The function of a loud speaker is to convert the amplified audio frequency currents into sound waves. In order to accomplish this the loud speaker must be designed in such a way that it will cause the varying electric currents to set in vibration a diaphragm similar to that used in a telephone receiver, only larger.

The vibration of the diaphragm in turn sets the surrounding air molecules into motion. The vibration of this comparatively large volume of air produces the sound, which the ear receives and the brain sometimes appreciates.

The efficiency of a loud speaker is defined as the ratio of the useful acoustical power radiated, to the electrified power supplied to the load and is very low even in the most carefully designed.

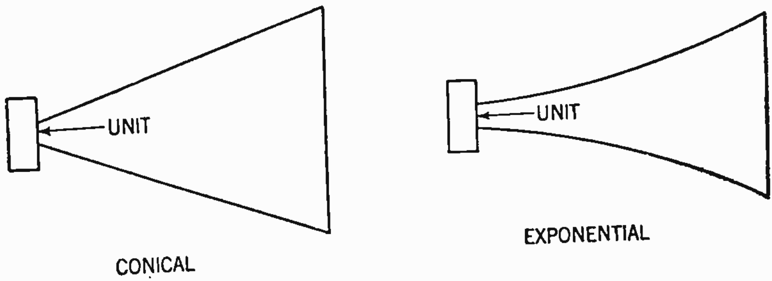
The most efficient type in common use in sound picture work has an efficiency of only about 30%.

Speaker Parts.—Generally loud speakers consist of two main parts:

1. That part of a loud speaker which changes the varying currents of the audio frequency amplifier into mechanical vibrations, which is called variously *the driving unit or motor*.

2. The other part is that which acts in conjunction with the driving unit to produce the vibration of the air molecules, and consists of a surface of various geometrical designs such as a *conical* or *flat shaped horns*.

The horn has been known and widely used for centuries for increasing the radiation from a sound source. Although it is not within the province of this chapter to enter into a discussion of



FIGS. 1 and 2—Conical and exponential horn forms.

horn design, it may be well to mention that the horns most commonly used for sound reproduction are the *conical* and the *exponential* types.

Figs. 1 and 2 show the two forms of horns most commonly in use.

The *conical* horn may be defined as one in which the cross-sectional area of the horn varies in direct proportion to its length, whereas in the exponential form the area of the horn varies as an exponent of its length.

Classification of Speakers.—Loud speakers may be divided into the following general classes, depending upon the principle involved in operation of the driving unit, namely:

1. Magnetic
2. Dynamic, variously called electro-dynamic
3. Balanced armature
4. Induction
5. Metal strip
6. Electro-static, variously called condenser speaker
7. Piezo-electric, variously called crystal speaker.

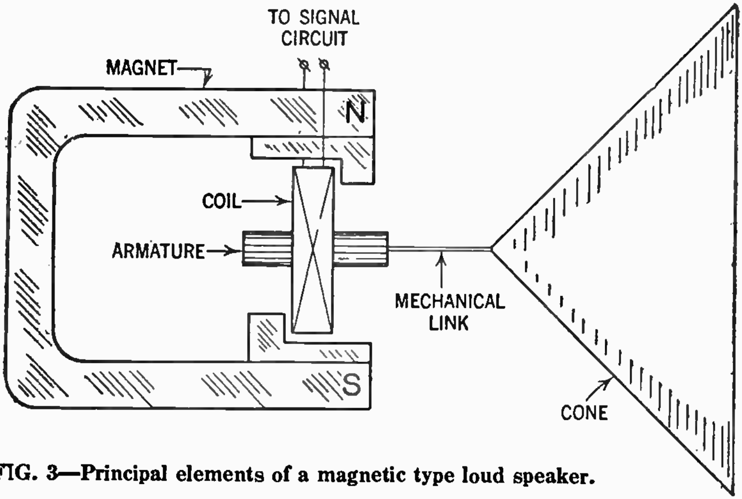


FIG. 3—Principal elements of a magnetic type loud speaker.

Magnetic Speakers.—In this type the moving iron driving type is employed. The principle of operation is based on the varying of the magnetic polarity of the armature. These variations are caused by the electrical impulses flowing through the coil winding which encircles the armature.

The movement to the armature is effected by the induced nagnetism, causing it to oscillate between the two poles of the permanent magnet.

Dynamic Speakers.—A speaker of this type illustrated in figs. 4 and 5 consists principally of the following parts: 1, field coil; 2, voice coil; 3, cone.

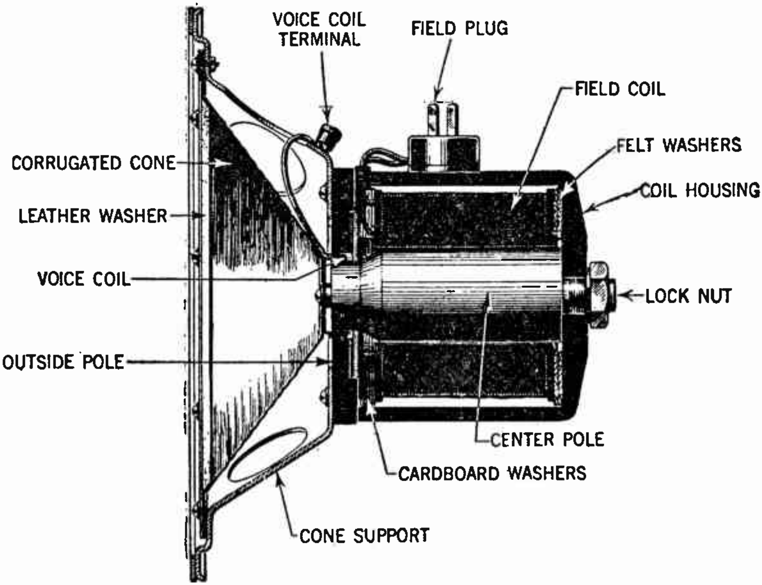


FIG. 4—Cross-section view of a dynamic type loud speaker with a moving coil driving a cone type diaphragm. Details of the various units are here clearly represented.

The field coil is connected to a *d.c.* source, effecting a strong magnetic field across an air gap in which the voice coil is inserted. The signal current from the output terminal of the receiver, flowing through the voice or moving coil placed around the middle pole of a three pole magnet, causes the voice coil to oscillate corresponding to the oscillations of the signal current.

The diaphragm being mechanically connected with the voice coil oscillates in a similar manner.

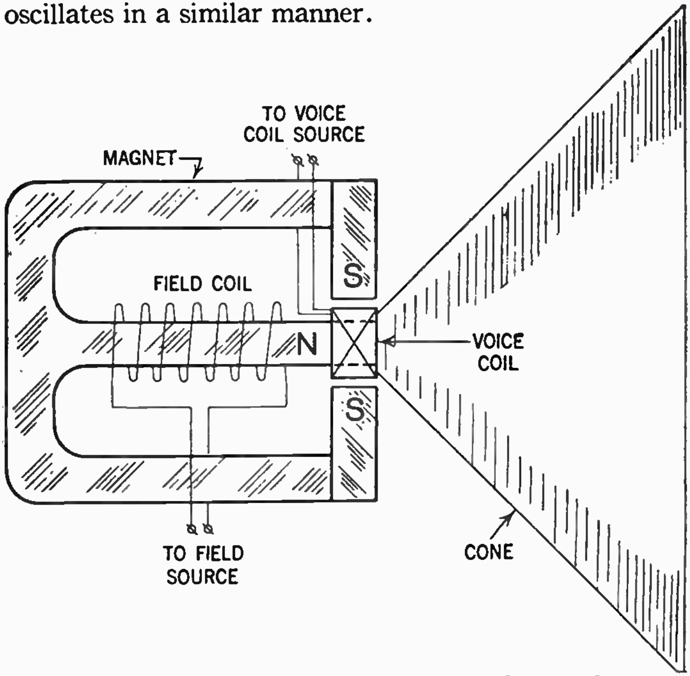


FIG. 5—Simplified diagram of dynamic speaker units shown in fig. 4.

Balanced Armature Speaker.—In this type of speaker the armature (as the name implies) is balanced between the two poles of a permanent magnet as shown in fig. 8. The armature is provided with a coil through which the signal current flows as indicated, so that the reaction between the magnetic field due to this current and that due to the permanent magnet causes the armature to oscillate about its pivot.

These movements are communicated to the diaphragm by means of the link connection in a similar manner as in the dynamic speaker previously described.

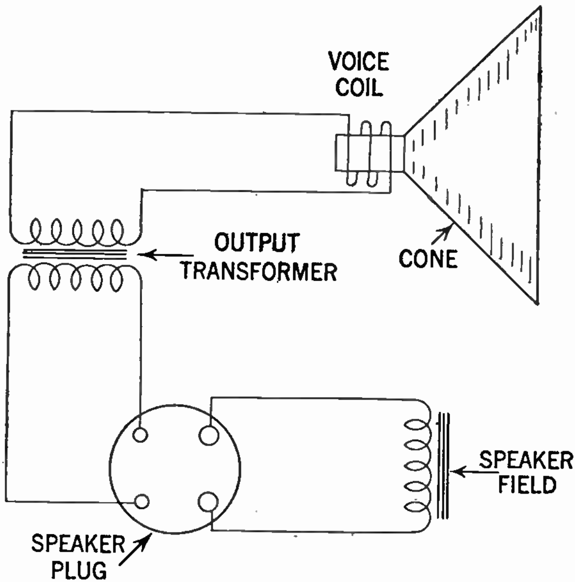


FIG. 6—When the dynamic speakers as in some commercial sets are connected by means of plug and cable to the chassis, the connections may be as shown in fig. 6 or 7; generally however, there is no set rule for these connections. The output transformer may be mounted on the receiver chassis or on the speaker frame. Again, the output tubes may be connected in parallel or in push-pull. Therefore, the connections shown are typical only and may not be considered as standard, but in each case the makers diagram should be carefully checked and followed.

The principal features in this construction is a complete elimination of chattering on loud signals, usually encountered in the magnetic type. However, one of its limitations is that for a good sensitivity the air gap between the armature and the pole pieces must of necessity be made very small to reduce the reluctance and so as to obtain a strong magnetic field. This is objectional since when receiving low notes the movement of the armature may be so great as to strike the pole pieces, emitting a rattling sound.

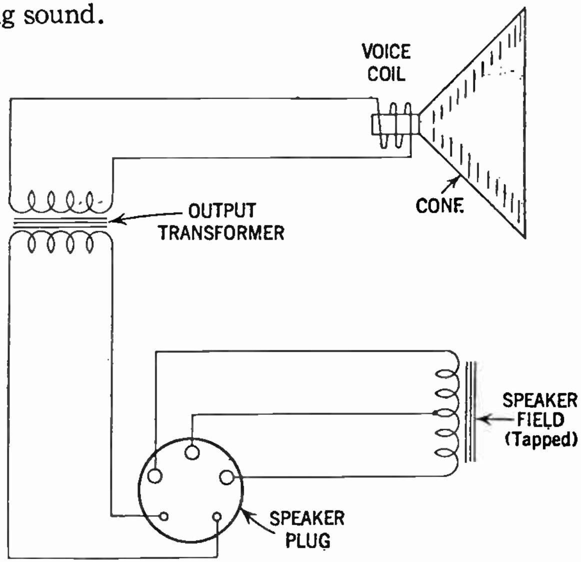


FIG. 7.—Schematic diagram of connections to speaker by means of plug-cable arrangement.

When the air gap is made larger, eliminating this rattling, the field strength decreases with a proportional loss in sensitivity.

Induction Type Speakers.—The name induction speaker is derived from the fact that the motion of the driving unit is obtained from a magnetic induction similar to that of the well known A.C. induction motor, where a rotor revolves under the influence of a changing magnetic field.

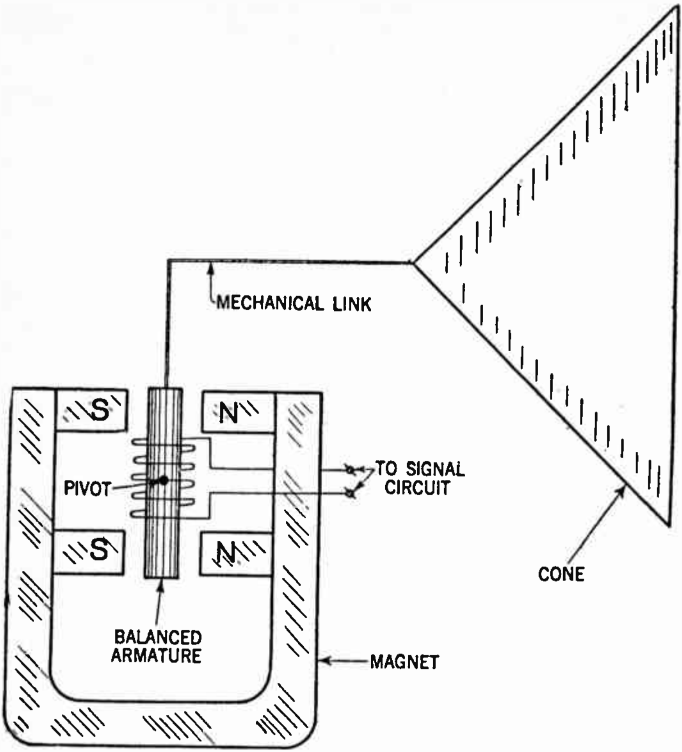


FIG. 8—Balanced armature type speaker. ***In construction*** **the balanced pivoted armature is a soft iron bar forming a core of a coil of several thousand turns of fine wire supplied with audio frequency current.** ***In operation*** **when a signal current flows through the coil, a magnetic field is produced. which magnetizes the soft iron armature. The poles react on the poles of the permanent magnet and attraction between the unlike poles and repulsion between the like poles take place. With the polarities shown, the top end of the armature would move to the left and the bottom end to the right when the signal current flows through the coil in the corresponding direction. The amount of pull or movement is proportional to the current flowing through the coil, so the armature moves in accordance with the variations in the current.**

As shown in fig. 9, the diaphragm is placed between two sets of concentric coils. Direct current is applied to the two sets of coils in opposite directions, causing a radial field.

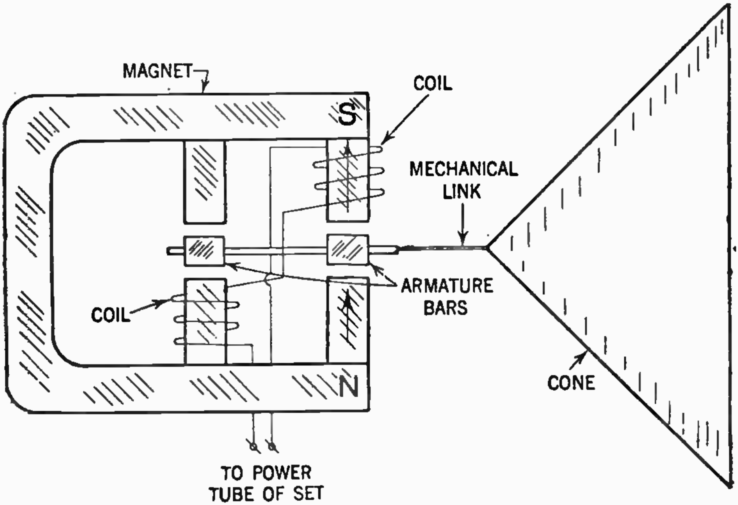


FIG. 9—View showing various units and connections for an induction type loud speaker.

The signal current is also passed through the coils which causes the steady field due to the direct current to vary and which in turn induces eddy currents in the diaphragm.

Since the eddy currents give polarity to the faces of the diaphragm these poles react with the poles of the coils, thus causing vibration of the diaphragm and resulting sound waves.

The utilization of strong permanent magnets makes for a low-priced and simple unit, and since there is very little possibility of objectionable hum being introduced when used in connection with battery operated receivers, it is particularly adaptable for automobile radio use.

Metal Strip Types.—In this type a metal strip is suspended between the poles of a permanent or electro-magnet. The signal current passes through this strip (see fig. 10) establishing a magnetic field around it which reacts with the field, due to the permanent magnet, which acts to displace the metal strip in accordance with the variations in the signal currents.

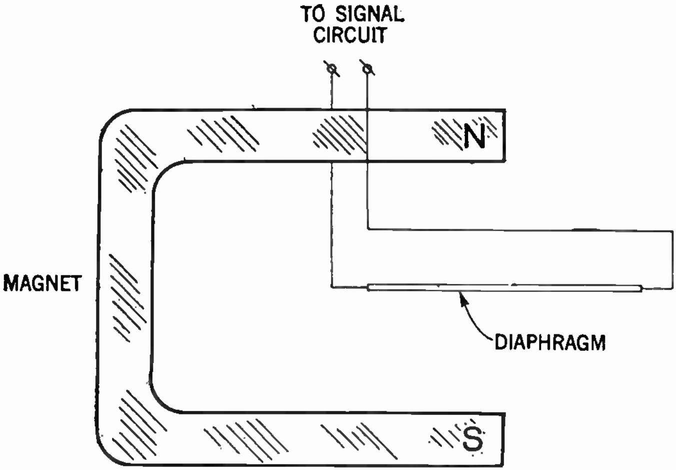


FIG. 10—Principal element of metal strip speaker. A megaphone is usually associated with this type of speaker.

The metal strip is in this case the diaphragm and obviously need not be of magnetic metal.

Electro-Static Types.—This type variously called a condenser speaker consists essentially of three parts, namely: two plates of which one is stationary and the other free to vibrate, in addition to the dielectric, assembled as shown in figs. 11 and 12.

It operates on the well known principle of electrostatic attraction and repulsion, in that two bodies of similar charges of electricity repel each other, whereas two opposite charges attract each other.

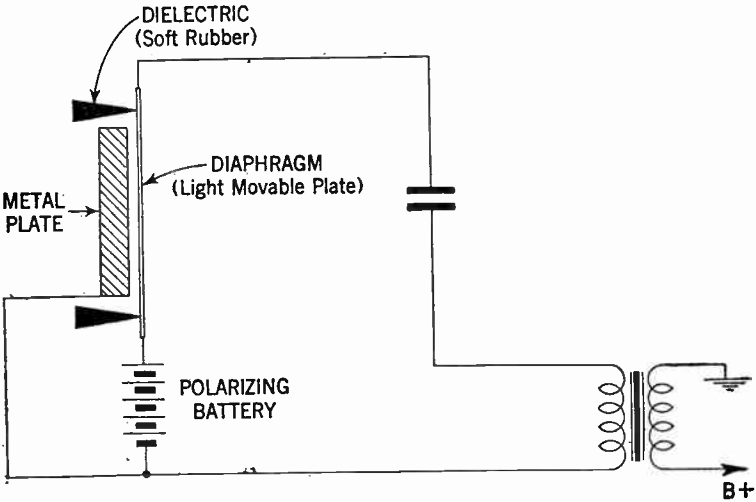


FIG. 11—Electrostatic speaker showing circuit connections. In construction, the metal plate is made rigid. The diaphragm consists of a thin layer of metal sprayed on the rubber dielectric.

When a polarizing voltage is applied to the plates a steady electric field is built up; superimposed upon this is the audio-frequency alternating electrostatic field. This, according to the foregoing, causes an attraction and repulsion between the two plates, producing in the free plate oscillations corresponding to the audio-frequency impulses.

The back or stationary plate in the commercial types of condenser speakers consist usually of stiff metal such as copper, iron or aluminum. The back plate is usually perforated with slots in order to prevent compression of air between the two plates.

To obtain a large force on the movable plate the dielectric must be very thin and flexible and must have the largest possible dielectric constant, in addition to a high break-down voltage.

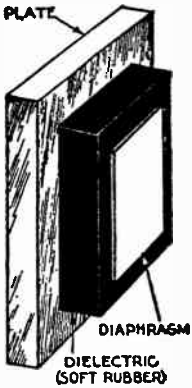
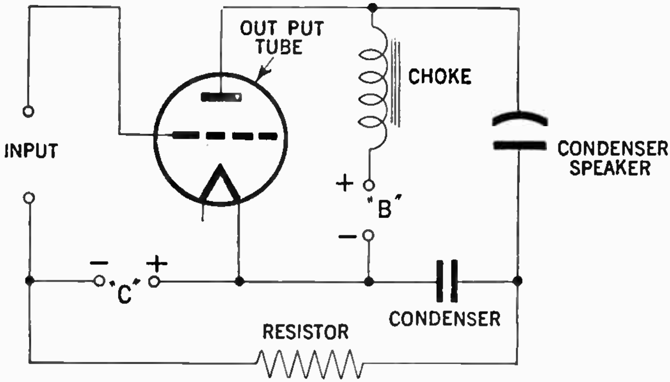
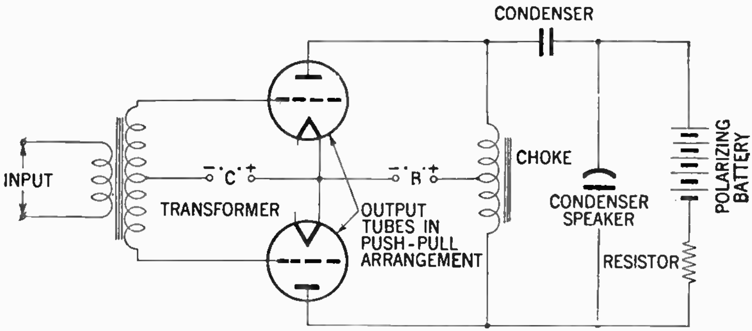


FIG. 12—Elements of an electrostatic speaker. It consists essentially of a form of condenser, hence the name as it is often called a condenser speaker.

Piezo-Electric Speakers.—This type of speaker (often referred to as *crystal speaker*) depends for its operation on the property of a crystal of expanding and contracting in accordance with the electrical strain to which it is subjected.

The crystal speakers are often used in connection with high-frequency reproduction, its use up to the present, however, has been limited to small units. As a speaker of this type is inherently a rectifier, it is obvious that there is no need for any separate output transformer or frequency filtering network.





FIGS. 13 and 14—Showing two circuit arrangements for connections of a condenser type speaker to the power amplifier stage of the receiver.

Loudspeaker Baffle.—In a loudspeaker such as that shown in fig. 4 the material constituting the cone is driven forward and backward in the manner of a piston by the action of the impressed audio frequency signal. This constant movement displaces a certain amount of air, and it is this displaced air which generates sound that is perceived by the ear.

The air pushed back in the forward motion must go somewhere, and as a partial vacuum is created in the back as the cone moves forward, the displaced air in the front encounters very little resistance and hence flows rapidly to fill the vacuum created by the forward thrust of the cone.

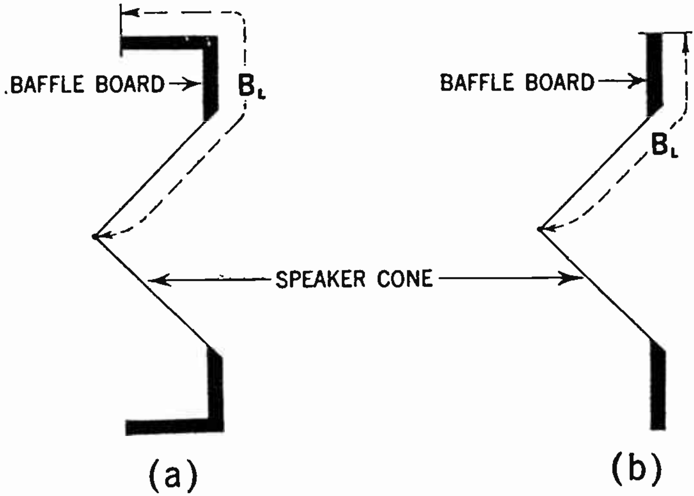


FIG. 15—Various speaker baffles; *a*, and *b*, indicates box and flat baffle types respectively. Dotted lines indicate length of baffle board in each type.

If these air movements were allowed to neutralize each other completely, there would be no air movements and hence no sound waves would be created. The method used to delay these rapid movements is to increase the path of air travel by means of a *baffle board* surrounding the cone as shown in fig. 15.

The amplitude of air movement in a speaker however, is relatively low and therefore theoretically at least sound waves are produced only in the air very close to the moving cone. This is true for low, but not for high frequencies.

Thus in practice an unbaffled speaker will reproduce high tones, but will lack almost entirely all low tones due to the neutralization already described.

Baffle Purpose.—The purpose of the *baffle* is to delay the meeting of the air creating the sound waves, by an artificial lengthening of the path of its travel.

The baffle, can be anything that will lengthen the airpath from cone center back, to cone center rear.

In practical speakers the baffle is made up of some acoustically suitable material, such as soft wood, thick felt, Celotex, etc.

Calculation of Baffle Length.—By recalling that the speed of sound is 1130 feet per second in air, it is possible to calculate the minimum baffle length for a certain frequency.

If B_L denotes the baffle length in feet, and f the frequency of the sound wave, then

$$B_L = \frac{1}{4} \times \frac{1130}{f} = \frac{282.5}{f} \qquad (1)$$

or expressed in a non-mathematical form, the baffle length in feet is equal to one quarter the wave-length of the note to be reproduced.

Example.—*Assuming* 40 *cycles as the lowest tone to be reproduced by a speaker, what is the minimum baffle length required:*

Solution.—Substituting the numerical values in equation (1) we obtain:

$$B_L = \frac{282.5}{40} \text{ or 7 feet (approximately)}$$

In a similar manner the following baffle lengths for low frequency cut-offs below which a loud speaker will not reproduce is as follows:

Lowest frequency to be reproduced.	*Baffle length from cone center in feet.*
100	2.825
60	4.708
40	7.006
30	9.417
20	14.125

As the tones corresponding to the lowest frequency of various instruments are approximately 20 cycles per second, it follows that for their reproduction baffles of considerable length must be created.

Example.—*A loud speaker whose inductance is* 1.15 *henries is coupled to a power tube through a condenser of* 2 *micro-farads capacity. To what frequency will the combination be resonant?*

Solution.—In this example it is only necessary to find the resonant frequency of a series tuning circuit. When in such a circuit the inductance *L*, and capacity *C*, are both expressed in the fundamental units of henries and farads, then the resonant frequency in cycles per second is given by the expression

$$f=\frac{1}{2\pi\sqrt{L\times C}}$$

In the present example however, the condenser is of 2 micro-farads capacity, hence it is necessary to convert this unit into the terms of farads before substitution into the above formula.

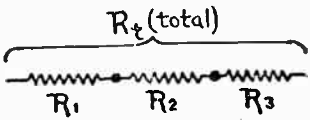
Inserting values, it is found—

$$f=\frac{1}{2\pi\sqrt{1.15\times2\times10^{-6}}}=\frac{1{,}000}{2\pi\sqrt{2.3}}=105 \text{ cycles per second.}$$

CHAPTER 18

Circuit Fundamentals

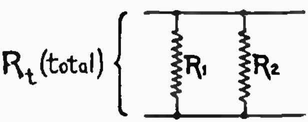
Series Circuits.—A series circuit may be defined as one in which the resistances are connected in a continuous run (i.e., connected end to end) as shown.

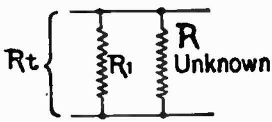


$$R_t = R_1 + R_2 + R_3 + \text{etc.}$$

Where: R_t is the total resistance
R_1, R_2, R_3, etc., are the individual resistances
All resistances must be expressed in the *same* unit (*ohms, megohms,* etc.)

RESISTANCES IN PARALLEL (two only):

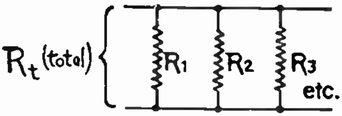




$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_{(\text{unknown})} = \frac{R_t \times R_1}{R_1 - R_t}$$

RESISTANCES IN PARALLEL (many):



$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{etc.}$$

$$\text{or, } R_t = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \text{etc.}}$$

(all resistances in above formulae must be expressed in *same* unit (*ohms*, *megohms*, etc.)

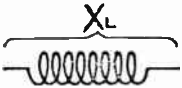
OHM'S LAW FORMULAE FOR DIRECT CURRENT CIRCUITS

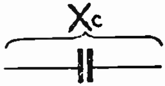
Ohm's Law can be expressed in several different forms, all of which are conveniently tabulated below.

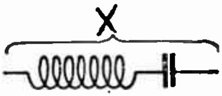
I (amperes) =			$\frac{E}{R}$	$\sqrt{\frac{W}{R}}$	$\frac{W}{E}$	
R (ohms) =	$\frac{E}{I}$				$\frac{E^2}{W}$	$\frac{W}{I^2}$
E (volts) =		IR		$\sqrt{WR}$		$\frac{W}{I}$
W (watts) =	EI	I^2R	$\frac{E^2}{R}$			
G (mhos) =	$\frac{I}{E}$				$\frac{W}{E^2}$	$\frac{I^2}{W}$

RELATIONS FOR ALTERNATING CURRENT CIRCUITS

SIMPLE REACTANCE:



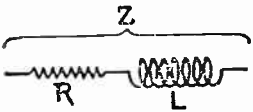




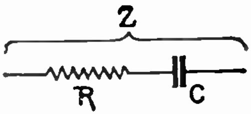
$$X_L = 2\pi f L \qquad X_c = \frac{1}{2\pi f C} \qquad X = 2\pi f L - \frac{1}{2\pi f C}$$

Where: X_L is the inductive reactance in *ohms*
X_C is the capacitive reactance in *ohms*
X is the *net* reactance in *ohms*
2π is a "constant" equal to *6.28*
f is the frequency in *cycles per second*
L is the inductance in *henries*
C is the capacitance in *farads*

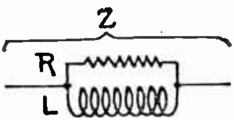
COMPLEX IMPEDENCE:



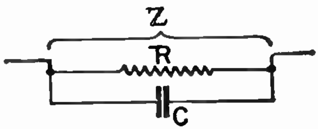
$$Z = \sqrt{R^2 + (2\pi L f)^2}$$



$$Z = \sqrt{R^2 + \frac{1}{(2\pi C f)^2}}$$



$$Z = \frac{2\pi L R f}{\sqrt{R^2 + (2\pi L f)^2}}$$



$$Z = \frac{R}{\sqrt{4\pi^2 R^2 C^2 f^2 + 1}}$$

Where: Z is the impedance of the circuit in *ohms* all other quantities have the same meaning as explained above for *"SIMPLE REACTANCE"*.

IMPEDANCE OF RESISTANCE, CAPACITANCE & INDUCTANCE IN SERIES:

$$Z = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fc}\right)^2}$$

IMPEDANCE OF RESISTANCE, CAPACITANCE & INDUCTANCE IN PARALLEL:

$$Z = \frac{RX_LX_C}{\sqrt{X_L^2X_C^2 + R^2(X_L - X_C)^2}} \text{ ohms}$$

OHM'S LAW FOR A-C CIRCUITS:

$$I = \frac{E}{Z}, \quad E = I \times Z, \quad Z = \frac{E}{I}$$

Where: I = current in *amperes*
E = e.m.f in *volts*
Z = the impedance in *ohms*

SINE-WAVE VOLTAGE RELATIONS:

For a sine-wave voltage:

(1) *Maximum* voltage = 1.414 × Effective voltage

(2) *Effective* voltage = 0.707 × Maximum voltage

(3) *Average* voltage = 0.636 × Maximum voltage

POWER IN AN A-C CIRCUIT:

$$W = E \times I \times \frac{R}{Z}, \text{ or } E \times I \times Cosine\phi$$

Where: W = power in *watts*

and $\frac{R}{Z}$ is called the *Power Factor*

$$= \frac{\textit{true power}}{\textit{apparent power}} = \frac{I \times R}{E}$$

RESONANCE FORMULAE:

$$f = \frac{1}{2\pi\sqrt{LC}}, \text{ or } L = \frac{1}{(2\pi f)^2C}, \text{ or } C = \frac{1}{(2\pi f)^2L}$$

Where: f = resonance frequency in *cycles*, L = inductance in *henrys*, and C = capacitance in *farads*.

When f, L and C are expressed in the units indicated below, the formulae become:

$$f_{(kc)} = \frac{159.2}{\sqrt{L\ (microhenries) \times C\ (mfd.)}}$$

or,

$$f_{(kc)} = \frac{159{,}200}{\sqrt{L\ (microhenries) \times C\ (mmfd.)}}$$

$$L_{(microhenries)} = \frac{(159.2)^2}{f^2{}_{(kc)}\ C_{(mfd.)}}$$

$$C_{(mfd.)} = \frac{(159.2)^2}{f^2{}_{(kc)}\ L_{(microhenries)}}$$

RESONANT WAVELENTH:

Wavelength (in *meters*) at which resonance occurs with given values of inductance (L) and capacitance (C).

$$\text{Wavelength} = 1885 \sqrt{L\ (\text{microhenries}) \times C\ (\text{mfd.})}$$

or,

$$\text{Wavelength} = 1.885 \sqrt{L\ (\text{microhenries}) \times C\ (\text{mmfd.})}$$

FREQUENCY AND WAVELENGTH RELATIONS:

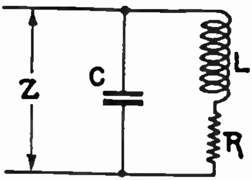
$$\text{Wavelength (meters)} = \frac{300{,}000{,}000}{\text{Frequency (cycles)}}$$

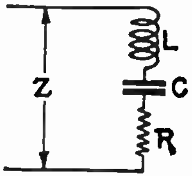
$$\text{Wavelength (meters)} = \frac{300{,}000}{\text{Frequency (kc)}}$$

$$\text{Frequency (cycles)} = \frac{300{,}000{,}000}{\text{Wavelength (meters)}}$$

$$\text{Frequency (kc)} = \frac{300{,}000}{\text{Wavelength (meters)}}$$

IMPEDANCE RELATIONS IN SERIES AND PARALLEL RESONANT CIRCUITS:





$$Z = \frac{2\pi fL}{4\pi^2 f^2 LC - 1}$$

At Resonance:
$Z = Q\,2\pi fL$

$$Z = \sqrt{\left(2\pi fL - \frac{1}{2\pi fC}\right)^2 + R^2}$$

At Resonance:
$Z = R$

(Where Q is the "factor of merit" of the coil $= \dfrac{2\pi fL}{R}$

CHAPTER 19

Auto-Radio Receivers

(Adjustments and Servicing)

Radio receivers mounted in automobiles, or auto-radio receivers, as they are usually termed, employ the superheterodyne circuit, with automatic volume control, and differ from the conventional radio receiver, only with respect to its *extreme compactness, its tuning controls, and power supply units.*

Power Supply Unit.—Power units employed to convert the 6 volts storage battery *d.c.* current to the high voltage required for the radio receiver plate circuits are commonly of the vibrating type.

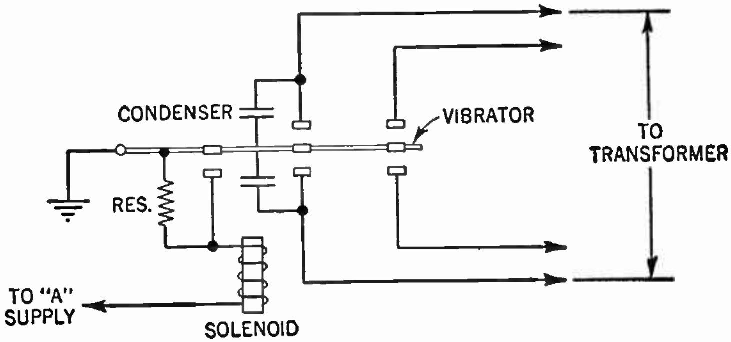


FIG. 1—Schematic diagram showing internal connection of vibrator.

In the vibrating type of power supply, a rapidly rotating reed interrupter is employed to produce a pulsating direct current. When this pulsating current is fed through the primary of a properly designed transformer it produces a high voltage alternating current in its secondary.

This high voltage *a.c.* current is in turn rectified in the conventional manner, as noted in fig. 2, and after proper filtering applied to the plates of auto-radio receiver tubes.

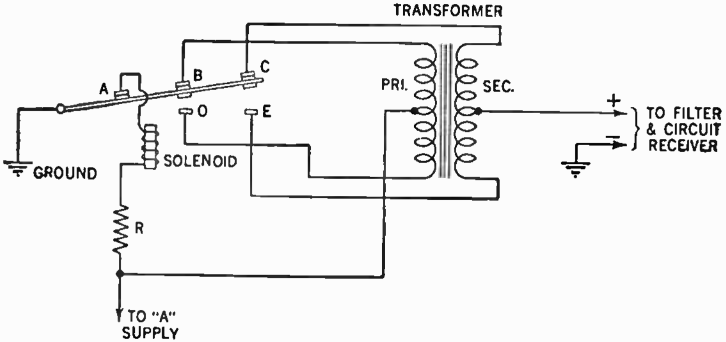


FIG. 2—Schematic diagram showing operating principles of vibrator as employed in automobile radio receivers. With reference to the diagram the vibrator reed employs three contacts *A*, *B*, and *D*, arranged as indicated. When the reed is in the upper position contacts *A* and *B* are closed. The battery current then flows through the upper half of the transformer primary winding, through contact *B*, through the reed to ground, thus completing the circuit. When the reed is in the lower position contact *B* is open and contact *D* is closed. The current then flows through the lower half of the transformer primary (in the opposite direction) through contact *D*, through the reed and finally to ground as before. In this manner the circuit alternates and the rapid reversal of the current is thus transformed to a higher value in the transformer secondary winding. As noted in the diagram the secondary transformer winding is center-tapped and is further connected to a full-wave rectifier tube and filter in the conventional manner.

Another vibrator unit of somewhat different construction is shown schematically in fig. 3. It functions as a combined *a.c.* generator and mechanical rectifier. With reference to the diagram, it will be noted that both the primary and secondary of the transformer are center tapped. By connecting the outside of each winding to the contacts of the vibrator and using the arms and center taps of the windings as sources of input and output voltage a combined generating and rectifying action is obtained.

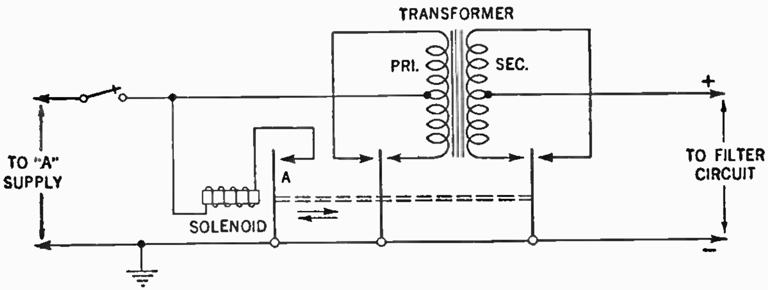


FIG. 3—Schematic diagram of vibrator unit.

When the switch is turned "on" the vibrator makes and breaks contact at point "A". This constitutes the driving action of the unit and is in no way connected with the other circuits. The primary vibrator function is to connect the input low voltage current first across one-half and then across the other half of the primary of the transformer. This results in an *a.c.* voltage emanating from the secondary of the transformer. Due to the transformer having a step-up ratio the *a.c.* secondary voltage is considerably greater than the primary. The secondary vibrator functions in a similar manner as that on the primary side, so that by reversing the alternations applied to the load, a pulsating *d.c.* current is obtained. After filtering this is used as plate and grid supply to the radio tubes.

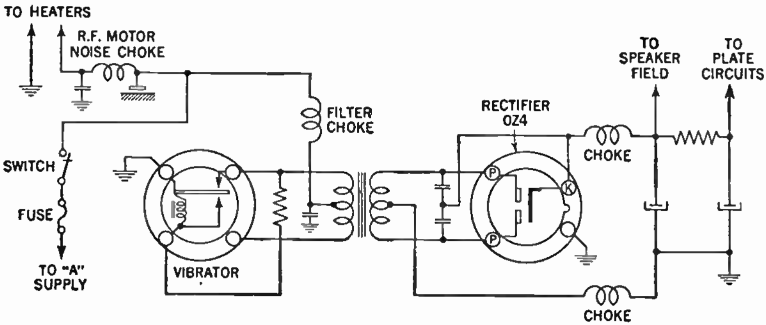


FIG. 4—Typical non-synchronous vibrator and rectifier circuit in a commercial auto-radio receiver. It should be noted that there are several *r.f.* filter chokes and by-pass condensers included in the battery circuit to prevent the transmission of radio interference from the vibrator unit to the receiver by way of the battery circuit.

Servicing Vibrator Units.—It is usually not advisable to attempt to service, adjust or repair a vibrator after it has given a normal period of service. Experience indicates that repaired or adjusted vibrators seldom give dependable satisfactory service for any length of time, unless the repair or adjustment is of a minor nature.

Vibrator dead.—If there be no sound from the vibrator and if the pilot lamp does not light, check for a blown fuse or for a poor connection in the fuse container, or at the "A+" connection at the ignition switch. It is also possible that the "on-off" switch in the receiver is defective.

Vibrator normal.—If the vibrator seems normal but there is no sound from the set, look for a burned out or defective rectifier or audio tube (OZ4 tubes in the power supply are frequent offenders). Check also for a shorted condenser (usually the plate bypass in the audio output stage) and check the plate voltages in the 6SQ7 (and similar) audio stages.

A common trouble is failure (open condition) of plate supply resistors due to short leads. When replacing resistors, make all leads long enough to allow for expansion and vibration.

If there be a background hiss from the receiver and if this hiss increases and decreases with the volume control setting, but no stations are received, touch the antenna with a screwdriver. If interfering "pops" are heard, try disconnecting and reconnecting the antenna lead-in. Check also for a defective *r.f.* or other tube ahead of the second detector. (If the tubes are accessible, feel the envelopes or try removing the last *i.f.* tube from its socket and work back toward the *r.f.* or converter tube). Listen for noise when a tube is removed and reinserted. Trouble usually will be found in the stage just ahead of the one in which the noise last appeared.

If the stations be received normally, but are accompanied by vibrator interference, check for broken or loose ground connections, and loose tube shield, or *i.f.* can shield. In some of the older automobiles, this type of interference may require bonding of fenders, instrument panel, etc. or installation of spark plug and distributor suppressors. See that the usual 0.5-MF condensers are connected across the low voltage ("A+") side of the generator and from the hot side of the ignition switch to ground.

Vibrator erratic.—If the vibrator acts intermittently and if there be no sound from the set, check for a defective vibrator (sometimes caused by defective buffer condensers) which may not be furnishing enough voltage to operate the receiver.

If there be noise in the set but no station reception, check for a defective vibrator and for defective buffer condensers (generally across the secondary of the power transformer) or rectifier tubes.

If the vibrator sticks, blowing fuses, the points of the vibrator are probably badly pitted. Replace the vibrator. (Filing the points generally is only a temporary measure and should be avoided except in emergencies). Before replacement, check the buffer condensers. If the set be several years old, or if the buffers look suspicious, replace them as a safety policy.

If a new vibrator does not start properly, or does not start at all, check for low battery voltage, blown fuse, or oxidized points on the vibrator. Note if the pilot light operates. If the vibrator will start when the auto engine is running, this is an indication that the battery voltage is probably low. If the vibrator points are oxidized (this is fairly common if the vibrator has been idle or on the shelf for some time), apply about 12 volts *a.c.* (from pins on your tube-tester socket) and allow the vibrator to run for several seconds to remove the oxidized film.

In several receivers (1950 Dodge and similar) the current drain on the vibrator is rather heavy and ordinary vibrators will not last too long. In making replacements, try a heavy vibrator such as the *Philco* 83-0026. Also check the buffer condensers for trouble.

Vibrator Spring and Contact Adjustments.—When vibrator condition is such that the contact must be adjusted, the various contacts should be adjusted in the following order and manner:

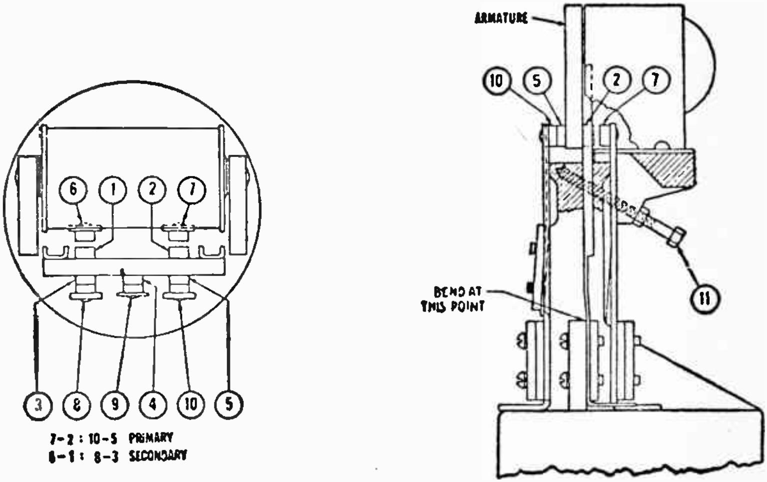


FIG. 5—Showing contact arrangement in typical vibrator.

1. With 8 and 10 fig. 5, firmly held against their respective stops and with 3 and 5 in contact with 8 and 10 respectively, the air gap between 1,6 and 2,7 shall be 0.015 in. plus or minus 0.005 in.

2. Adjust the buzzer screw 11, fig. 5, so that when the position of the armature is such that 1 and 2 are just making contact with 6 and 7 respectively, the contact between 4 and 9 shall just be breaking.

Vibrator Adjustment for Minimum Sparking.—If any pair of contacts show excessive sparking, the following procedure will in general reduce the sparking to a minimum. For example, consider the case where excessive sparking is occuring between 6 and 1. Sparking will be reduced to a minimum by bending the armature spring on that side (secondary side) away from 6 and toward 8. If the bend be too small, only a small change will be noted. If an excessive bend be made, however, the sparking will be transferred from 6,1 to 8,3.

The same method may be applied to any pair of contacts. Usually only a slight bend will be necessary. Although after bending, no change in the position of the armature contacts may be noted, a sufficient change in the initial force requirements will have been made to reduce sparking.

Output Voltage.—When vibrator is connected to the 6 volt primary source, the output voltage across a 5,000 ohms resistor (connected in place of the receiver load at the output of the filter) must be 240 volts or greater. The output voltage on receivers should be at least 225 volts.

Failure of Vibrator to Start.—Failure of vibrator to start may be due to any of the following:

1. *Low battery voltage.* This may be due to either a low voltage battery or high resistance connections. The connection to the vibrator should be made to the battery side of the charge indicator, otherwise the internal resistance of the indicator may be sufficient to reduce the voltage at the vibrator to a degree that it will fail to start. If any doubt exists as to the proper voltage, measure it with an accurate voltmeter at the vibrator with the set turned on.

2. *Improper adjustment of the buzzer screw.* Unless the buzzer screw is adjusted so that the center contact breaks just as

the outer contacts make when being pushed toward the coil, failure to start or sticking may occur.

3. *Improper tension of center contact spring.* If there be any indication of improper tension of the center contact spring, such as small or irregular amplitude of armature vibration, it should be removed and flattened so that it is entirely straight before being replaced. If the vibrator initially operated properly and then failed, a slight bow should be placed in the center contact spring in the direction of the contact.

AUTO-RADIO RECEIVER OPERATION

Radio Switch, Volume and Tone Control Operation.—An auto-receiver should be turned off while starting the engine because certain radio parts may be damaged if cranking motor be operated with radio turned on.

Clockwise rotation of the switch knob to left of dial, turns the radio on, and further rotation increases the volume. Rotation clockwise of the tone control knob, behind the switch knob, to extreme "treble" position gives the full tone range which will produce speech very clearly and distinctly. Rotation counter-clockwise toward "bass" diminishes brilliance and accentuates low notes.

Push Button Tuning Operation.—To tune in the station for which the push button is set simply push the button in as far as possible. The button will move easily at start then a slightly harder push is required to complete the travel. At end of button travel the tuner will move to the station for which the button has previously been set.

Manual Tuning Operation.—The manual tuning knob to the right of the dial may be used to tune in stations other than those for which the push buttons are set. This knob is also used when tuning to set the buttons for selected stations.

When tuning manually, and particularly when setting up a station on one of the push buttons, careful adjustment of the tuning knob is essential to good reception. If the program sounds screechy or distorted, it is probably caused by improper tuning and can be corrected by adjusting the tuning knob slightly. Since low notes are more affected by tuning than high ones, it is a good plan to tune the receiver to a point where the low notes are heard best and high notes are clear but not screechy. Turning the control knob back and forth until the station is almost lost on either side will enable the operator to hear the difference in reception and select an intermediate position giving best results.

Radio Reception is Weak.—In case of weak reception proceed as follows:

1. Fully extend the antenna and turn on set. Turn volume control to maximum position and tune across the dial.
2. If reception seems slightly weak, tune in a station having good volume for listening and grasp the antenna rod with your hand. If volume increases adjust the antenna trimmer.
3. Check for weak tubes by replacing one at a time until the faulty one is located, or test the tubes with a reliable tube checker.
4. If tubes be not faulty, substitute a test antenna consisting of a piece of wire about ten feet in length and connect the foregoing to a standard antenna lead-in cable. Place test

antenna outside and away from the car. If radio operates near normal with substitute antenna some part of car antenna or lead-in is at fault. If this does not reveal source of trouble, the receiver will have to be removed for a thorough test.

Radio Noisy with Car Standing Still.—The procedure when trouble of this kind occurs is as follows:

1. Start engine, turn on radio and tune radio to a spot between stations. Engine noise will usually appear in radio as a clicking sound that varies in frequency with speed of engine. If noise be present, disconnect antenna lead-in cable from receiver.

2. If engine noise stops when antenna is disconnected, check all high tension wires for full seat in sockets of coil and distributor car. Check distributor rotor (resistance type) by substituting a known good one. If external suppressor be used, it must be installed at distributor end of coil-to-distributor high tension wire. Do not use a suppressor and a resistance type distributor together.

3. If distributor rotor or suppressor does not correct the noise, check antenna lead-in cable shield for proper ground.

4. If engine noise continues with antenna disconnected, check ignition coil and generator capacitors for clean, tight connections; also check the bond strap on the water temperature gauge tube to make sure it has clean tight connection to cowl. Remove generator cover band and observe sparking. If sparking be excessive, check for open armature coil.

5. If source of noise has not been found, replace ignition coil and generator capacitors with known good ones. Ignition coil capacitor lead must be attached to battery terminal of coil. Generator capacitor lead must be connected to "A" terminal of generator. Both capacitors must have clean metal ground contact.

6. If engine noise be present when engine is running at approximately 2,000 *r.p.m.* and all the foregoing items are satisfactory, the noise is probably due to generator regulator. Correction may be made by mounting a 0.33 *m.f.d.* capacitor at one end of the regulator mounting ground screws and attaching the capacitor lead to the battery terminal of regulator.

Set Does Not Light Up.—If the set does not light up, check for a blown fuse. If the fuse is not blown, examine the fuse contact ends for corrosion or loose connections, and replace the fuse if necessary. If the fuse holder connections are poor, stretch the spring in the fuse holder to restore proper contact pressure. Also check the sealing of the fuse since it may be the wrong type, in which case the fuse should be replaced with one of the correct type and rating.

Intermittent Reception.—In the case of intermittent reception wiggle the antenna and lead-in connections and check the antenna for loose or intermittently grounded mounting screws. If a push-type antenna plug is used, see that the plug is in the receptacle properly, making good solid contact. Check for the same condition on bayonet or pin-type plugs and see that solder is built up sufficiently to make a positive contact.

If the plug pins or soldered connections appear to be cold soldered, sweat the connection with a hot iron and flow in a small amount of new solder. Try similar method with the lead-in at the antenna end. Check the tubes by tapping lightly with a pencil and it should be noted that in some instances the set may have to be removed from its mounting to get off the cover.

If a portion of the broadcast band is dead or intermittent, check for a defective oscillator tube or possibly a shorting connection between the plates in the condenser-tuned circuit. If a new oscillator tube fails to correct the trouble, check the rectifier tube or measure operating voltages at the oscillator socket. Defective oscillator coupling or padding condensers are other possibilities.

Set is Noisy.—One of the most common source of trouble in many auto-sets is an extremely noisy volume control that results in high-pitched oscillations preventing correct volume setting. This condition indicates a defective volume control. If a thorough cleaning proves ineffective in correcting the trouble, replacement with a new control of correct taper is usually the only solution.

A microphonic "squeal" usually affected by vibration or high volume, may be due to a noisy tube, generally the oscillator or second detector. A similar effect can also be caused by an intermittent open or loose lead of one of the coupling condensers.

If the complaint is low volume with distortion during the first half-hour or so of operation, with satisfactory reception thereafter, check for a weak input filter condenser. A satisfactory test of this condition consists in bridging the faulty condenser with a good one of the same rating.

Noise Due to Speaker Defects.—When the receiver has audio distortion at low levels only, and is normal at medium and high volume, check the speaker voice coil alignment. If it is rubbing against the pole piece, try to realign the cone. If alignment is impossible the only lasting remedy is to replace the speaker.

Audio distortion at high volume levels only indicates a gassy audio output tube or leaky coupling condenser. Also ascertain that the speaker cone is properly glued and centered and that the audio output is not exceeding the speakers normal rating.

Other speaker defects causing noise and unsatisfactory reception may be caused by a loose unglued rim on the speaker cone, a warped cone or a collection of foreign matter or metal filings lodged in the magnet gap.

If the cone is unglued, reglue with regular speaker cement, making sure that the cone is properly centered. Use speaker shims or small strips of negative photographic film. If neither is available, tune in a station at low volume and move the speaker cone carefully back and forth while exerting pressure against and around the rim of the cone. Adjust the cone position for the best apparent quality and freedom of motion. Apply pressure evenly around the rim to properly set the glue. If the speaker has an extra centering spider or disc near the air gap, check this also for unglued condition.

In case the speaker cone is warped, try moistening the cone at a point directly opposite the warp. When dry, the cone often will warp an equal amount in the opposite direction and correct the trouble. On smaller speakers, also try warping a corner of the frame by springing and twisting slightly with long nose pliers.

Ignition Noise.—This is one of the more frequent complaints when dealing with auto receivers. The usual remedy is the connection of 0.5 *mfd.* condensers across the ignition switch, generator and other electrical components. Also cleaning and tightening of ground connections. If the foregoing does not correct the trouble, try cleaning the base and insulator of the whip antenna. Corrosion often causes considerable leakage between the antenna and auto body.

If the ignition noise continues to be picked up even with the antenna removed, the trouble may be picked up via the 6 volt lead. The most practical solution in this case is to run a separate No. 8 or 12 wire directly from the receiver to the battery, keeping the lead as short as possible and dressing it away from other A+ wiring to avoid pickup.

Wheel Static.—A high pitched noise from the receiver present only when the car is in motion indicates wheel static. If the noise stops or is reduced when the brakes are applied, install coiled spring suppressors inside the hub caps of the front wheels. These suppressors insure good contact between the wheel and axle.

Parts Replacement.—Auto receiver parts are now generally standardized and thus presents no problem in replacement. In some cases, however, the vibrator and power transformer may be of different construction. Because of the fact that most well equipped distributors carry all popular types of vibrators a suitable substitution can almost always be made from one of these types.

In case of a burnt out power transformer replace it with one having the same voltage ratio as the transformer to be replaced.

The only difficulty in making this type of substitution might be in finding a transformer to fit into the space allotted for it.

After all the necessary adjustments of the receiver is compleated, a complete alignment check should be made. This should include an accurate check of the dial pointer positions throughout the dial range. In addition a peeking check of the *i.f.* preselector and *r.f.* trimmers and a final check of the antenna trimmer (with the set in mounted position) on about 1,400 *kc.* should be made.

Receiver Alignment

Auto Receiver Alignment Procedure.—Radio receiver manufacturers often make general recommendations with regard to alignment procedure of their products, which recommendations are commonly available and thus well known to servicemen. Circuit alignment should be made only when necessary, and only when all other causes of trouble are removed.

As previously noted, modern auto-receivers employ the superheterodyne circuit which uses an intermediate frequency (*i.f.*) amplifier, the characteristics of which largely govern the selectivity of the receiver. The *i.f.* amplifier characteristics are determined principally by the adjustment and design of the *i.f.* transformers.

It is, therefore, important that the *i.f.* amplifier be correctly adjusted to provide the best selectivity. These adjustments are in the form of iron cores placed within the coils.

During alignment it is necessary to adjust only these iron cores as specified in the tabulated adjustment procedure, to obtain the best operation.

Incorporated in every receiver is a local oscillator, the output of which mixes with the incoming signal from the antenna. The local oscillator does not operate at the same frequency as the incoming signal, which is to be received. The resonant (acceptance) frequency of the *i.f.* amplifier establishes the difference in frequency required; 260 *k.c.* is generally employed in auto-receivers. The local oscillator operates at a frequency higher than the incoming signals, the two predominating resultant frequencies produced are the sum and the difference of the two frequencies.

The design of these receivers is such that the difference in frequency is the same as the *i.f.* amplifier resonant frequency. Modulation of the incoming signal will be present as modulation of input to the *i.f.* amplifier.

Alignment is generally necessary when replacements have been made in *r.f.* and *i.f.* circuits. This includes replacement of tubes, by-pass condensers, *r.f.* chokes, etc. Before alignment however, run both the signal generator and receiver for about 15 to 20 minutes for frequency and temperature stabilization. Non-metallic tools should be used exclusively for alignment.

To perform alignment correctly, accurately calibrated oscillators and some type of output measuring device must be used. The output meter may be connected across the secondary of the output transformer. All alignments should be made with the receiver volume control on maximum and with the test oscillator output as low as practical to prevent the *a.v.c.* throttling action from influencing the reading.

The intermediate frequency stage should be aligned as the first step. It is a well known fact that maximum output of a receiver is obtained only when every tuned section of it is properly aligned. Maximum output from the *i.f.* amplifier is obtained when it is adjusted to the frequency for which it is designed and when exactly that frequency is applied to the *i.f.* amplifier by the output of the mixer.

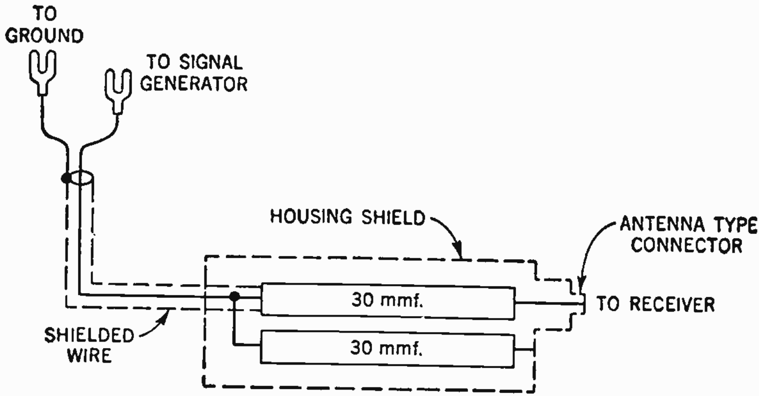


FIG. 6—Dummy antenna for use in alignment and touch up of auto radio receivers.

To sum up the best sequence to follow when making these adjustments on standard broadcast band receivers (unless the manufacturer of the receiver prescribes a different procedure) is:

a. First align the various tuned circuits of the *i.f.* amplifier properly with each other at the *i.f.* for which the *i.f.* amplifier is designed.

b. The oscillator circuit should then be adjusted at about 1,500 *k.c.* so that it "tracks" properly with the *r.f.* circuits at the high frequency part of the dial. This adjustment should be repeated at about 600 *k.c.* so that it "tracks" properly with these circuits at the low frequency part of the dial.

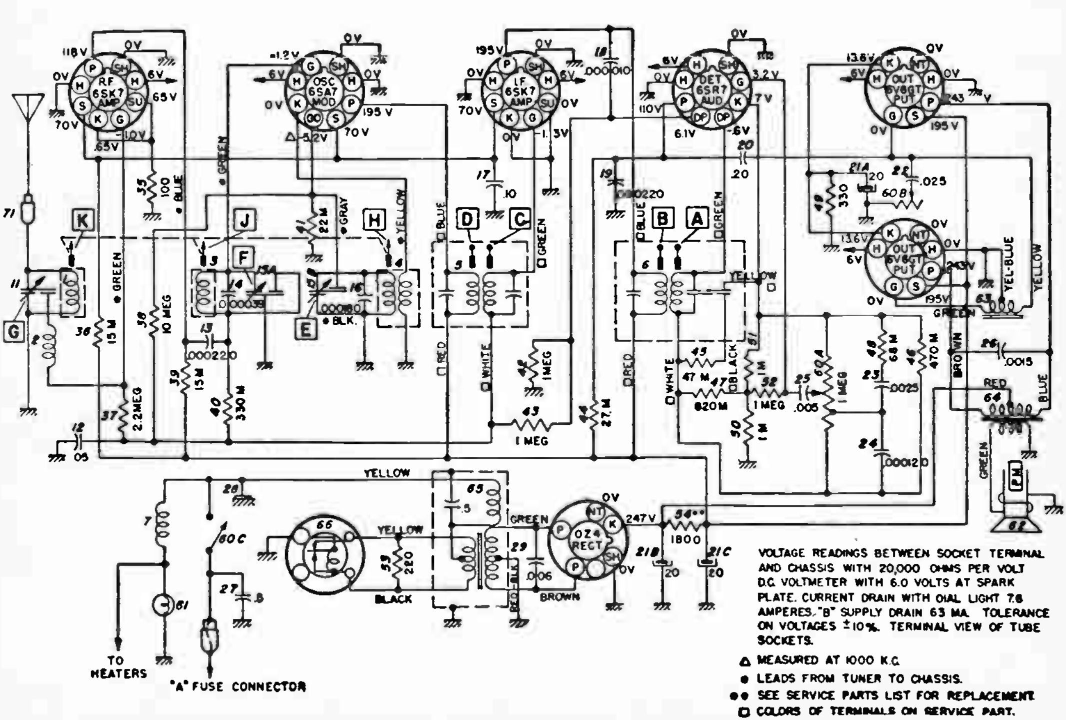


FIG. 7—Typical auto-radio receiver circuit used in late Buick automobile.

c. Simultaneous with the tracking adjustment of the oscillator it is preferable (in most instances) to properly align the tuned circuits of the *r.f.* (preselector) stages with each other.

The dummy antenna illustrated in fig. 6 will be helpful in providing a good match between the set and signal generator. This gives a much better balance than the makeshift coupling condenser so often used.

Alignment of Typical Circuit.—A typical auto receiver circuit is shown in fig. 7. The receiver consists of six tubes and rectifier. It has a permanent magnet speaker and the tuning is accomplished either manual or by means of any one of five mechanical push buttons. The set has a tuning range from 550 to 1,600 kilocycles.

Alignment Procedure

Output meter connection . . . Across voice coil
Generator return . . . . To receiver chassis
Dummy antenna . . . . In series with generator
Volume control position . . . . Maximum volume
Tone control position . . . . . . Treble
Generator output . . . . Minimum for readable indication

Step	Series Condenser or Dummy Antenna	Connect Signal Generator to	Signal Generator Frequency	Tune Receiver to	Adjust in Sequence for Max. Output
1	0.1 Mfd.	12BE6 Grid (Pin #7)	262 *k.c.*	High Frequency Stop	A, B, C, D
2	0.000075 Mfd.	Antenna Connector	1,615 *k.c.*	High Frequency Stop	*E, F, G
3	0.000075 Mfd.	Antenna Connector	1,000 *k.c.*	Signal Generator Signal	J, K
4	0.000075 Mfd.	Antenna Connector	1,615 *k.c.*	High Frequency Stop	F, G
5	0.000075 Mfd.	Antenna Connector	1,000 *k.c.*	Signal Generator Signal	L**

NOTES:

*Before making this adjustment check mechanical setting of oscillator core "H". The rear of the core should be 1 25/32 inch from the mounting end of the coil form. (This measurement is readily made by inserting a suitable plug in the mounting end of the coil form). Core adjustment should be made with an insulated screwdriver, and core studs should be cemented in place with glyptal or household cement after alignment.

**"L" is the pointer adjustment screw which is on the connecting link, between the pointer assembly and the parallel guide bar. It should be adjusted so that the dial pointer corresponds with the 1,000 *k.c.* mark on the dial (on first "0" of "100").

With the radio installed and the car antenna plugged in, adjust the antenna trimmer "G" for maximum volume with the receiver tuned to a weak station between 600 and 1,000 kilocycles.

Effects of R.F. and I.F. Misalignment.—The effects of misaligned *r.f.* and *i.f.* stages are most commonly observed as a loss of sensitivity either over a portion or over entire broadcast band; loss of sensitivity, often characterized by the selectivity being noticeably unequal on the two sides of the point of best reception; change in fidelity and inaccurate dial readings.

Loss of fidelity will be apparent as a loss of high or low audio frequencies. If the *i.f.* amplifier is not tuned to the specific frequency, the oscillator and other tuned circuits will not track. The dial readings will then be incorrect and a portion of the band will have low sensitivity.

Test Oscillator Connection.—The chassis or frame of the radio receiver is considered as being at ground potential and the "GND" terminal of the test oscillator should be connected to the chassis wherever good contact can be established.

The "ANT" or "HIGH" terminal of the test oscillator output must be connected to the antenna connection or other points in the radio receiver as specified in the tabulated alignment specification.

The use of a fixed condenser in series with the test oscillator lead is specified in some instances. When this condenser (sometimes called "dummy antenna") be used, it provides proper input loading to the receiver. It is important that this condenser (when used) be connected at the point where the test oscillator lead joins the radio set, and should not be connected at the test oscillator.

Output Meter Connection.—Any standard type of output meter can be employed during alignment. The meter should be connected across the secondary of the output transformer. It is best to leave the voice coil connected while using the output meter. It is essential that an output meter with sufficient sensitivity be used to avoid the possibility of requiring too much oscillator output to obtain a readable indication on the output meter.

Sometimes it may be desirable to connect the output meter from plate to plate of output tubes. When this connection is employed a 0.1 mfd. condenser must be connected in series with the meter to afford proper protection from the *d.c.* potential.

CHAPTER 20

Phonograph Pick-ups

By definition a phonograph pick-up is a device which converts the vibrations of a phonograph needle in traversing a phonograph record into audio frequency currents for reproduction through a radio receiver. See fig. 1.

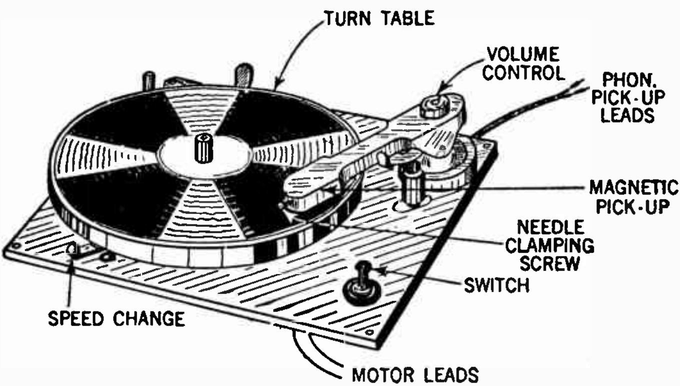


FIG. 1—Modern phonograph pick-up unit.

Phonograph pick-up operating on various well known principles have been developed, such as the condenser type, carbon resistance, magnetic or crystal type.

The pick-ups at present are found almost exclusively to be of either the magnetic or the crystal type. Magnetic pick-ups are divided into two classes depending on the method of damping employed, namely:

1. Rubber damped
2. Oil damped.

Conventional types of rubber damped magnetic pick-ups are shown in figs. 2 and 4.

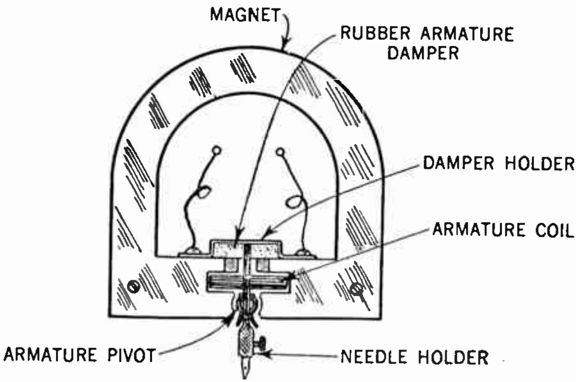


FIG. 2—Principal parts of a rubber damped magnetic pick-up.

The operation principles are as follows: The movement of the needle and hence the armature to which the needle is attached is accomplished by the ripples inscribed in the record which rotates at a constant speed.

The coil of wire wound on the armature is made to intercept the magnetic lines of force flowing from the North to the South pole of a strong permanent magnet.

At any instant that the coil cuts the lines of force between the two poles, a voltage is induced within the coil, the value of which is regulated by the amplitude of the vibration. The two terminals of the coil are brought out to the input terminals of the audio amplifier which amplifies the audio-frequency voltage variations sufficiently to load speaker volume.

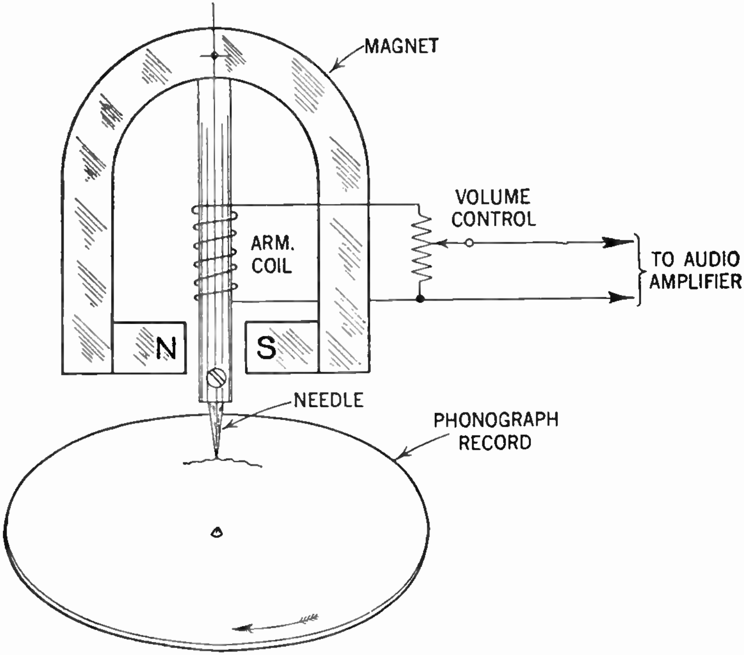


FIG. 3—Simplified layout of a phonograph pick-up.

One detrimental factor with the average pick-up unit, regardless of principle or type, is the weight of the moving parts. The mass of the usual iron armature for example, causes it to have a resonance in the audible range which reveals itself to the ear as a snarly sound in the middle range, and its inertia, coupled with the type and amount of damping necessary, very often curtails the brilliance of reproduction, which is largely bound up with responsiveness to transients.

In order to counteract the weight of the pick-up head and so mitigate the aforementioned undesirable qualities, a counter-balance arm is usually resorted to, although it is not desirable to completely balance the weight of the pick-up because some weight must act on the needle in order to keep it from jumping out of the groove, especially when low frequency notes are being reproduced.

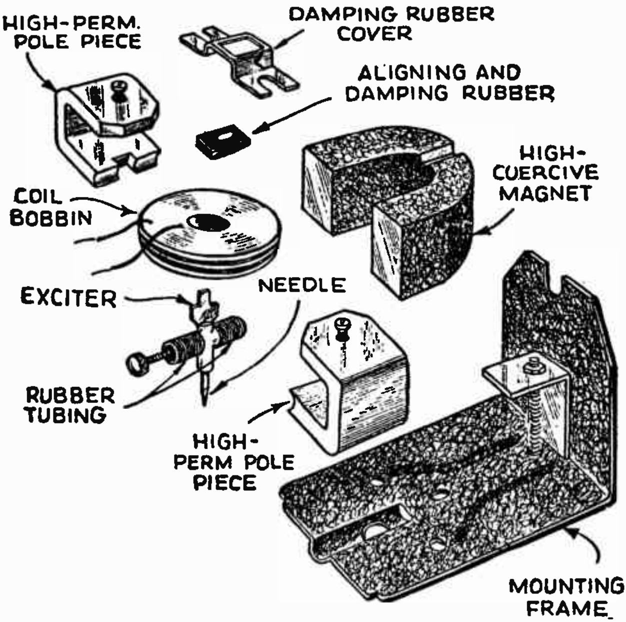


FIG. 4—Parts of modern rubber damped pick-up.

Therefore, it is important that records should be made of hard materials, and at the same time possess abrasive qualities sufficient to grind the needle point at the beginning of its travel in order to reduce the pressure of the needle.

Impedance Values.—Magnetic pick-ups are made in all impedance values, the average being around 20,000 ohms. This allows direct feeding of the output into the grid circuit of an amplifier stage without the interposition of any matching transformer.

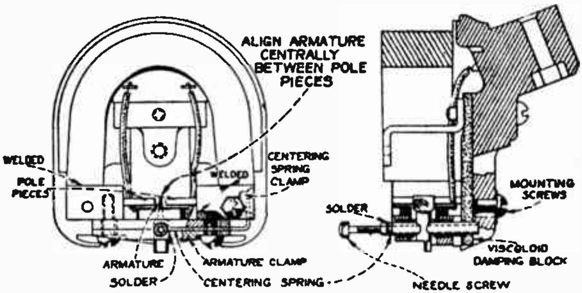


FIG. 5—Front view and section of phonograph pick-up. (Courtesy General Electric Co.)

However, where quality is of the utmost importance, as for example in broadcasting and recording studios, where long cables are commonly employed, 200 to 500 ohms being practical averages.

These lower values are much less affected by long connections in regards to hum pick-up or loss of high frequencies, due to the distributed capacity of the cables and of the armature coil winding itself.

When as in some commercial sets low impedance values are used, a step-up transformer must be resorted to in order to obtain satisfactory operation.

The Oil-damped Magnetic Pick-up.—This type of pick-up is more complicated in construction and hence more expensive than the rubber damped type. However on account of its superior frequency response characteristics, it is frequently employed in sound picture reproduction as well as in high grade sound amplifier systems.

In this type the horse shoe magnet is enclosed in a case, and surrounded by oil (which takes the place of rubber in the rubber-damped type pick-up) damping the action of the armature.

The Crystal, Variously Called Piezo-Electric Pick-up.—The action of this device, which on account of certain favorable qualities has found an increased use, depends upon the property of a Rochelle salt crystal in converting mechanical motion into electrical voltage. In practice this is accomplished by placing two small crystal slabs together which results in what is known as a bi-morph crystal element. This crystal element is then mounted between two small discs of sponge rubber in a bakelite housing, and a light aluminum rocker arm with rubber pivoted bearings (substantially the same as that employed in magnetic units) is used to communicate the motion of the needle to one end of the crystal.

The "fish tail" of the rocker arm employs a forklike notch in the extreme end to which the crystal is clamped. On account of the fact that this armature is much lighter than the iron ones used in the magnetic pick-ups, they require less damping in addition to the attractive properties of the voltage generating element itself.

The impedance in this unit is very high and the element is inherently capacitive—which two features call for a somewhat different technique in the proper operation of the pick-up.

Good results are being obtained with a volume control of 0.5 megohm. All leads should be well shielded.

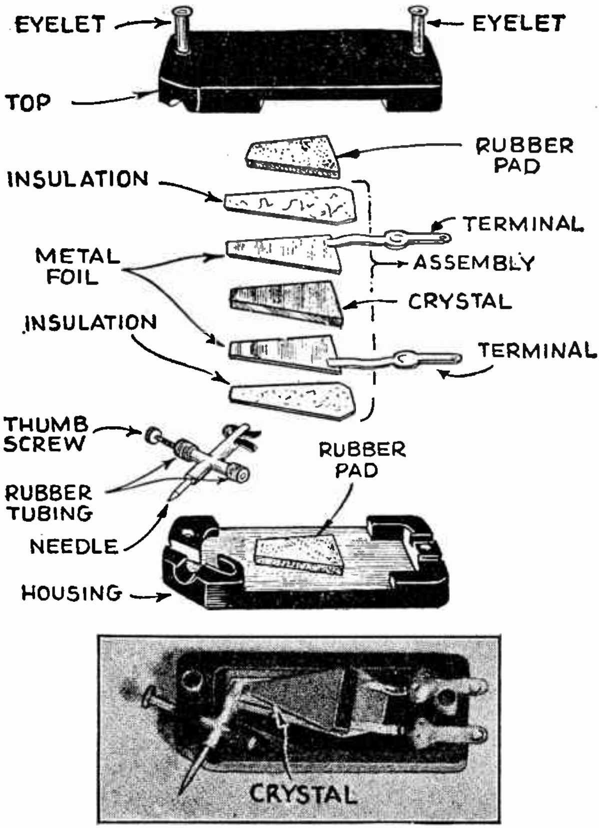


FIG. 6—Parts and assembly of crystal pick-up.

One of the most unfavorable points in the employment of a pick-up of this type is the extreme fragility of the pick-up itself, another being the variations of output with the temperatures in excess of 100° Fahr.

Additional points to be considered when selecting a pick-up unit, regardless of specific types, are solidity of carrying arm construction and freedom of movement of the horizontal and vertical bearings.

The pick-up should be so constructed that not more than three ounces of needle pressure will be used on the record.

Phonograph Motors.—An important part of the phonograph mechanism is that of the motor, its function being to produce the revolving motion to the phonographic disc.

The speed of the record should be as nearly constant as possible. The usual speed of the phonograph disc record being 78 *r.p.m.* At 78 *r.p.m.* a 10 inch record plays for 2½ minutes, while the 12 inch record plays for 4 minutes. Again a 16 inch record (employed in sound picture work) revolving at 33⅓ *r.p.m.* plays for approximately 14 minutes.

Motors of the *a.c.* current type are most generally of the induction or synchronous type, its speed being controlled by a governor, as shown in fig. 7. In later type motors a stroboscope disc is employed which makes closed speed adjustment very easy.

If a stroboscope disc is not available the following method may be employed for correct speed adjustments:

1. Place a record on the turntable and insert a small piece of paper under the edge of the record to serve as an indicator.

2. Play the record in the normal manner and count the number of revolutions made by the turntable in one minute. The speed should be 78 revolutions per minute.

3. Turning the speed regulating screw clockwise allows the motor to run faster, and counter-clockwise slower.

Adjust by trial until the speed is as exactly as possible 78 *r.p.m.* as determined from a full minute count.

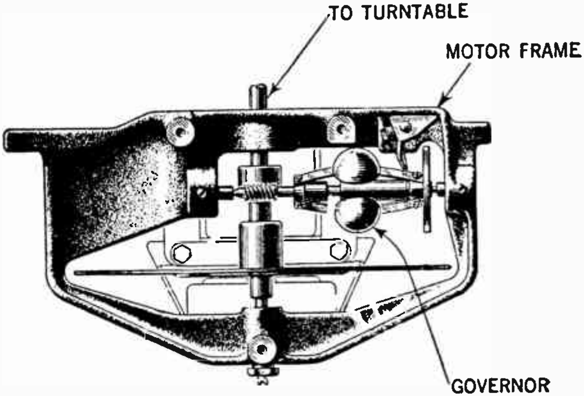


FIG. 7—Motor frame, motor and governor in modern electric phonograph.

The speed of disc should be checked about every two months. Variation in speed will cause distortion.

The governors are generally designed to maintain a constant speed of the motor within a range of sudden voltage changes of 20 volts, if the parts be properly adjusted. Therefore any adjustment made on the motor, including lubrication, will have a certain effect on the speed, which should be checked as previously described.

Phonograph Pick-Up Connection.—When a phonograph of the high impedance type pick-up is employed in connection with the radio receiver, it may be connected in one of several ways as shown in figs. 8 to 10.

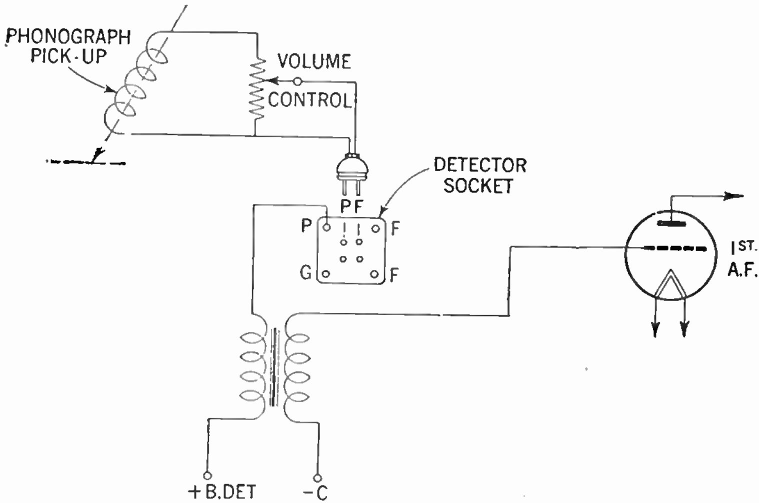


FIG. 8—Method of connecting phonograph pick-up when unit be provided with an adapter for plugging into the detector tube socket. When plugged in the pick-up will be connected to the input of the audio amplifier.

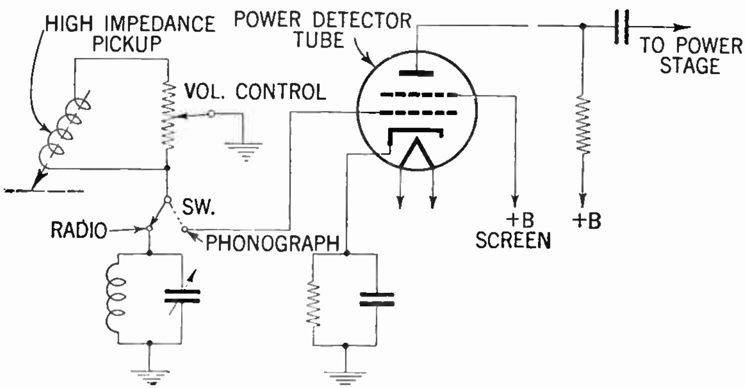


FIG. 9—Conventional method for connection of radio high impedance pick-up.

In more expensive radio phonograph units a so called scratch filter consisting of a combination of inductance and capacity is employed to eliminate or suppress the scratch or hiss caused by the friction of the needle on the record.

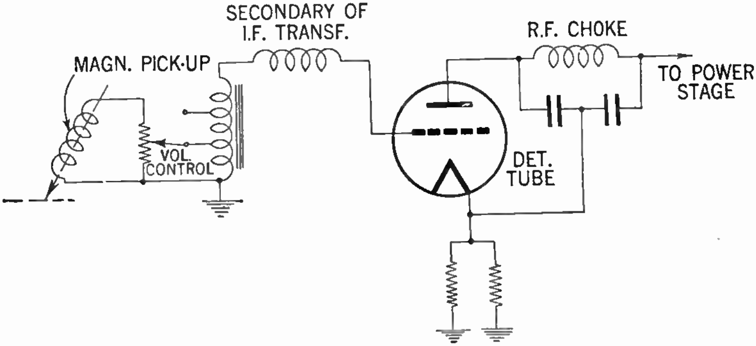


FIG. 10—Method of radio phonograph pick-up connection.

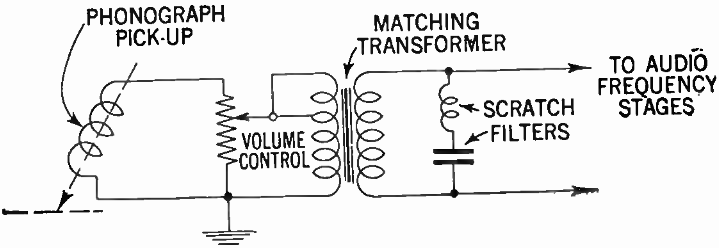


FIG. 11—Method of connection for a needle scratch filter.

The loudspeaker reproduction of scratch is due to the fact that the sides of the wavy grooves in a phonographic record are seldom cut clean or smooth. The almost microscopic rough edges will to some extent, affect the motion of the needle and are responsible for the above described defect. A scratch filter as commonly used, is shown in fig. 11.

The simplest method of record reproduction is to employ an oscillator unit shown in fig. 12. This oscillator in effect is a miniature broadcasting station and the radio is turned to it exactly as to any other station. The oscillator and its connection is clearly indicated in fig. 12 and no changes whatsoever need be made in the receiver.

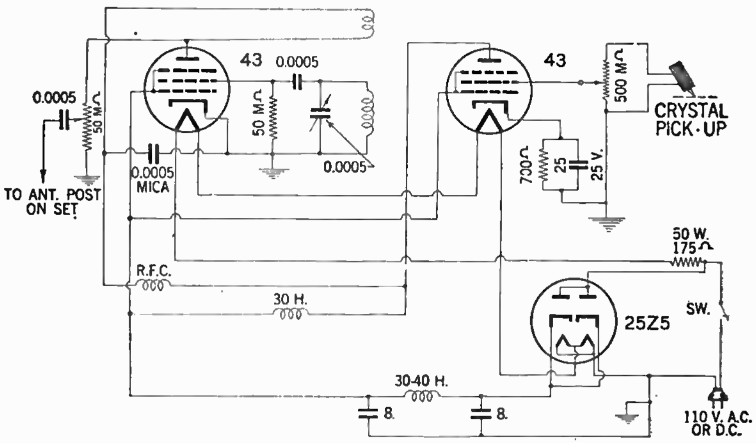


FIG. 12—A portable A.C.-D.C. phonograph oscillator, which may be worked through existing radio receiver. In this phonograph the record reproduction is introduced by means of a miniature carrier wave generated by a local oscillator which is plate-modulated by a single audio power stage into whose grid the output of the pickup can be connected with a minimum of trouble and equipment. In effect this is nothing but a small broadcasting station to which the radio set is tuned, and the carrier pickup is either by conductive or inductive transformers to the sets antenna lead and the set operated in the usual manner.

The frequency of the oscillator may be varied so as to select a channel that is clear of broadcasting.

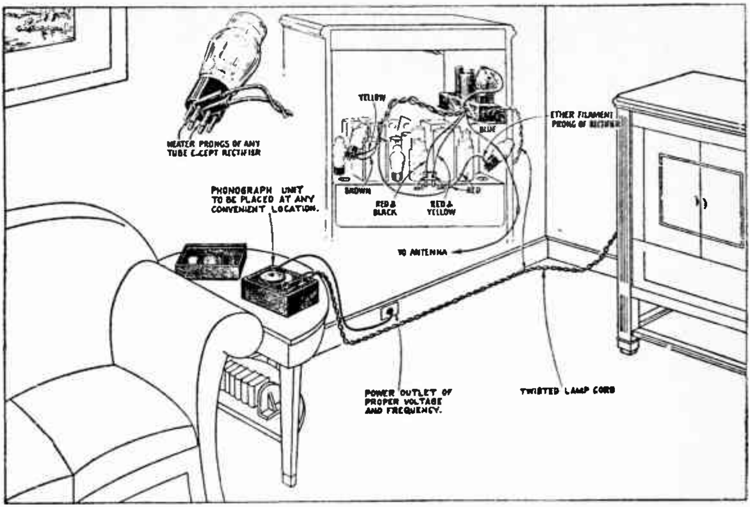


FIG. 13—Diagram of connection when oscillator-phonograph units are employed in connection with receiver for music reproduction.

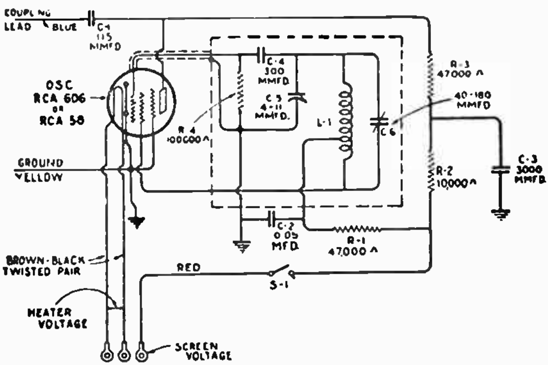


FIG. 14—Schematic circuit diagram of typical oscillator unit.

A schematic diagram of a simple phonograph oscillator which will give high quality performance is shown in fig. 15, when used either with a *crystal phone pick-up or a crystal microphone.* The output is sufficient to operate a radio receiver located 50 to 75 feet away.

The oscillator portion utilizes the control grid, screen grid, and plate of a 12SK7 tube. The audio modulating voltage is impressed on the supressor grid, and the per cent modulation may be varied by adjusting R_3, which controls the cathode potential of the tube.

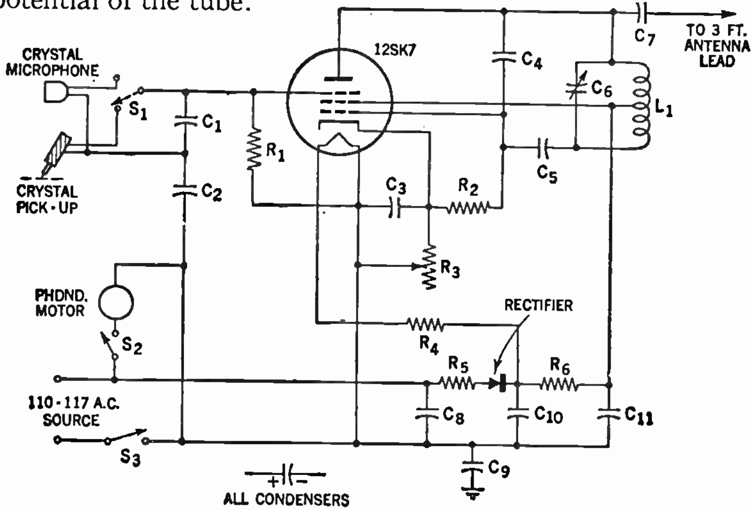


FIG. 15—Schematic diagram of phonograph oscillator, operative for either voice or recordings. The components employed are as follows:

R_1—4.7 megohm, ½ w. res.
R_2—47,000 ohm, ½ w. res.
R_3—10,000 ohm rheostat (adjust. for % of modulation)
R_4—740 ohm, 20 w. res.
R_5—22 ohm, ½ w. res.
R_6—7000 ohm, 1 w. res.
C_1—500 μμfd. mica cond.
C_2, C_8, C_9—.05 μfd., 400 v. cond.
C_3—10 μfd., 25 v. dry elec. cond.
C_4, C_7—25 μμfd. mica cond.
C_5—250 μμfd. mica cond.
C_6—20-160 μμfd. var. cond.
C_{10}, C_{11}—40 μfd., 150 v. elec. cond.
S_1—S.p.d.t. sw.
S_2, S_3—S.p.s.t. sw.
L_1—Broadcast ant. coil c.t. (1000 to 1700 kc.)
Rect.—200 ma. selenium rectifier (or two 100 ma. rect. in parallel)
1—12SK7 tube

CHAPTER 21

Automatic Record Changers

(Adjustments and Servicing)

Turntable Speed Regulation.—One of the most common troubles with record players is that of sound distortion. This condition while sometimes caused by trouble in the pickup is more often due to incorrect speed of the turntable.

Thus, for example, a "wow" sound caused by variations in the speed of the turntable, is commonly evidenced by distortion on long sustained notes especially on L.P. records. As a first step toward eliminating trouble of this nature is a thorough check of the turntable speed.

Standard three-speed automatic record changers are designed to play 78, 45 and 33⅓ *r.p.m.* records of standard commercial dimensions. The sizes of standard records for which the changers are set are 7, 10 and 12 inches, the 7 inch records being used exclusively for the 45 *r.p.m.* speed.

Due to the scope of practical manufacturing tolerances and often because of voltage variations, three-speed changers are frequently inaccurate at one or more speeds; and whereas professional standards call for a maximum speed deviation of 0.3 per cent from that required, errors as high as 5 per cent and more are sometimes found in commercial record changers.

Thus, in extreme cases it may be found that a 78 *r.p.m.* record changer may run as fast as nearly 82 or as slow as 74 revolutions per minute. Similarly, at 45 *r.p.m.* the same changer may run as fast as 47¾ or as slow as 42¾ *r.p.m.*

FIG. 1—Illustrating Webcor Model 1122 plug-in, three speed automatic record changer. ***Courtesy Webster-Chicago Corporation.***

Speed Determination.—Although an approximate determination of speed values may be obtained by counting the number of revolutions made in a minute or multiple thereof by inserting a small strip of ordinary white paper between the record and the turntable, it is preferable to check the speed with the aid of a stroboscopic disc.

A stroboscopic disc or strobe card is essentially a circular cardboard disc with lines so drawn and spaced that when the disc is placed on a record being played, and illuminated by a Neon lamp connected to a 60 cycle alternating current source, the lines appear to stand still when the speed of the record and turntable is correct. When, on the other hand, the lines are moving forward, the speed of the turntable is too fast and when the lines appear to travel backward the turntable is regulated at too slow a speed.

As previously noted, professional standards call for a maximum speed deviation of 0.3 per cent, which means that when using a strobe card not more than 21 bars should appear to pass a given point during one minute.

A strobe card for speeds of 33⅓, 78 and 45 *r.p.m.* is usually divided into three sections one for each speed, with each section divided into numerous bars or dots. These bars or dots are calculated in the following manner, assuming a turntable speed of exactly 33⅓ *r.p.m.*

A Neon lamp connected to a 60 cycle *a.c.* source flashes 120 times per second or 7,200 times per minute. If the phonograph turntable revolves exactly 33⅓ times per minute, the lamp flashes 7200/33⅓ or 216 times per revolution of the turntable. Conversely each flash corresponds to 1/216 revolutions of the turntable, but since there are 216 bars or dots on the 33⅓ *r.p.m.* section of the strobe card, each flash from the 60 cycle Neon lamp illuminates a bar that has arrived in exactly the same position that was occupied in the preceding flash by the bar ahead of it. This, aided by the persistence of vision, produces the illusion of the bars remaining stationary. If the turntable speed exceeds 33⅓ revolutions per minute, each bar moves more than one bar distance during the interval between the flashes, thus making it appear that the bars are moving in a forward or clockwise direction.

In a similar manner the strobe card bars appear to be moving in a counter-clockwise direction when the turntable rotates too slow or at a speed of less than 33⅓ *r.p.m.*

Noting the fact that the Neon lamp flashes 7,200 times per minute and illuminates 7,200 bars during this period (33⅓ revolutions × 216 bars in the case of a 33⅓ strobe card), a 0.3 per cent error in turntable speed is 0.003 × 7,200 bars or 21.6 bars.

It is evident from the foregoing that the 78 *r.p.m.* section of the strobe card, will not contain the same number of bars as the 33⅓ *r.p.m.* section. For testing 78 *r.p.m.*, the strobe card will have 7,200/78 or 92 bars. Thus, when the Neon lamp flashes 7,200 times per minute, it still illuminates 7,200 bars at 78 *r.p.m.* because 78 × 92 equals 7,200 approximately. As previously, a 0.3 per cent in turntable speed at 78 *r.p.m.* would cause approximately 21 bars to appear to pass a given point.

For speed testing of a 45 *r.p.m.* turntable the strobe card requires 7,200/45 or 160 bars or dots equally spaced on its circular surface.

If it be desired to find the center angle between each one of the bars or dots on the periphery of the strobe card a simple calculation will show that the various spacings on the 33⅓, 45 and 78 *r.p.m.* cards should be 1.67°, 2.25° and 3.91° respectively.

Speed Adjustment Procedure.—Because of the fact that automatic record changers vary in construction, it is not possible to give a procedure by means of which all changers may be adjusted as to their speeds, unless a particular model or type be selected.

It has been found that the speed of a *Webster* three-speed changer can be corrected by varying the tension on the spring between the mainplate of the changer and the link bearing the idler wheel which moves the turntable.

When the turntable and idler wheel are removed, this spring is exposed to view. Increasing the spring tension (shortening the spring) serves to decrease the speed and vice versa.

Sometimes incorrect speeds may be due to dirty or worn speed reduction pulleys and idler wheel; these should be kept clean at all times. Replace worn out or stretched drive belts (turning them inside out will work in an emergency).

On manual single speed record changers, the turntable speed is regulated easily by a screw or lever adjustment which controls the action of the governor operating in conjunction with the phonograph motor.

In some instances, the entire motor must be overhauled, oiled and greased, and each electrical connection checked and resoldered. When the motor is of the commutator-brush type, the commutator and brushes must be carefully cleaned with fine sandpaper and fitted properly.

Changer Does Not Trip Into the Change Cycle.—During normal playing, the friction lever is prevented from contacting the trip switch to complete the solenoid circuit by the oscillating stud. The rapid movement of the tone arm in the trip groove

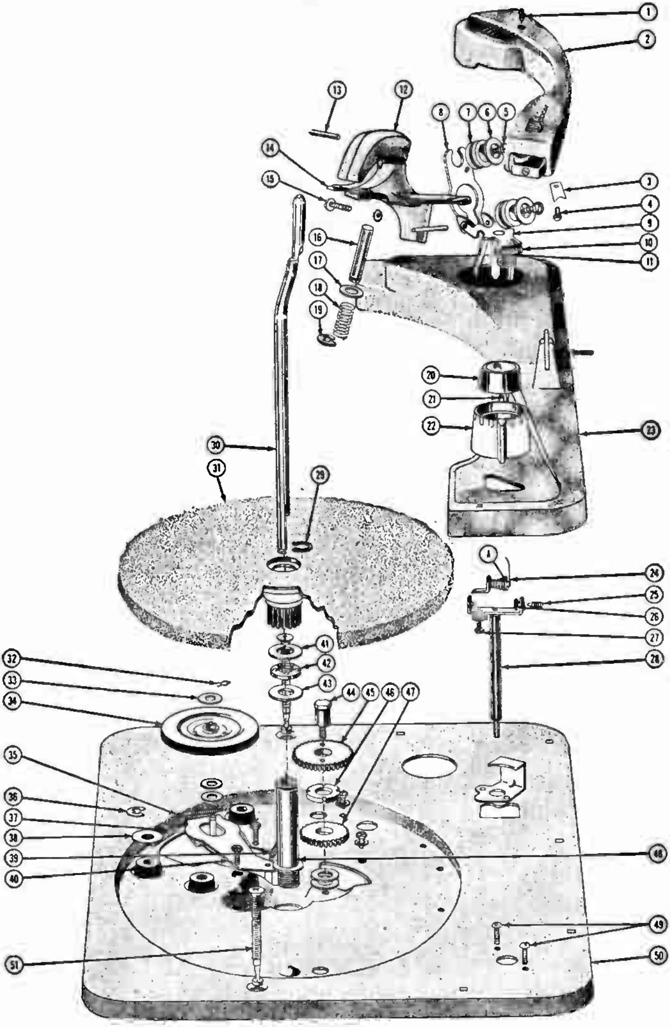


FIG. 2—Exploded view of parts above baseplate in Webster automatic three-speed record changer.

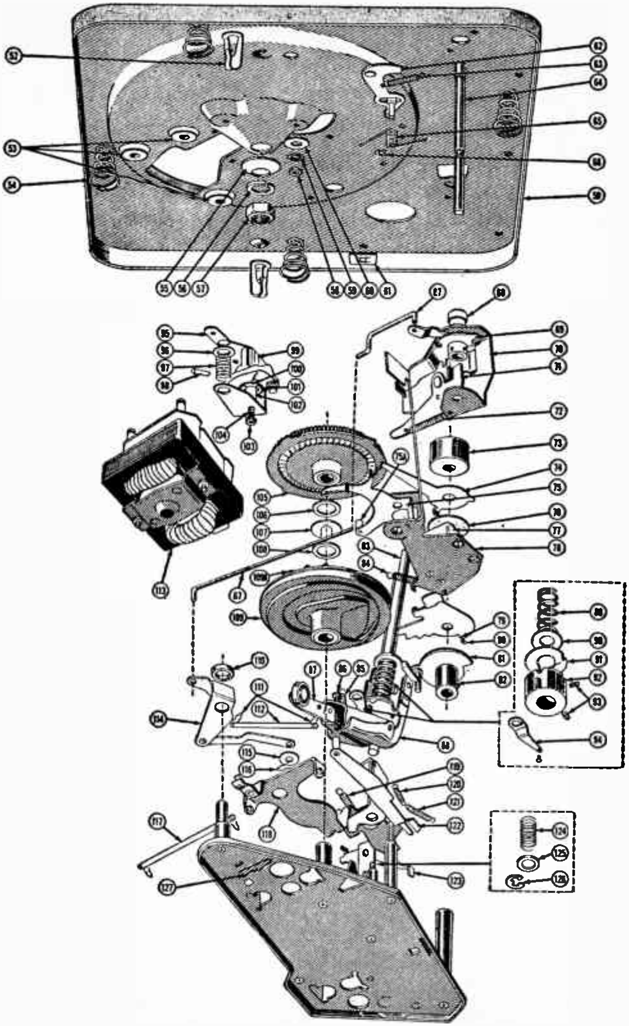


FIG. 3—Exploded view of parts below baseplate in Webster automatic three-speed record changer.

of the record, however, allows the friction lever to contact the trip switch before the oscillating stud can prevent it.

The solenoid is then energized and attracts the trip pawl assembly, releasing a segment of the clutch gear to contact the rotating pinion gear under the turntable. If the maximum outward travel of the oscillating stud be more than 1/16 in. beyond the switch contacts, faulty operation may result. The trip switch support may be bent if necessary to correct this. Check also for dirty contacts on the friction lever and trip switch.

Changer Does Not Trip Into Change Cycle or Trips Too Soon. The trip slide operates the trip assembly and it must move with the least possible resistance. It must not be bent, rusted or hindered in its movement. It should be clean and free from grease. The friction washer holding the gear engagement pawl and trip motion arm together must be loose enough to allow the gear engagement pawl to be kicked backward during the playing of the record.

It must be tight enough to allow the assembly to follow the quick movement of the trip slide when the tone arm enters the trip groove of the record. If the washer be too loose, there will be no tripping; if it be too tight, there will be constant tripping. The washer may be reshaped to increase or decrease its friction. The stud upon which the friction washer rests may be too loose and may be tightened by inserting an additional washer under the main gear.

Changer Trips Too Soon.—This may result if the maximum outward travel of the oscillating stud be less than 1/16 in. beyond the switch contacts.

Changer Trips Continually or Erratically.—The tip of the trip pawl may be too near the edge of the gear segment. A slight bending of the post against which the pawl rests may correct this.

Records Do Not Drop.—Check for loose set screw holding ejector lever. The position of the ejector lever and link assembly on the centerpost shaft is critical. If it be incorrect, the ejector cam in the centerpost may break. The ejector lever set screw should be tightened with the ejector cam flush with the centerpost and the changer in playing position.

The top of the spindle may be bent so that the spacing between the heel of the floating latch and the spindle does not allow a record to slide between. If this condition exists, bend with thumb the top of the spindle slightly in a direction away from the record selector shelf.

Removal of Tone Arm.—If it be necessary to remove the tone arm, close attention should be paid to the position of the spring in the base. If the spring be replaced backwards, the tone arm will not get down on the record.

Warped Strobe Disc.—To remove the strobe disc, first slide the selector lever to the extreme right and speed shift lever to the far left. Next lift off the turntable and remove the strobe bracket screw and spring. After removal, immerse the strobe disc in hot water for a few minutes to straighten it.

Records Do Not Drop.—Records are dropped by the action of the ejector cam which pushes the bottom record clear of the shelf of the centerpost. The length of travel of the ejector cam can be increased by turning the push-off adjustment nut

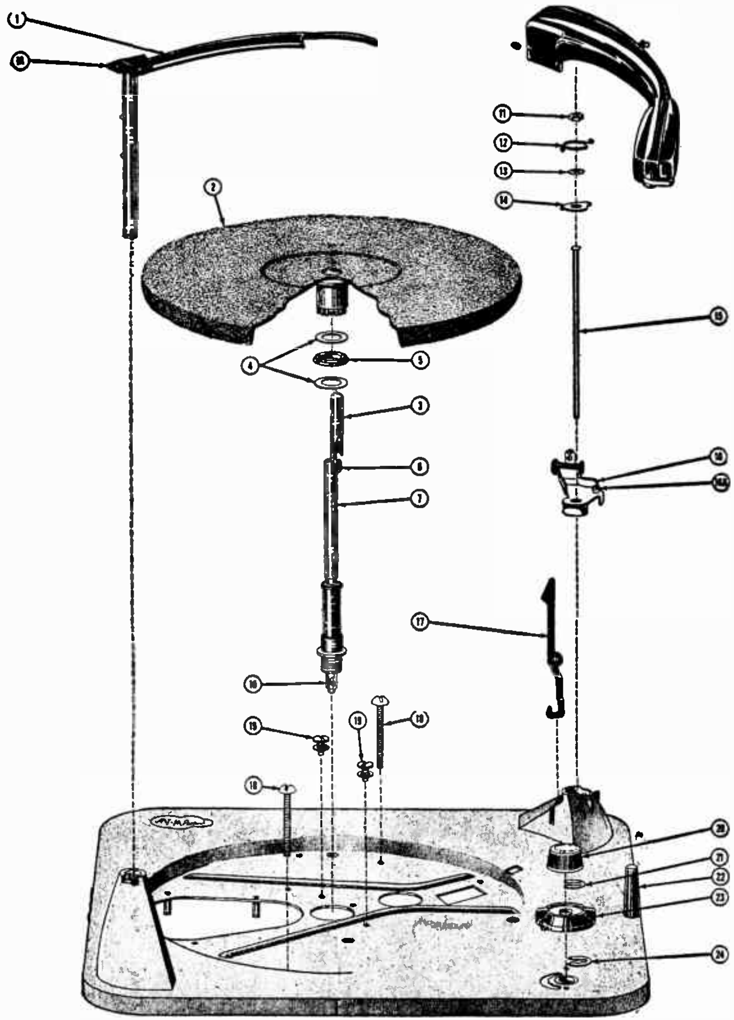


FIG. 4—Exploded view of parts above baseplate in V-M automatic three-speed record changer.

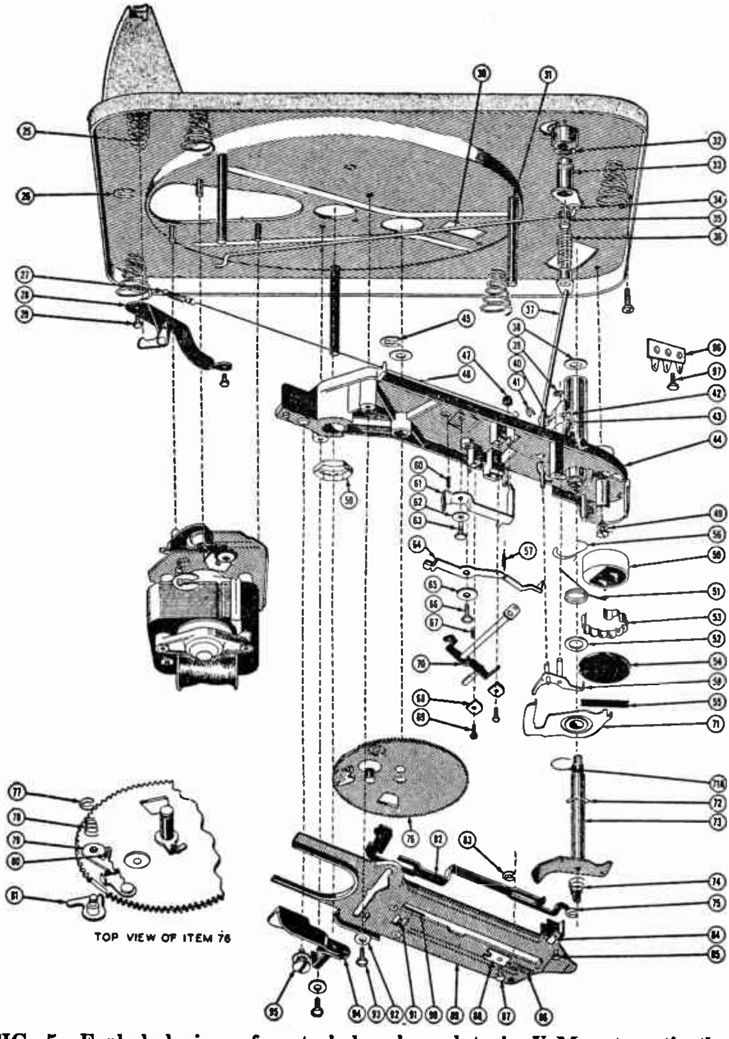


FIG. 5—Exploded view of parts below baseplate in V-M automatic three-speed record changer.

counter-clockwise. Do not increase the length of travel of the ejector cam excessively as this may damage the centerpost and cause jamming during the change cycle.

Fig. 6—Exterior view of automatic, three-speed record changer. ***Courtesy V-M Corporation.***

More Than One Record Drops at a Time.—This may be due to oversize holes in records, or records may be exceptionally thin. If the spindle slide be not all the way down more than one record may drop at a time. Check the slide to see if it be free and do not bind at any point.

Tone Arm Does Not Index Correctly For the Size Record Being Played.—Set down position for the tone arm is determined by the automatic index assembly working in conjunction with the index finger. This finger extends momentarily above the changer pan during the change cycle. If it touch a record the index assembly sets the tone arm for a 12 inch record; if it does not and continues upward so that the lower step on the cap touches a record, the tone arm is set for a 10 inch record. A 7 inch record permits the index finger to go even higher and this sets the tone arm correctly for this size.

If the index finger be bent or loses its rubber cap, the indexing will be incorrect. Burrs in the slots of the index assembly or binding of the pin which rides in these slots cause incorrect indexing.

Tone Arm Does Not Land in Correct Indexing Groove of Record.—A slight adjustment of the tone arm set-down position is performed by means of the adjustment screw located near the base of the tone arm.

45 R.P.M. Records.—Because of the special design features of certain 45 *r.p.m.* records, most modern automatic record players have either a special spider or hole adapter for playing these records or else are equipped with a 45 *r.p.m.* spindle.

Lubrication.—Record changers are usually completely oiled and lubricated at time of manufacture.

Under normal conditions this should be sufficient for approximately one year or 1,000 hours of operation. When operated under extreme conditions of dust or heat, they should be oiled more frequently as required.

Do not permit oil or grease to get on the rubber idler wheel, motor sleeve, turntable drive rim, velocity trip arm clutch or raising disc clutch.

Turntable Does Not Revolve When Control Switch is Turned On.—When this condition occurs, a check should be made to ascertain that the current actually is reaching the *a.c.* leads on changer. Also check that the switch is closing properly and that wiring and soldered terminals in changer are in satisfactory condition.

To check for a defective motor, remove turntable to allow motor to operate without load. If current be available at motor and drive spindle does not rotate the motor is defective.

If drive spindle is turning, but turntable is not, check motor idler assembly to determine if it be free to contact the drive spindle and turntable rim. Wipe off inside rim of turntable to remove flock, or if oily, clean the turntable rim and rubber tire of the idler wheel with naphtha or alcohol.

Motor Noise.—If a low-pitched rumbling sound comes from the loudspeaker while a record is being played, check motor grommets to be sure that the motor is freely suspended on them. The motor lead wires should have slack to allow the motor to float.

Motor rumble may also come from an unbalanced motor rotor, in which case the motor should be replaced.

A rapid thumping sound while the motor is running may indicate a flat spot on the motor idler wheel or speed pulleys. If this condition does not clear up after ten minutes of running time, remove the turntable and check the rubber tire on the idler or pulleys. If the surface of the rubber tire be not smooth and even, replace the part. Should the bearing of the idler wheel show signs of excessive wear or be extremely wobbly, the idler wheel must be replaced.

Defective turntable bearings are also apt to cause a rumbling sound. Check for foreign matter in the bearing, defective balls, binding between balls and ball retainer or rough surface on washers. Clean ball bearing, sleeve bearing, and washers; lubricate with light mineral oil.

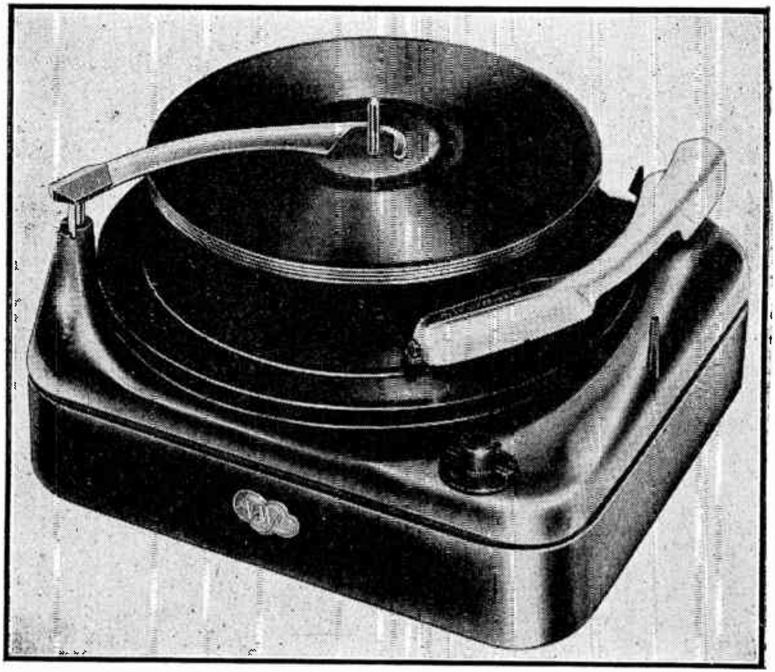


FIG. 7—Webcor Model 1127 plug-in, three-speed automatic record changer. *Courtesy Webster-Chicago Corporation.*

Defective Records.—Worn or defective records will cause needle scratch and distortion of the recorded sound. If the record be warped, it may slip on the other records causing a waver in the recorded sound. An enlarged hole in the record will cause similar trouble and sound distortion.

If a scraping sound occurs as the turntable revolves, the turntable itself may be warped, causing its outer rim to rise and fall.

A similar scraping sound may also be caused if the motor idler or mounting plate be bent or out of alignment.

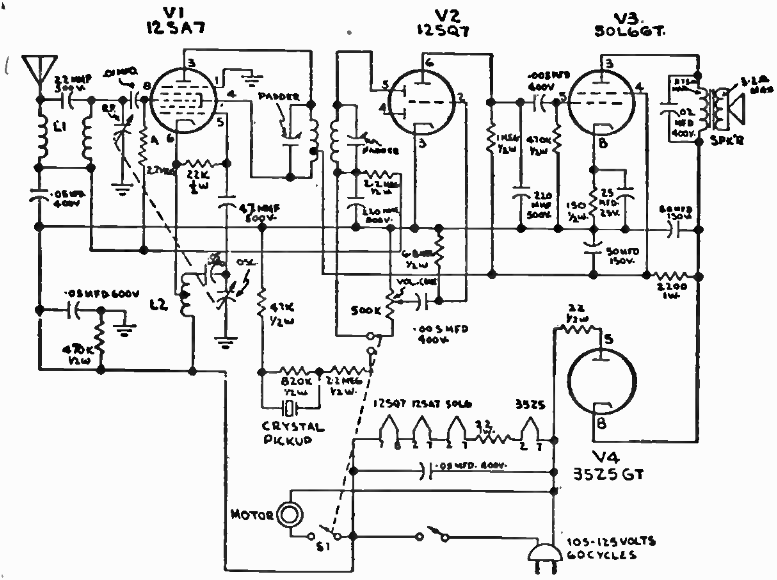


FIG. 8—Schematic wiring diagram of General Electric Model 4SJ3A1 radio phonograph combination. Alignment procedure: 1. Turn S1 to radio and volume to maximum. Connect an output meter across the speaker voice coil. Connect signal generator ground to B—through a, .1 *mfd.* condenser, and the high side to pin 8 of the 12SA7 tube through .03 *mfd.* Tune signal generator to 445 *kc.* and tune T1 trimmers for maximum output reading. 2. Remove signal generator connection to pin 8, unsolder antenna and attach generator to L1 through 25 *mmfd.* Turn tuning condenser of set fully open. Set signal generator to 1620 *kc.* Tune oscillator trimmer on tuning gang for maximum reading; set R.F. trimmer for maximum output reading. Use only enough signal generator output to obtain a reading on the output meter.

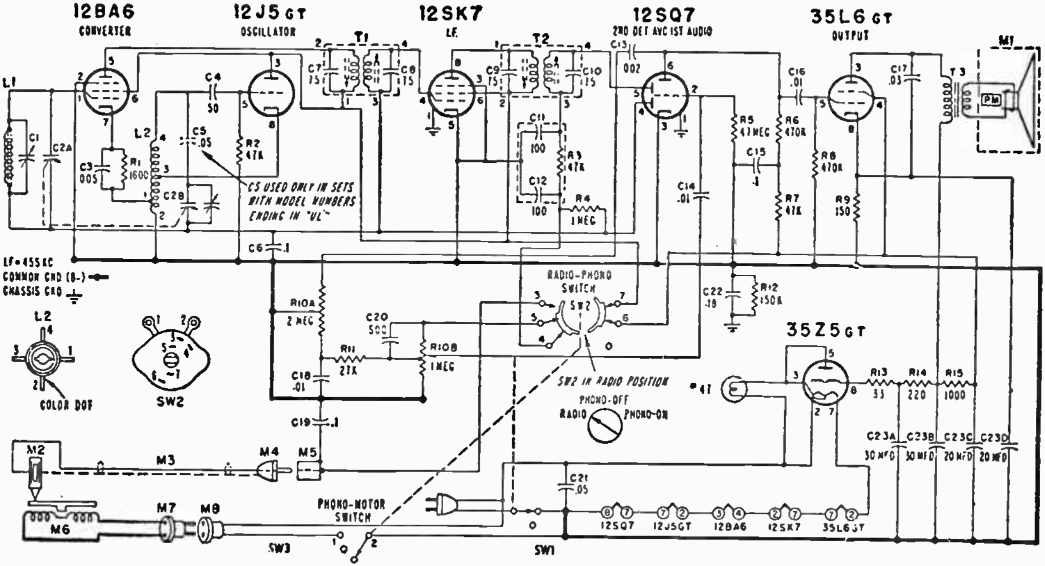


FIG. 9—Schematic wiring diagram of Admiral Model 6S11 and 6S12 radio phonograph combination.

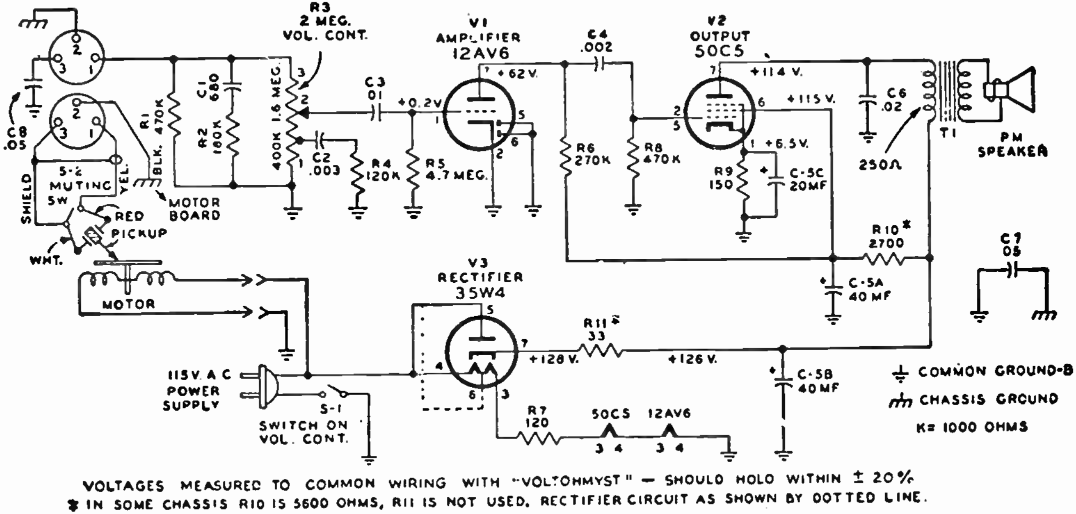


FIG. 10—Schematic circuit diagram of RCA Victor 45 *r.p.m.* automatic record player Model 9EY3, 9EY35 and 9EY36.

CHAPTER 22

Magnetic Tape Recorders

These are presently manufactured in various sizes to suit individual requirements, ranging from elaborate professional recording equipment to small comparatively inexpensive home tape recorders.

Taking advantage of their experience in building quality equipment, manufacturers of such gear are now offering small compact home recorders capable of reproducing all of the quality formerly available only on professionally recorded magnetic tapes.

Because of the fact that the home user, for example, will not need the heavy duty editing facilities required by broadcasting and recording studios, manufacturers of the home type class of equipment generally feature single speed machines of 7½ inch per second, which gives full fidelity rather than two speeds usually found in commercial equipment. Single speed recorders require a smaller less expensive motor and also eliminates the necessity for providing facilities for changing equalization to meet different tape speeds.

Basic Principles.—The basic idea of tape recording is extremely simple and although the principles have been known for a long time it is only during the last decade that the tape recorder has come into popular use in the home.

The tape consists of a paper or plastic material coated with fine particles of iron oxide in an adhesive binder. The tape (motivated by a small *a.c.* motor) passes over an electromagnet, the field strength of which is varied by the incoming audio waves.

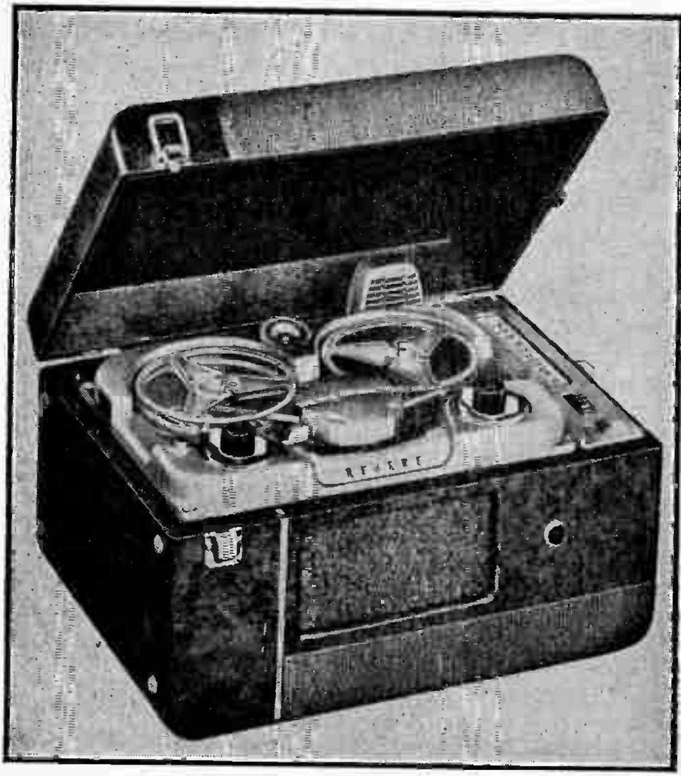


FIG. 1—Typical tape recorder designed to magnetically record on 5 or 7 inch reel. The one-quarter inch tape width provides a dual tape track. Tape speeds are 3¾ and 7½ inch per second. (Courtesy Revere Camera Company).

It is in this manner that the tape is magnetized at a varying strength along its length, the comparative strength being a measurement of each audio wave as the tape proceeds on its path through the electromagnet.

In the playback process, the tape is passed over a similar electromagnet whose coil is connected to the input of an amplifier. The moving magnetic lines of force from the tape are picked up by the electromagnet core and in cutting the wires of the coil, induces in them voltages of varying amplitude. These are amplified and the audio is thus reproduced.

The electromagnet used in the recording process is known as the *recording head*, whereas the electromagnet employed in the playback process is termed the *playback head*.

The foregoing magnets are so similar in requirements that a single head is commonly used for both recording and playback with provisions for appropriate circuit switching. Such heads are used in all of the less expensive non-professional tape recorders, such as the machine shown in fig. 1.

Professional recorders have separate heads. This has a dual advantage in that (1) each head can be designed for a particular application, and (2) with separate heads for recording ana playback. The recording can be monitored from the tape during the recording process.

A diagrammatic view of one type of recording or playback head is illustrated in fig. 2, viewed from the edge of the tape. The core consists of a ring of magnetically "soft" material with high permeability. Such a material is very easily magnetized but does not retain an appreciable amount of magnetism when the current is removed from the coil. A typical material used in recording or playback heads is *mu-metal*.

The iron-oxide coating of the tape is magnetically "hard", that is, once it is magnetized, it retains much of its magnetism over a long period of time. In recording, the tape moves continuously over the small gap in the iron core. When the magnetic lines of force pass through the iron core they are

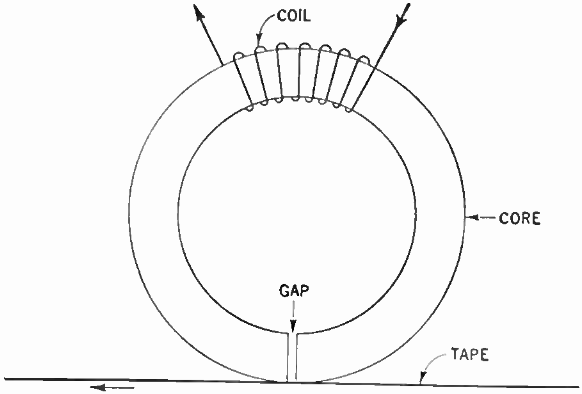


FIG. 2—Construction principles of recording head. In actual practice manufacturers of tape recording machines endeavor to keep an effective gap width of about 0.5 mil. This makes reproduction of 15,000 cycles impossible, but with equalization, satisfactory response is possible to around 10,000 cycles and output can easily be linear to 7,500 cycles at 7½ *i.p.s.* Increasing the speed to 15 *i.p.s.* gives full linear 15,000 cycle response necessary for high fidelity.

subject to the reluctance or magnetic resistance of air (or whatever other material which may fill the gap) which is comparatively high. These lines, therefore, pass more easily through the tape coating, and in doing so they magnetize the coating within the gap.

Now since the strength of the field varies with the audio waves, each successive small area of tape coating that passes the gap is magnetized to a somewhat different field strength.

In playback, the tape may again be passed over the same head. This time the coil is connected to the amplifier input. As each little magnetized section of tape passes the gap, its magnetic field causes lines of force to pass through the core and cut the coil. The induced voltage is then amplified.

Hysteresis Effect.—The magnetic hysteresis in iron is the cause of certain detrimental factors in the faithful reproduction of sound in a magnetic tape recorder. It may easily be visualized that when an unmagnetized tape is subjected to a magnetic field of certain strength, it is magnetized to a corresponding strength over a certain range. When the magnetic field is removed, however, the section of tape leaves the head, and in so doing the tape magnetism falls to a certain lower value. This lower value will vary with that of the inducing field over a very small range, but will never reach zero.

As a result of the foregoing, a sine wave recorded on tape is somewhat distorted as illustrated in fig. 3. This distortion is removed by ultrasonic bias, that is, a signal of between 30 and 60 kilocycles is superimposed on the audio fed to the head. The bias signal is generated by an oscillator incorporated in the circuit.

Frequency Response.—The frequency response is an important factor in the performance of any magnetic tape recorder. While head inductance causes a change in head reactance as frequency varies, this is usually countered by feeding the head from a constant current source such as from a pentode tube. Since the magnetic field depends upon coil current, the recorded magnetism on the tape is fairly constant from the low range up to some midrange frequency. Above this point however, core losses and gap effect reduce the treble.

In playback there is a reduction in output between the midrange and the bass, as well as from midrange to treble. Fig. 4, shows the general shape from the output curve of a playback head from a tape recorded without equalization. The lower

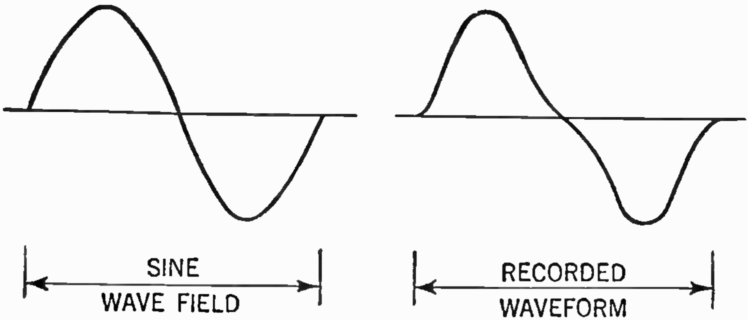


FIG. 3—Showing distortion of sine wave field due to lag of magnetic effect behind their source. This is known as the hysteresis effect of the magnetizing material.

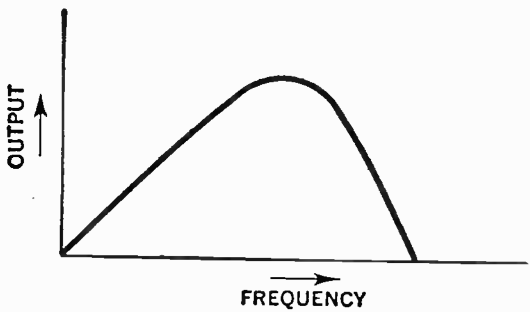


FIG. 4—Typical curve representing the output of a playback head.

part of the curve is due to the induced voltage depending on the speed at which the lines are cutting the field. At lower frequencies the velocity is obviously lower, therefore the output is also lower.

Gap and Tape Speed Effect.—An additional loss occurs in the treble due largely to the gap effect. This may best be comprehended by referring to fig. 2. Here it will be noted that the length of tape played back at any one instant is equal to the gap length. Thus, if the gap be very small with respect to a wavelength, say 1/20 wavelength, then it scans only 1/20 of the wave at a time and the output voltage will show a good representation of the wave.

Suppose, however, that an entire wavelength fits under the gap at one time. The wavelength contains all values of magnetism from zero to maximum in both directions, the sum total of which is zero, therefore, the head output is also zero. From the foregoing it follows that there is a loss in output as soon as the wavelength of recorded sound on the tape begins to approach the length of the gap, and there is a total loss when the wavelength and the gap are equal.

There are two methods used in extending the high frequency response before it is necessary to equalize electrically. These are important because equalization causes loss of gain, increased noise and is seldom obtained with any degree of precision. First the gap should be made as small as possible, second the length of waves can be increased by making the tape run faster; this has the effect of spreading out the wave over a longer portion of the tape.

From the foregoing discussion it will be observed that for best results the gap width must be as small as possible and in actual practice manufacturers of magnetic tape recorders are keeping effective gap width to about 0.5 mil, and while small inexpensive machines run at a speed of 3.75 and 7.5 inches per second for speed recording, high fidelity recording of music is as a rule impossible on machines having speeds of less than 15 inches per second. This latter type of recorders give the full linear 15,000 cycle response necessary for high fidelity work.

Basic Sections.—Magnetic tape recorders consist of three basic sections, they are:

1. The recording amplifier
2. The playback amplifier, and
3. The tape transport mechanism.

In the home type recorder only one amplifier is used for the recording and playback, with the different functions selected by a "*record-listen*" switch. This switch when in the "*record*" position connects the record and playback coil in the head assembly (one coil performs both functions) to the output of the amplifier which supplies the audio voltage to be recorded.

In this position, the switch also converts the output stage to an oscillator, usually 30 to 60 *k.c.* to provide bias for the recording head and also erase current for the erase coil in the head, although on some machines a separate bias and erase oscillator is employed.

Equalization is also inserted in the amplifier to compensate for frequency response characteristics of the head and tape speed. The equalization is in the form of high frequency boost. This increases the signal-to-noise ratio of the recording during playback.

In the *playback* position, the recording coil in the head assembly is connected to the input of the amplifier. The bias oscillator is converted back into the output stage, and the high-frequency boost is removed. The equalization in the *playback* position is different from that in the record position.

The high frequency response is attenuated to retain the balance of the original program material, and the low-frequency response is boosted. The low-frequency equalization is accomplished during playback rather than during recording to prevent the low-frequency components from saturating the tape.

The Tape Transport Mechanism.—The mechanical section of the recorder such as the tape transport mechanism must comply with certain requirements in order to qualify for its exacting duty. Thus, for example, its speed must be constant and wow and flutter held to a low value. It must also be quiet in operation and able to stand a fair amount of rough treatment as may be caused by day-to-day usage.

A tape transport mechanism includes the following basic components:

1. A capstan and flywheel assembly which pulls the tape past the record and erase-head assembly at a constant rate of speed, usually 3¾ or 7½ inches per second. This capstan and flywheel assembly is driven by a small synchronous motor through a rubber idler wheel. The tape is held against the capstan by a spring-loaded rubber pressure roller, and against the heads by a pressure pad assembly as noted in fig. 5.

2. A take-up spindle assembly. This take-up spindle is usually driven by the motor that drives the flywheel through some form of clutch as noted in fig. 6. This clutch is needed because the diameter of the take-up reel is constantly changing as it takes up tape, causing it to pull more tape with each revolution, but since the capstan will only feed the tape at a constant rate, the clutch must supply the necessary slippage.

3. A rewind spindle assembly. This may be driven from the flywheel by a chain belt or from the motor shaft by a rubber idler wheel as illustrated in fig. 7.

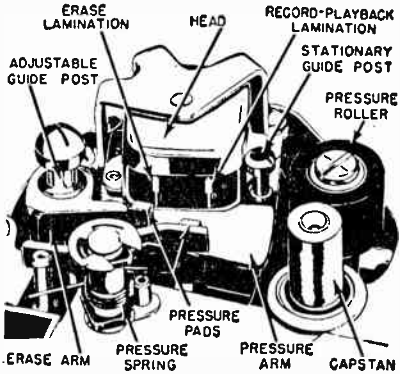


FIG. 5—The head assembly and capstan of a typical tape recorder. Note that the head assembly includes the record-playback and erase head in one unit.

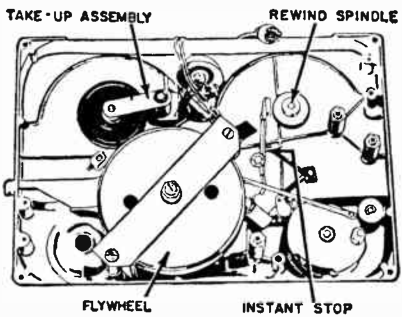


FIG. 6—Illustrating typical method of using a flywheel for driving the take-up reel of a tape recorder. The flywheel is coupled to the motor through an idler pulley.

Servicing of Mechanical Section

Although tape recorders are manufactured to give years of trouble free service under normal operating conditions, minor adjustments and servicing may become necessary from time to time.

The most common source of trouble are the rubber wheels used to drive the different moving parts. These wheels may become glazed and start slipping or they will wear and get lumpy, causing wow and flutter.

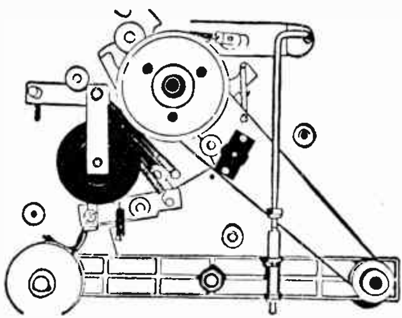


FIG. 7—Illustrating how the rewind spindle in the lower right is driven by means of a chain belt from the motor in a typical recorder.

The rubber pressure roller may become fouled with oxide from the tape which will also cause slipping. Particular care should be observed in preventing oil from contacting the rubber wheels.

Wheels that have become glazed after considerable use can be restored by cleaning with alcohol or by holding a piece of fine sandpaper on the wheel while it is running. Be careful not to remove too much rubber if sandpaper be used. Wheels that have had oil on them must be replaced. In this latter case cleaning will not help, since oil will cause a change in the rubber structure.

Motor bearings should be lubricated at certain time intervals with a couple of drops of light machine oil. Be careful that no oil gets on any one of the driving surfaces. Cams and levers should be lubricated with a small amount of light grease on the bearing surfaces only.

The pole pieces in the recording head or heads are also subject to considerable wear. The tape used for magnetic recording is coated with a metal oxide which acts as a fine abrasive, something like a crocus cloth. When the pole pieces wear down, the machine will not record and erase properly because of the change in gap dimensions, causing low volume, poor high frequency response and incomplete erase.

A thorough examination of the pole pieces may be made with the assistance of a magnifying glass or jeweler's loupe to detect wear and irregularities in the gap.

The record gap should be in the form of a very fine line, and the spacing along the full length of the gap should be even.

The erase pole piece has a gap of from four to five times the size of the record gap and this should also be even along the full length of the gap.

Improper recording and erasing can also be caused by a dirty head. Be sure that the head is free from all oxide that may come off the tape. When replacing heads or pole pieces, they must be peaked for maximum high-frequency response. This is accomplished by running a test tape with 7,500 *c.p.s.* recorded on it, made on a machine known to be perfect and slowly rocking the head back and forth until maximum response is obtained. Then lock the head in position.

Wow and flutter can be traced by listening to its rate, and watching for drive wheels and pulleys that turn at the same rate. Thus, for example, a fast flutter would not be caused by a pressure roller that turns at a slower speed than the rate of the flutter.

Speed should be checked by making a recording of music with piano or wind instruments and listening for wow and flutter. There are instruments on the market made for measurement of wow and flutter, but these are rather expensive and therefore out of reach for the average service technician.

Some of the more important precautions to observe when servicing magnetic tape recorders, are:

1. Do not over-lubricate.

2. Do not use carbon tetrachloride to clean rubber wheels as this will ruin them. Use alcohol.

3. Do not wash oilite bearings in any type of solvent.

4. Do not use magnetized tools on or near recording heads. Be careful not to scratch or mar the pole pieces.

5. Do not check heads with ohmmeter which may cause the heads to become heavily magnetized and cause a high background hiss of the recording.

6. Make sure that the tape being used on the recorder has the correct wind. Tape is made in two winds; the "*A-wind*" which has the oxide wound facing the hub of the reel, and the "*B-wind*" which has the oxide wound facing away from the hub. After threading the tape through the machine, the oxide or dull side of the tape should face against the heads.

Editing and Tape Splicing.—In case the tape is broken accidentally or if it be desired to insert a length of tape of recorded material from another reel, a splice may conveniently be made with Scotch tape. To make reliable splice, cut the broken ends at a 60° angle as shown in fig. 8, and butt the ends together. Fasten the two ends together with a piece of Scotch

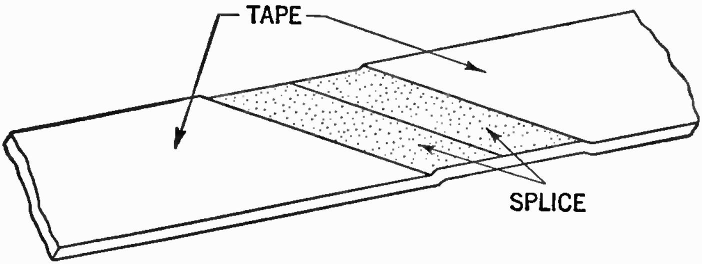


FIG. 8—Showing method of tape splicing.

No. 41 splicing tape or ordinary Scotch Cellulose tape placed parallel to the cut. Be sure to place this splicing tape on the back of the recording tape (light colored side of paper tape and glossy side of plastic tape). Trim the edges so that the recording tape is slightly narrower at the splice.

Erasing of Recorded Material.—Erasing of recorded material takes place automatically when new material is recorded, hence no special steps are necessary to erase old recordings before new recordings are made.

Adjusting of Tape Tension.—The tape tension may be measured by attaching a spring balance to the end of a piece of tape drawn only through the erase head; then through the record head. The tension required to move the tape through the erase head should be from 1 to 1½ oz., on the average for typical recorders.

Cleaning.—The record-play head, capstan and pressure roller are, as with all tape recorders, subject to an accumulation of tape coating residue which is worn off the tape as it passes these parts. Use a soft cloth or cotton swabs and alchol or carbon tetrachloride to clean the surfaces of those parts. *Caution:* Do not use a brush when cleaning the recording head as this might mar the lamination.

Lubrication.—All rotating parts of modern tape recorders generally require no lubrication. When unit is disassembled for repairs, clean all bearings and lubricate with a light grade of machine oil. If cam and lever actions become sluggish and slow to respond, it may be due to gum or dirt in the pivots and under the levers. Clean off all old lubricant, accumulated dirt and gum with a clean cloth and cleaning solvent. Apply lubricant in thin film on working surfaces only. *Caution:* Do not get oil on rubber parts or on any surfaces which contact the magnetic tape.

Signal to Noise Ratio.—By definition, signal-to-noise ratio is the ratio of peak recording level to the total unweighted playback noise when erasing a signal peak recording level and in the absence of a new signal.

Peak Recording Level.—The peak recording level is defined as that level at which the overall (input to output) total *r.m.s.* harmonic distortion does not exceed 3% when measured on a 400 cycle tone.

Servicing of Electrical Section

The servicing of the electrical section of a magnetic tape recorder does not differ in any important respect from servicing encountered in other types of sound producing equipment. Thus all of the troubles likely to occur in the amplifier will respond to conventional service techniques.

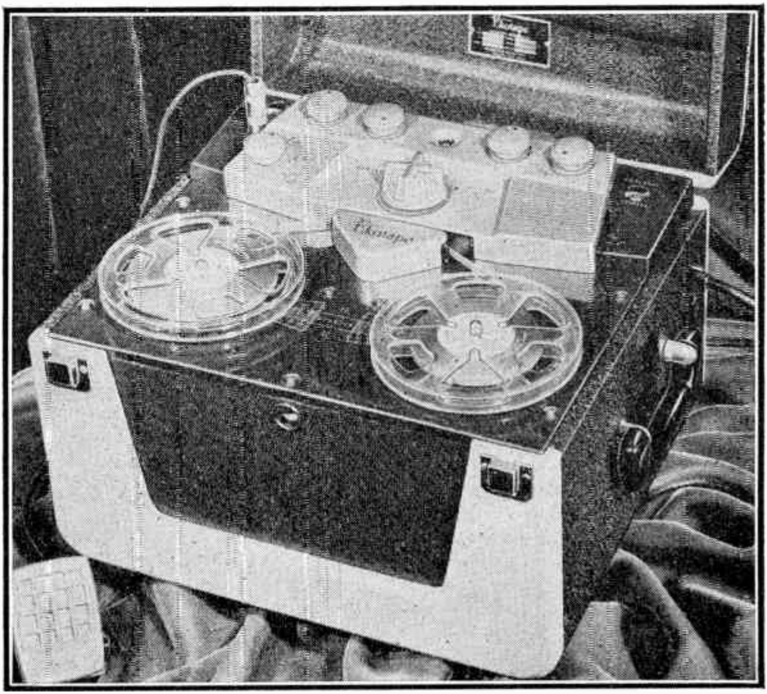


FIG. 9—Illustrating a popular twin-track two speed model tape recorder, operating at tape speeds of either 3¾ or 7½ inches per second. (Courtesy Webster Electric).

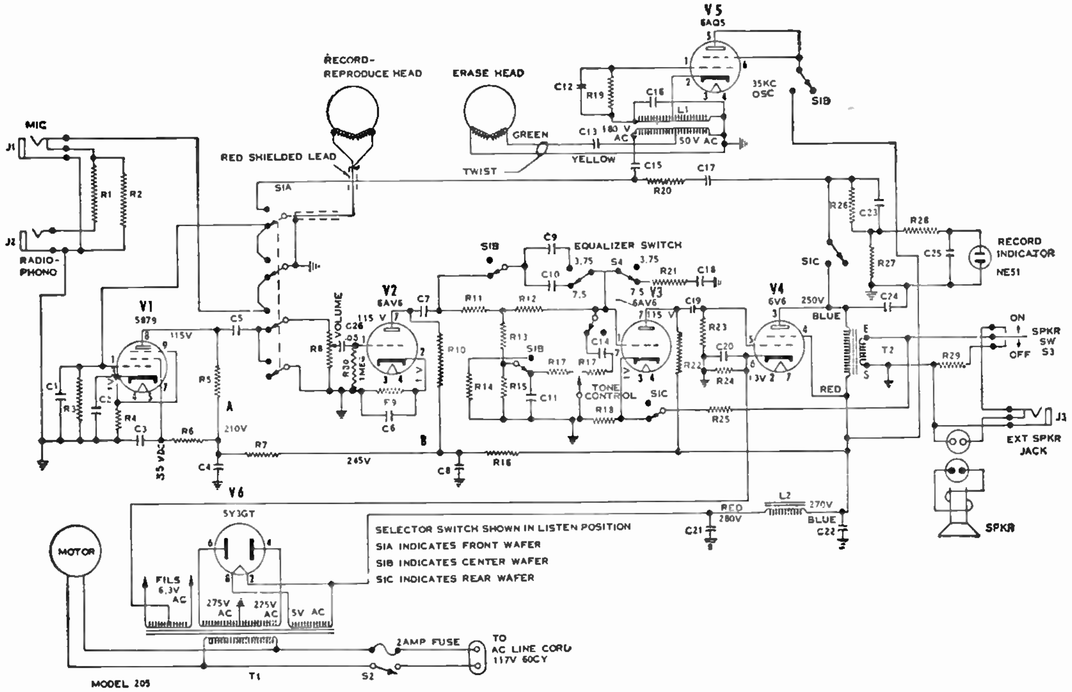


Fig. 10—Schematic wiring diagram of electrical system of tape recorder shown in fig. 9. (Courtesy Webster Electric).

When the machine fails to erase properly, and the recordings become low in volume and distorted, the trouble will usually be found in the bias-erase oscillator. A quick check may be made by placing a neon bulb on the plate of the oscillator and also on the leads going to the head. If the bulb glows, the oscillator will usually be found in a satisfactory condition. Also check for worn or dirty pole pieces as they will give the same type of symptoms.

Head Magnetization.—Occasionally the heads may become magnetized through an electrical fault in the amplifier, improper use of the machine or by heads coming in contact with a magnetized object. This will result in an increase in the noise level.

It is especially important that the heads be free from magnetization if the dynamic range of the recorder is to be realized. It should be remembered that any phenomena that tends to put an unbalanced pulse through the record head will magnetize it. Such pulses can appear in the form of signal or power line pulses. If the following precautions be observed, no difficulties should be experienced:

1. Do not remove any tube from the record amplifier while the machine is recording.

2. Do not connect or disconnect input leads or head leads while recording.

3. Do not depress the record button until after depressing the start button. In other words, allow the transient caused by switching the motors and solenoids to die out before the record head is connected. A one-half second pause is sufficient.

4. Do not saturate the record amplifier with an abnormally high input signal. Such a signal would be 10 *db.* greater than tape saturation or approximately 30 *db.* greater than normal operating level.

5. Do not test continuity in heads with an ohmmeter. Should the heads become magnetized, they can be demagnetized with a head demagnetizer. When demagnetizing, the following procedure should be followed: Bring the tip of the demagnetizer in direct contact or close proximity to the head or core stack. Run the tip of the demagnetizer up and down the entire height of the core stack three or four times. Remove the demagnetizer very slowly, allowing the *a.c.* field to die off gradually. Repeat this procedure on record and playback heads only, as the erase head will demagnetize itself. In the event demagnetization is not effected, repeat the process several times.

If a demagnetizer be not available, place the head near a strong 60 cycle *a.c.* field and slowly reduce the field to zero. This treatment if repeated a few times should demagnetize the head.

Capstan Magnetization.—The capstan may become magnetized by contact with a magnetized tool. Capstan magnetization appears as noise components usually occurring at the rotational period of the capstan. They will be present on the playback of a tape only and will not be heard when monitoring a tape during the recording process because they will be erased by the erase head. Should this magnetization occur it may be removed with an *a.c.* solenoid placed over the shaft and slowly pulled away.

Operating Instructions

Tape recorders are manufactured in a great variety of models depending upon their use. Thus, for example, professional recorders employed in broadcast, television and recording studios must, because of their exact requirements, incorporate the latest mechanical and electronic refinement, whereas small portable type recorders used in homes and offices incorporate only those components which are necessary for their proper operation.

Because of the limited space available in this chapter, only the smaller home or office recorders are treated here, and although the operation may vary, depending upon the type of machine involved, the instructions given should enable the operator to successfully deal with a machine differing in some small degree from that given on the following pages.

Preparing the Machine for Recording.—To prepare a typical machine for recording proceed as follows:

1. Insert the line cord into a convenient wall receptacle, having the proper voltage and current frequency.
2. Place a reel of tape on the right hand spindle in such a manner that when the tape is pulled the reel will turn in a clockwise direction. Make sure that the reel is engaged with the drive pin on the spindle.
3. Place an empty reel on the left hand spindle.
4. Pull about two feet of tape from the supply reel and feed it through the recording head slot and then through one of the radial slots in the empty reel. Use a pencil to hold the tape in place and rotate the reel clockwise until the tape is secured to the reel.

5. Turn the "off-on volume control" on. This supplies power to the entire recorder.

To Make a Recording.—To make a recording, proceed as follows:

1. Insert the microphone into the "Mic" jack.
2. Place the play-record control in "Record" position.
3. Turn the "Volume" control clockwise until the incoming signal is sufficient to cause the Neon level lamp to flash on high peaks.
4. Turn the control knob to "Forward" position. Any sound now entering the microphone will be recorded on the tape.

To Record Directly From Radio.—To record directly from radio, proceed as follows:

1. The special input cord, equipped with microphone plug and clips, is plugged into the "Mic" jack and clipped to the voice coil terminal of the speaker in the radio being used.
2. Tune in the radio program as usual, but use only enough volume to hear the program clearly. Set the recorder volume control so that the level lamp flickers occasionally, as when using a microphone.
3. Reverse the clips at the radio speaker if a test recording be not clear and relatively free of hum. It may be difficult or impossible to make clear, quiet recordings from some small *a.c.-d.c.* radio receivers.

To Stop Recorder.—The recorder may be stopped at any time by turning the control knob to "Stop". This stops the movement of the tape and shuts off the motor through the action of switch.

Two-Track Recording.—In recorders designed for two-channel recordings the heads are designed to record and erase on only half the width of the tape at a time. In machines of this type, therefore, after a reel of tape has been recorded, a second track may be recorded on the same reel.

To make the second recording, proceed as follows:

1. Another recording can be made on the same tape by removing the reels from the recorder, turning them over, then placing the full reel on one spindle and the empty reel on the other in the manner previously described.

2. Thread the tape and proceed with the recording as previously described.

3. After the second track has been recorded, the first track is ready to be played by changing reels as described in the foregoing.

To Rewind the Tape.—To rewind the tape proceed as follows:

1. Make sure the play-record control knob is in "Play" position.

2. Turn the control knob to "Rewind".

To Play a Recording.—When it be desired to play a recording, proceed as follows:

1. Make sure the play-record control knob is in "Play" position.
2. Turn control knob to "Forward" position.
3. Set the volume and tone controls at desired levels.

Fast Forward.—This is a time saving procedure which enables the playing of selected parts of the recording only while other non-essential parts may be omitted. The procedure is as follows:

1. The "Fast Forward" control operates only when control knob is in the "Forward" position. *Never attempt to operate the "Fast Forward" knob at any other time.*
2. Control knob will function normally only when "Fast Forward" knob is in the out position.
3. During the "Play Back" period any portion of a recording may be skipped or any recording on a tape may be located in a few seconds by pivoting the "Fast Forward" knob in a clockwise direction. A few seconds of "Fast Forward" is equivalent to several minutes of playing time. The "Fast Forward" knob has usually three positions.
   - *a.* "Out" at which position it must remain at all times, except for "Fast Forward".
   - *b.* "Pause" is the mid-position that brakes the fast moving reels and stops all tape movement.
   - *c.* "In" is the "Fast Forward" position.

To Play a Recording Through An External Amplifier.—When it is desired to play a record through an external amplifier, the procedure is as follows:

1. A phono plug and shielded line can be used to connect from the "Phones" jack on the recorded to the phono input of an external amplifier or public address system.

To Play a Recording Through an External Speaker.—When it is desired to play a recording through an external speaker, proceed as follows:

1. An external speaker of the permanent magnet type having a voice coil resistance of approximately 3 ohms may be used by plugging into the external speaker jack. When an external speaker is plugged in, the internal speaker is automatically disconnected.

CHAPTER 23

Public Address Systems

By definition a public address system consists of a sound amplifier system supplying sound programs from *radio*, *phonograph* or *microphones* to one or more *loud speakers*.

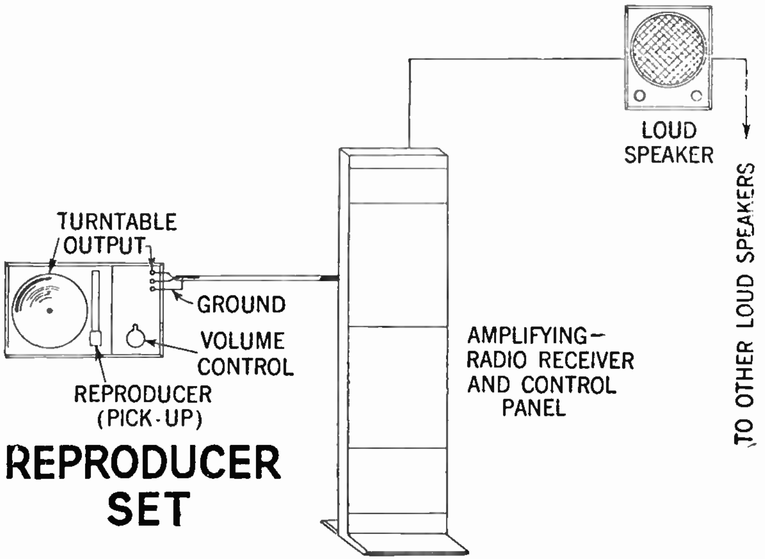


FIG. 1—Schematic view of a music reproducing and program distributing system.

A public address system may be designed to amplify sound in one single place such as in an *auditorium* or in a number of rooms such as in *hotels* or *hospitals*.

In order that the reader may obtain a clear conception of the various units comprising the system, the following definitions are given:

Music Reproducing System.—It may be defined as an assembly of apparatus consisting of a reproducer set (program source), the necessary amplifying and control equipment and one or more loud speakers. A music reproducing and program distribution system is shown in fig. 1.

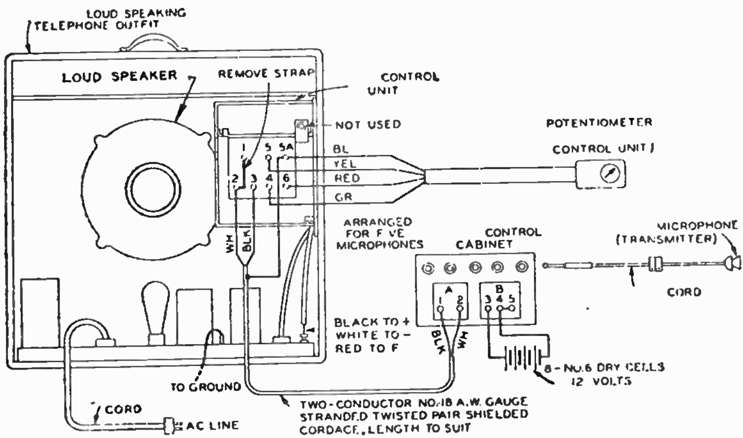


FIG. 2—A small portable announcing system.

Announcing System.—It may be defined as an assembly of apparatus comprising one or more announcer's microphones. The necessary amplifying and control equipment, and one or more loud speakers. A system of this type is illustrated in figs. 2 and 3.

Program Distribution System.—A system which provides facilities for the distribution of programs from a radio receiver in conjunction with a public address system, announcing system, or music reproducing system to one or more loud speaking telephones.

Operation Theory.—The aforementioned apparatus operates as follows: A microphone (which may be of various shapes and designs as shown in figs. 18 to 23 connected into an electric circuit, is placed in such a manner that the sound directed into it will be reinforced.

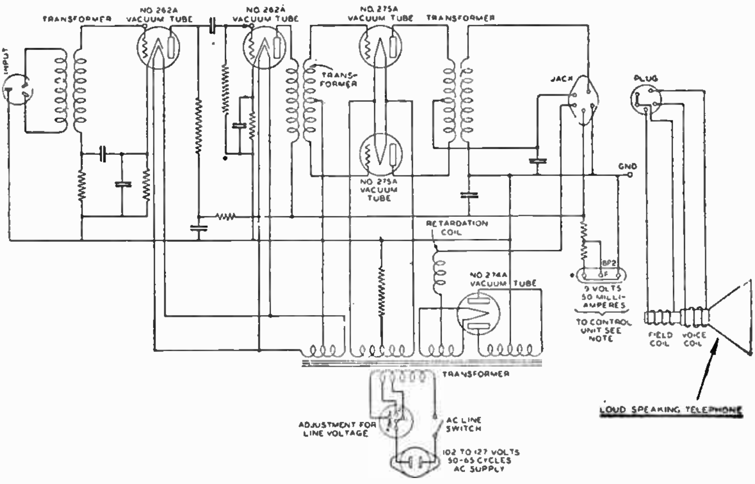


FIG. 3—Schematic diagram of amplifier shown in fig. 2.

The sound waves or vibrations register on the diaphragm of the microphone causing corresponding fluctuations in the electric current. This electrical energy is conducted by wires to control panels which regulate the energy fed into the amplifying

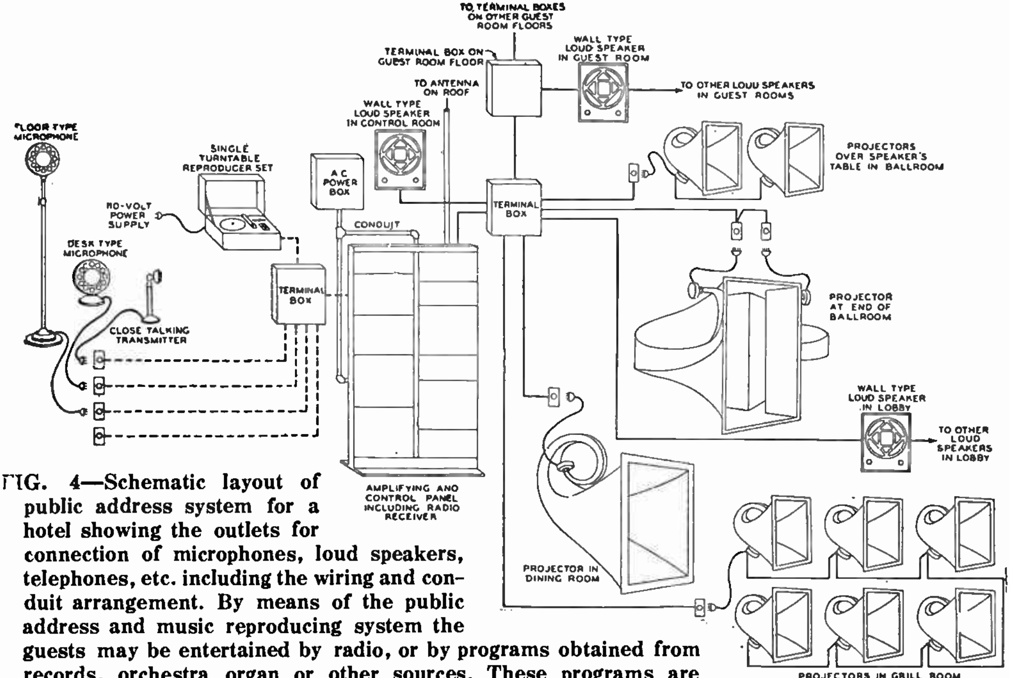


FIG. 4—Schematic layout of public address system for a hotel showing the outlets for connection of microphones, loud speakers, telephones, etc. including the wiring and conduit arrangement. By means of the public address and music reproducing system the guests may be entertained by radio, or by programs obtained from records, orchestra organ or other sources. These programs are amplified and distributed to the various guest rooms, dining rooms, grill, ballrooms as well as in foyers, lobbies and reception rooms. The ballroom is equipped for the reinforcement of speakers voices at banquets and similar functions.

equipment, where it is amplified to a level millions of times greater than the original energy put into the microphone. It is obvious that when reproducers or radio receivers are used as program sources, this apparatus may be connected directly into the amplifying equipment.

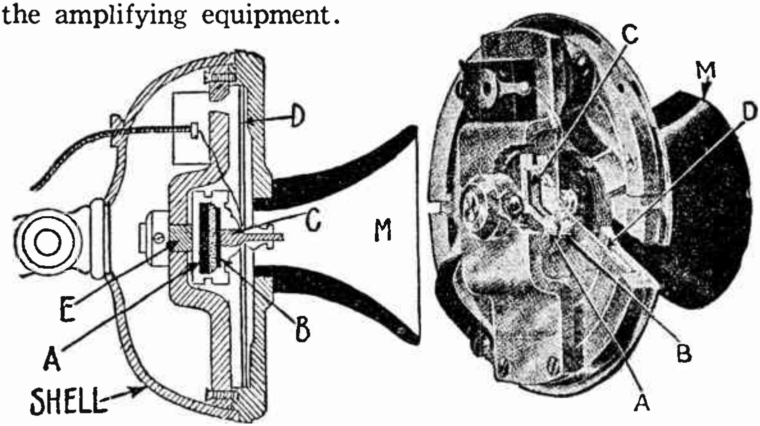


FIG. 5—Typical transmitter. The parts are: *A*, fixed carbon disc attached to the bridge at *E*; *B*, movable carbon disc attached to the center of the aluminum diaphragm *D*, at *C*; *M*, hard rubber mouth piece. The shell is for protection and for mounting the transmitter to a stand or bracket.

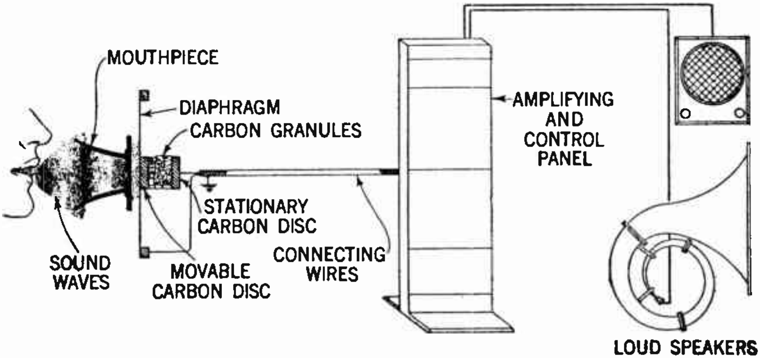


FIG. 6—Illustrating principal parts of a public address system.

The so amplified energy passes on to loud speakers which reconverts it into sound, which is hence distributed over the desired area.

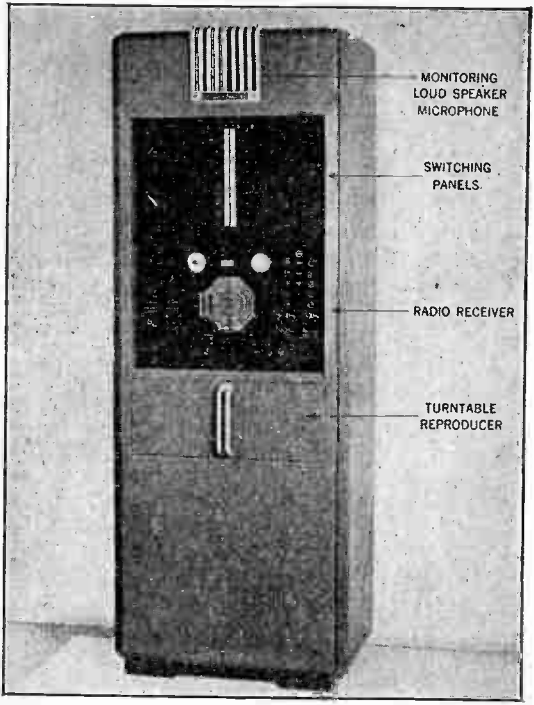


FIG. 7—In appearance and design, the new program sound system shows marked improvement over previous types. All the central control equipment is contained in an attractive modern cabinet, including amplifiers, retracting electric phonograph and the monitor loud speaker microphone which operates through a grille at the top. A high fidelity multirange radio receiver with automatic volume control and all necessary switches and extension controls are conveniently located on a bright black panel which makes a pleasing contrast to the aluminum gray finish of the cabinet and its chromium trimmings. (Courtesy Western Electric Co.)

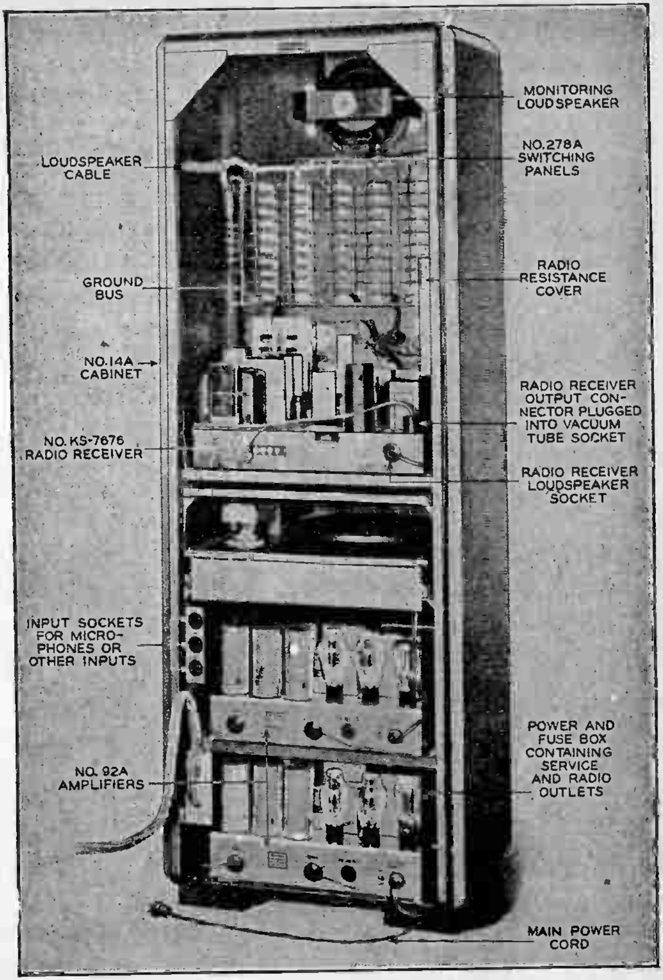


FIG. 8—Rear view of control equipment cabinet shown in fig. 7. Note: The electric phonograph unit is retractable and may be moved back and forth in drawer fashion to facilitate loading and unloading of records. (Courtesy Western Electric Co.)

Amplifying and Control Equipment.—Audio-amplifiers used in a P.A. system may be either large or small depending upon the size and the use of the system of which it forms a part.

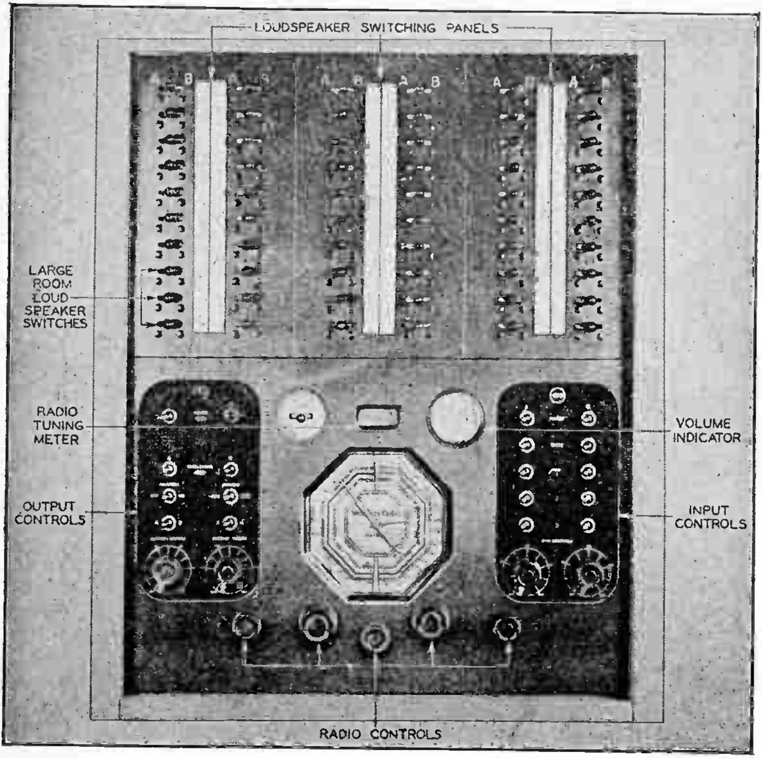
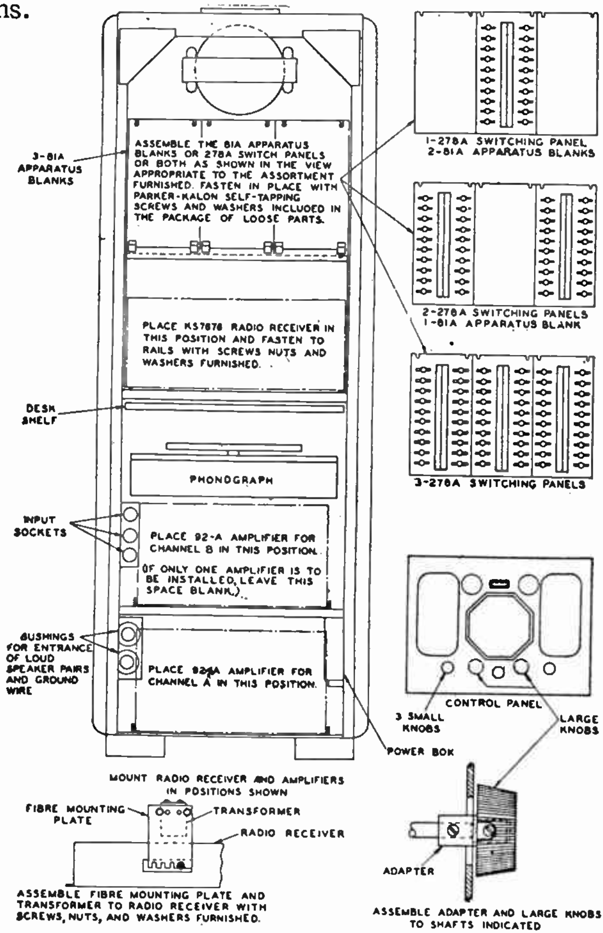


FIG. 9—Detail of radio receiver and switching panels shown in fig. 7. Note: Card rack for identification of speakers location. (Courtesy Western Electric Co.)

Equipment for small size systems is usually designed and assembled with particular attention to facilitate transportation, and is hence assembled in a small portable carrying case, and is suitable for small music reproducing and announcing systems.



ASSEMBLY OF SYSTEM

FIG. 10—Rear view of control equipment cabinet, showing assembly instructions and detail of switching panels. (Courtesy Western Electric Co.)

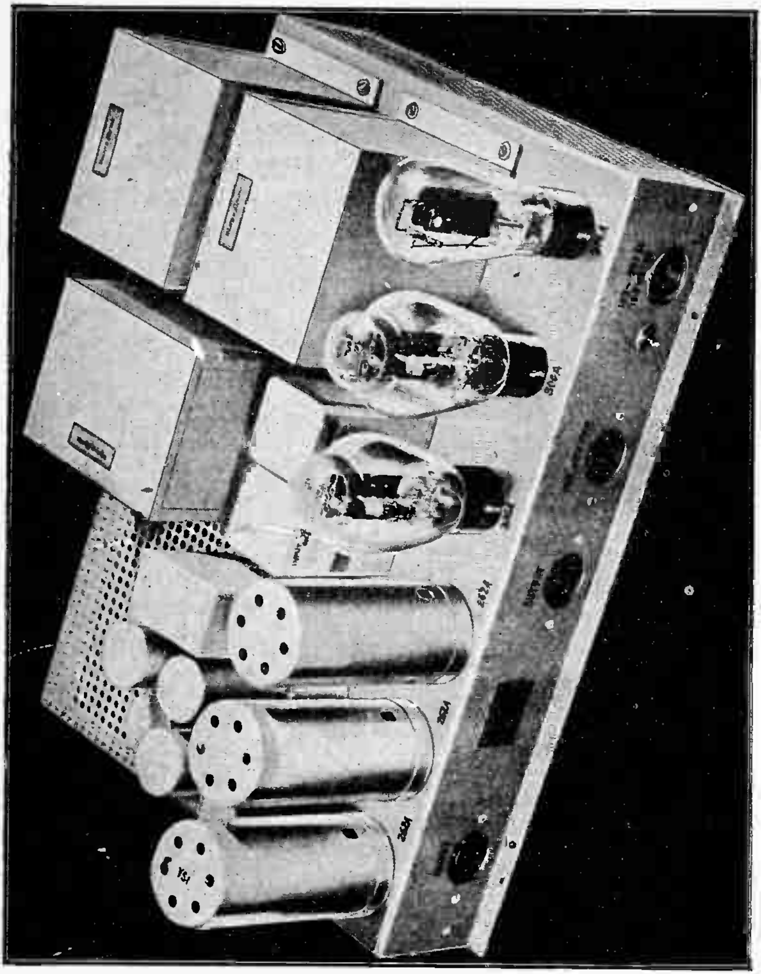


FIG. 11—Detail of amplifier unit shown in lower part of control equipment panel fig. 8. Note: When a two program system is desired, two similar amplifiers are used, as illustrated in fig. 8. (Courtesy Western Electric Co.)

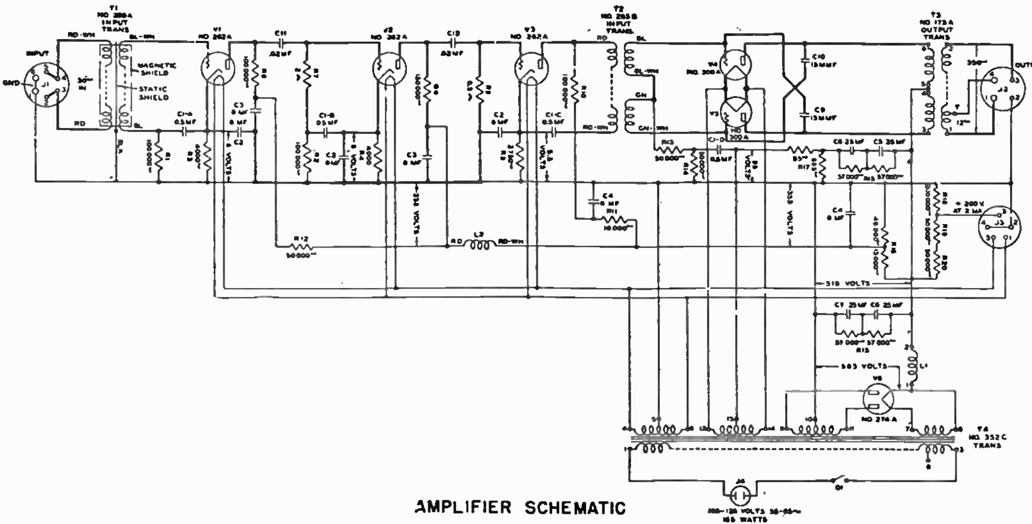


FIG. 12—Schematic wiring diagram of amplifier unit shown in fig. 11. (Courtesy Western Electric Co.)

Again the larger equipments are normally assembled in the *switchboard* manner on metal panels, mounted on angle irons or pipes, and supported securely from movement in either horizontal or vertical direction. These types are used whenever the small equipment just described is insufficient. A typical panel of a public address system of modern type is shown in figs. 7 and 8 with assembly details and amplifier unit shown in figs. 9 to 11.

The power output of an amplifier depends upon the number of loud speakers and input units employed, which in turn depends on the area served and such factors as cubical contents of rooms (if for indoor service) acoustical conditions, etc.

The amplifier schematic diagram for a P.A. system is shown in fig. 12. This amplifier has a power output rating of 20 watts, the input impedance (impedance amplifier is designed to work from) is 30 ohms, output impedance (impedance the amplifier is designed to work into) is 350 ohms. Tubes employed are three 262A—two 300A and one 274A as shown in diagram. Connections to the amplifier are made by plugs to facilitate the operation.

Amplifier Ratings.—The ultimate function of an amplifier is to enlarge the sound volume received from the microphone to a level which makes it possible to be heard over a large area.

Amplifiers in public address systems are rated according to the number of watts output delivered without distortion. The output depends upon the design and the size of the amplifier in question.

The amount of this output specifies what volume of sound will be received and hence the area that can be covered.

Before amplification of an amplifier can be measured, however, it is necessary to select some suitable unit of measurement. When, as stated, the output is measured in watts, it would be most convenient to measure the input in the same unit. This, however, cannot be readily done on account of the fact that the ear responds to different sound energies in an exponential way. From this it follows that the gain of an amplifier must be expressed in the same manner, i.e. by the use of logarithms.*

The Decibel.—The sound volume is measured by means of a unit named *decibel* (db.) which is the unit of sound transmission, and is defined as the smallest difference in loudness or intensity perceptible to the human ear. It is this unit which is used in sound calculations for comparison between power output and input values. Before a comparison can be made, however, it is necessary that the input and output power be expressed in the same units; for example, in kilowatts (kw), watts (w) or milliwatts (mw).

Now, if for example P_1 and P_2 be taken to represent power output and power input respectively and N, the number of decibles denoting their ratio, then the expressed units may be written thus:

$$N_{db} = 10 \log_{.10} \frac{P_1}{P_2} \qquad (1)$$

This formula is correct at all times for rating of amplifiers. The ratio is termed a **gain** when P_1 is greater than P_2 and a **loss** when P_1 is smaller than P_2.

The unit decibel can also be used for comparison of the two currents or the two voltages. Before such a comparison be made however, it is necessary first to translate the values into equivalent power ratios. As the power expressed in watts is I^2R or $\frac{E^2}{R}$ these values may be substituted for P_1 and P_2 in equation

*The logarithm of a number is the power to which 10 must be raised to equal the number in question. For example, log. 100 = 2 because $10^2 = 100$. Similarly log. 867 = 2.9380 because $10^{2.9380} = 867$, etc.

$$(1) \text{ or } N_{db} = 10 \log_{.10} \frac{I_1^2 R_1}{I^2 R_2} = 20 \log_{.10} \frac{I_1\sqrt{R_1}}{I_2\sqrt{R_2}} \quad \ldots\ldots\ldots (2)$$

Similarly

$$N_{db} = 20 \log_{.10} \frac{E_1 \div \sqrt{R_1}}{E_2 \div \sqrt{R_2}} \ldots\ldots\ldots\ldots\ldots (3)$$

Example.—*What gain in decibels will be received if the voltage of an amplifier rises to 5 times the normal level at a certain frequency?*

Solution.—

$$N = 20 \log_{.10} 5 = 20 \times 0.699 = 14 \text{ decibels (Approx.)}$$

Reference Level.—It is important to note that the decibel is not a power unit such as the watt or kilowatt but is strictly speaking, a co-operative unit in that it always expresses the comparison of a ratio between two powers.

In order to make such a comparison, a definite reference level or value has been set for various sound producing devices. This level for example for telephone work is set at 10 milliwatts (0.001 watts) which is the output of a standard transmitter used by telephone engineers, whereas for radio work the reference level has been set at 6 milliwatts (0.006 watts).

By using 6 milliwatts as reference level, amplifiers may be rated at a sound energy level of a certain number of decibels.

The convenience of such a reference may best be illustrated by the following example:

Assuming an amplifier delivers 6 watts output, what is its output level in decibels?

$$N_{db} = 10 \log_{.10} \frac{6}{0.006} = 10 \times 3 \text{ or } 30 \text{ decibels}$$

If the output be doubled the ear will notice an increase in volume which will not be twice as great but will increase in logarithm manner,

$$N_{db} = 10 \log. \frac{12}{0.006} = 10 \times 3.3 = 33 \text{ decibels}$$

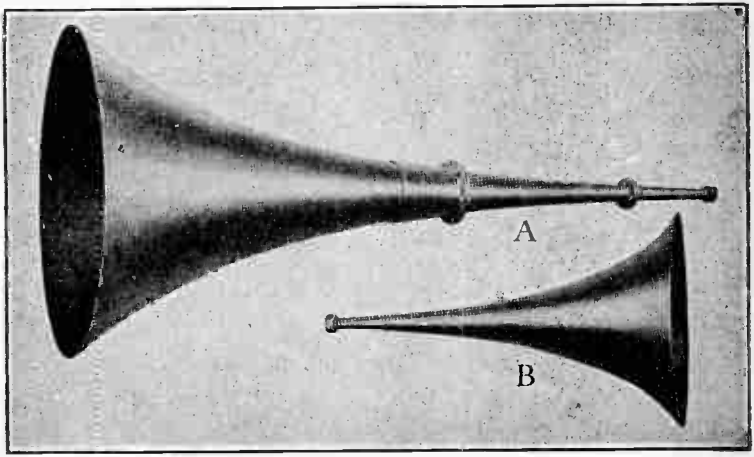


FIG. 13—Typical exponential loud speaker horns.

Loud speakers for Public Address System.—The determination of loud speakers to be employed depends on individual service requirement. For example, the straight horns Type A and B shown in figs. 13 are largely used for outdoor installations where it is desired to cover a broad area such as a race track, football field or similar locations. Several such straight horns are sometimes grouped together, as shown in fig. 14.

Because of space requirements the straight exponential horns are not usually employed in indoor installations.

The so called folded horns have been designed for this purpose. In this type the effective length is attained while the actual length has been materially decreased.

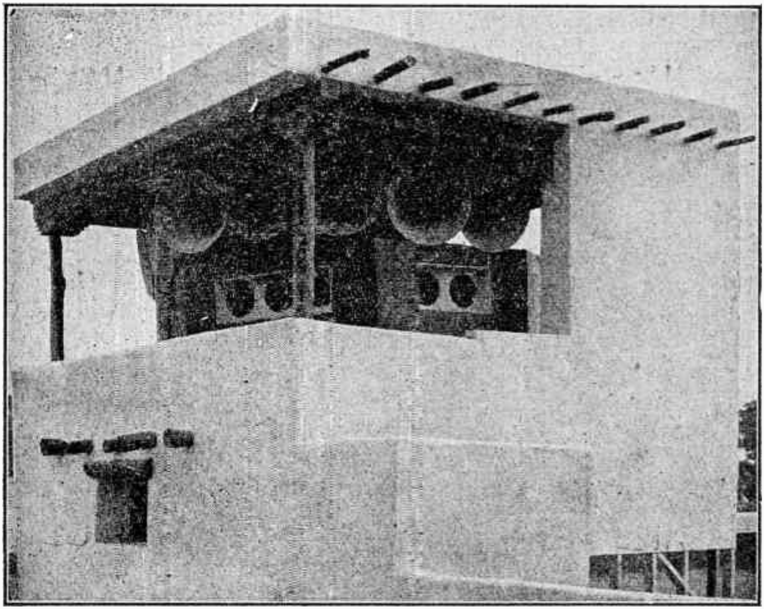


FIG. 14—Grouping of horns when used for outdoor installation.

When folded horns are employed in very large indoor systems, or in outdoor installations where the power requirements are large, the horns may be equipped with throat sections which will facilitate the attachment of a number of receiver units into one horn. See fig. 15.

In smaller indoor installations such as schools, hospitals, apartment houses, suites or offices, the direct radiator type shown in fig. 16 is largely employed. The loud speakers may be incorporated in the building design and mounted preferably flush with the wall.

In buildings already completed the loud speakers may be hung on the wall or placed on a suitable piece of furniture which will harmonize with the surroundings.

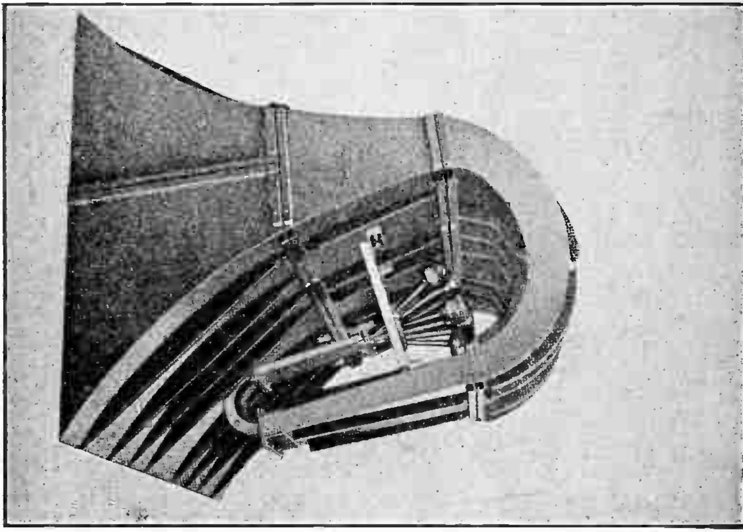


FIG. 15—Cluster of horns for indoor public address system.

Special selectors as well as volume controls may be incorporated to choose programs from any number of radio broadcasting stations when the system is equipped with the radio receiving apparatus required for such reception.

In hospitals and sanatoriums individual head sets or pillow type speakers are often utilized so that patients or guests who listen to programs will not disturb others in doing so.

Apparatus and Their Location.—Whenever possible the logical relationship between the various units comprising the P.A. system should be preserved. Locations giving the best results should always be used. Loud speakers should be placed as closely as possible to the program source and so that the sound be directed from it.

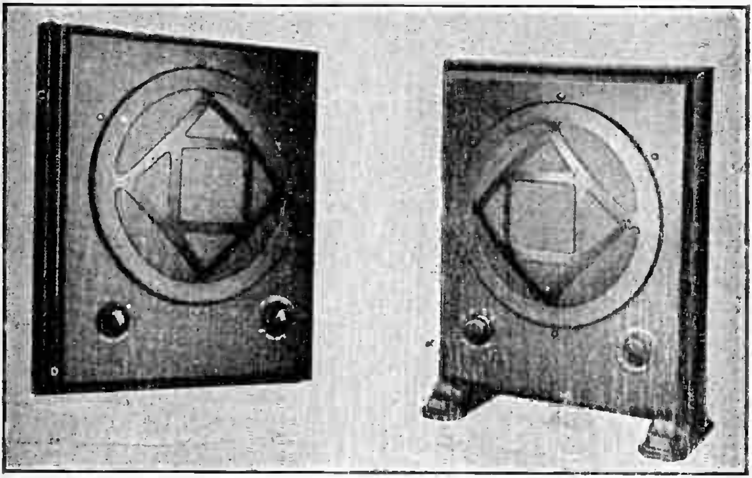


FIG. 16—Direct radiator type speaker suitable for indoor installation.

If the system be utilized entirely for music distribution from a reproducer set or a radio set, the location of loud speakers is important only from the standpoint of distribution, as long as care is exercised to guard against acoustic feed-back from the loud speaking telephones to the radio set.

In auditoriums and other buildings provided with a stage or raised platform, horn type loud speakers should be located above the stage in the center of the proscenium arch, mounted so that they are not directed at the microphones on the stage platform.

In buildings already erected, it may not be practicable to install loud speakers behind a grille in the arch. Then the preferable location is outside the arch in the center of the ceiling. When the loud speakers are suspended from the ceiling, the gondola which houses them, or the mouths of the loud speakers themselves should be covered with decorative grille work to harmonize with the architecture. If the ceiling be not more than 15 or 20 feet above the stage platform the horns may be suspended from trusses or other framework so that the tops of the loud speakers will be only a few feet from the ceiling.

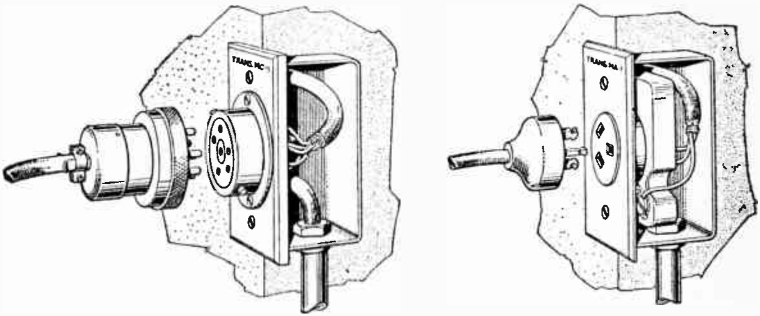


FIG. 17—Method of installing outlets for condenser and carbon microphones.

When simultaneous distribution to a number of committee or similar rooms be desired, individual small, horn type loud speakers with volume control units are preferred. With this equipment, the sound may be regulated to suit the size of each room. Loud speakers should be located at either end, in the corners or in the center of the room, to give equal distribution.

For outdoor use, such as at race tracks, football fields or airports, loud speakers should be of the horn type and in sufficient numbers and of adequate capacity to cover the prescribed area. Horns should be located above the heads of the audience and pointed slightly downward.

The number of microphone outlets provided on a stage or other platform is dependent upon the size of the stage and the kind of programs to be given. Normally, it is advisable to install at least three; one on each side of the stage and one in the center. If more are desired, they should be placed in the most convenient locations. The method of installation is illustrated in fig. 17.

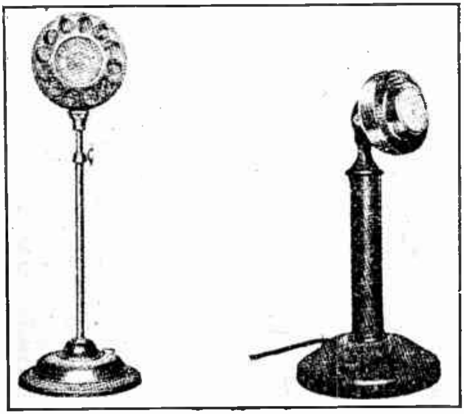
In announcing systems, installed in a hotel, or in a hospital, a close talking microphone is used with flush or surface mounted wall type loud speakers. The microphone may be installed in a telephone booth adjacent to the telephone exchange. Thus the transmitter is shielded from sound radiating from loud speakers and at the same time is conveniently located for use by the telephone switchboard operator. If a telephone booth be not used, the microphone may be located in any convenient place where there will be no interference from the loud speakers.

In indoor installations, available space determines the location of amplifying and control equipments. They should be located in any room which is free from dampness or moisture. For use in outdoor installations they should be located in a room set aside for the purpose in which they are fully protected from the weather. This room may be located under a grandstand or in any other convenient place where wires or cable for the necessary power circuits can be brought in.

The operator in charge of the control equipment should be provided with a monitoring loud speaker to keep him informed of the progress of the programs. For obvious reasons, only authorized persons should have access to the room in which control and amplifying equipments are located.

When a motor generator set be used for supplying power to the amplifiers, it should not be placed in the same room with the amplifying equipment unless there be an intervening space of at least 30 feet. Unless there be this space, the electrical field set up by the motor generator may be picked up on the input leads to the amplifiers and cause noise in the circuits.

Storage and dry batteries may be placed adjacent to the amplifying equipment or in any other convenient place. When a reproducer set and radio receiver form part of the equipment, they generally are installed in the control room. In auditoriums, they may be placed on or adjacent to the stage. In the latter location, control is provided easily.



FIGS. 18 and 19—Carbon type desk and close talking type microphone.

Microphones.—Microphones used in a public address system may be as follows:

(*a*) Carbon type.
(*b*) Condenser type.
(*c*) Moving coil type.

Carbon type microphones (see figs. 18 and 19) are used exclusively for announcing purposes. This microphone has a mounting similar to the well known desk telephone, except that the receiver and the switch hook is omitted.

When this type is used, it is usually placed upon a small desk or a pedestal where the user speaks into it similarly as he would into an ordinary telephone, holding it in his hand if desired.

Usually the microphones utilized for speech only are designed with a higher sensitivity, but smaller frequency range than types intended to cover ranges of both speech and music combined. The usual type of carbon microphone requires a power source of 12 volts direct current to energize the carbon buttons, with a current drain of approximately 50 M.A. for each microphone.

The condenser transmitter has a vacuum tube amplifier associated with it and requires plate filament power supply for the operation of the vacuum tubes.

A potential of 200 volts direct current usually obtained from dry cell batteries is required for a transmitter polarizing potential and for the plate circuit of the vacuum tubes.

The filaments of the vacuum tubes operate usually on a 6 volt direct current obtained from a storage battery.

The condenser and moving coil microphones are designed usually for use in studios and other locations where musical and other programs originate and where the very best acoustic pick-up characteristics are desired. For these purposes they give better performance than the carbon type.

A typical moving coil microphone of Western Electric manufacture is illustrated in fig. 20. Its basic simplicity is responsible for several distinct advantages. The fact that a permanent magnet of cobalt steel is used to provide the magnetic field in which the moving coil vibrates, obviates the necessity for supplying polarizing energy to the microphone.

A moving coil microphone being a low impedance device is less subject to disturbance from other circuits in the neighborhood than other microphones and may be used with complete satisfaction at a considerable distance from its amplifier.

It is obvious that since no amplifying equipment need be directly associated with it, much of the care formerly required in handling of microphones is unnecessary.

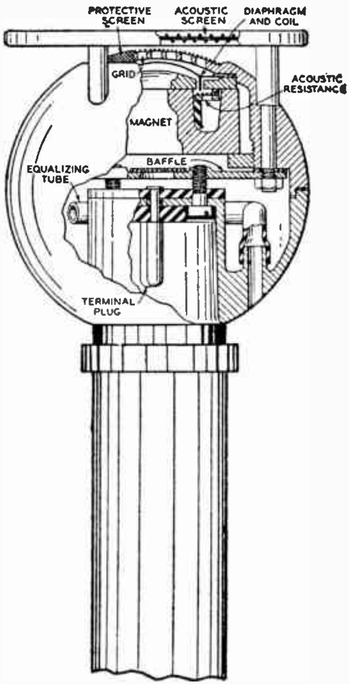
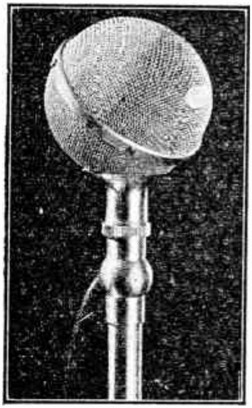
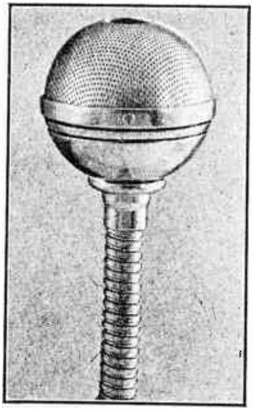


FIG. 20—Simplified cross-sectional view of a non-directional moving coil microphone.

Factors such as changes in temperature, humidity and barometric pressure which have long constituted obstacles in the consistent operation of microphones have no unfavorable effect on the performance of the moving coil microphone.

All microphones are usually furnished with a suitable length of cord and connecting plugs so that they may be connected in circuit by plugging into conveniently placed outlets.





FIGS. 21 to 23—Various sound cell type microphones, for use in public address systems. (Courtesy The Brush Development Co.)

Acoustic Consideration in Public Address Systems.—It is a well known fact that acoustic conditions exert a considerable influence on the reception of amplified sound. To obtain the most satisfactory result from a P.A. system, it is therefore necessary to understand the principles of acoustics and be accordingly guided when making installations.

There is for example a large difference in materials of which walls are constructed, and even when the two rooms are of the same size and shape a considerable difference may be encountered in tone, volume and clarity.

When surfaces or furnishings are made of hard smooth material such as plaster, brick, concrete, polished wood or glass, only part of the sound which reaches the listener's ear emanates from the original sound source, part of it comes by way of *reflection*. A full realization of the importance of sound reflection in buildings may be had when it is considered that an ordinary plaster wall is a better reflector of sound of certain frequencies used in speech and music than a good mirror is of light.

Sounds may be repeated and become unduly prolonged, one sound or syllable overlapping the beginning of the next, the result being a noisy, indistinct effect frequently multiplying into a continuous roar called *reverberation*.

When instead of multiple reflections, there is one predominating reflection, sounds being definitely repeated at a definite interval, there is an echo instead of reverberation; however, very frequently both reverberation and a distinct echo are simultaneously present.

Resonance occurs when a thin hard surface such as a wooden panel vibrates freely as a diaphragm at its own natural frequency, hence in the vicinity of a resonant area, tones which are unduly emphasized will sound louder than other tones.

Some porous and soft surfaced materials, such as special acoustic plasters, cloth curtains and felt are relatively poor reflectors of sound because they dissipate a portion of the sound which strikes them. This gives rise to a third effect which is known as *absorption*.

The combination of these three effects namely, *reflection*, *resonance* and *absorption* give rise to the complete phenomena of frequency selection and wave interference responsible for the difference in the volume of quality of sound, heard so often in different parts of a building.

Pointers in Construction of Walls, Floors and Ceilings and the Use of Sound Absorbing Materials.—From the foregoing it is evident that excessive reverberation can be largely overcome by covering some wall surfaces with soft porous sound absorbing material such as velour or upholstery fabric. It is on account of this property that velour or monk's cloth is used extensively in broadcasting studios.

If sound be undirected, the absorbent effect is practically independent of the location of the absorbent material with respect to the sound source. Again if sound be directed, the absorbent material as a general rule should be located in the area over which the sound is directed. Frequently the desired effect can be obtained by the use of carpets.

The amount of absorbent materials to be used and the area to be covered may best be determined by tests.

Certain wall surfaces, especially those broken up by pilasters, cornices, coffers, etc. will diffuse the sound and thus eliminate distinct echoes, and if those surfaces are absorbing, they will also help to dampen the sound waves.

It is a known fact that the presence of an audience aids greatly in decreasing reverberation, but at the same time increases the amount of sound absorption, and also increases the noise level in the room so that a greater acoustic power output is required of the loud speakers than would be necessary for the same space if no audience were present. Hence acoustic conditions may be best determined when an average fixed audience be present and the furnishings be all in place.

If sound absorbing materials have been utilized in the construction of a building, then excessive reverberation of voice or musical instruments can be eliminated only by the employment of acoustic treatment.

The proper location of loud speakers of a P.A. system in, for example, a large reverberant room may be assisted to some

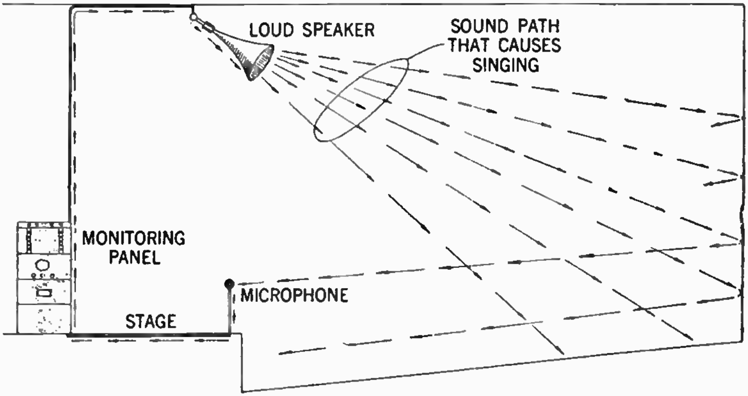


FIG. 24—When the horns are placed in front of the microphone as shown, the sounds will travel from the horns to the flat wall surface and then be reflected back, so that the reduced volume will be picked up by the microphone and passed through the amplifying equipment out through the horns again; i.e. a circuit is built partly of sound waves and partly of electrical waves, and in the electrical path a great deal of amplification is obtained. This circuit continues to build itself up until it develops a "sing" or "howl". The point where the equipment starts to sing is called the "singing point" and is the measure of the maximum amount of amplification which can be used under these conditions.

extent in overcoming the unpleasant results which are encountered with the unaided voice or unaided musical instruments.

Utilization of a P.A. system will permit the speaker to talk in a lower and more natural tone of voice and yet reach each one of his audience. It is evident that if a number of loud speakers are used, each assigned to a small part of the total area, the acoustic level of each individual loud speaker may be considerably lower than would be the case if only one was operated.

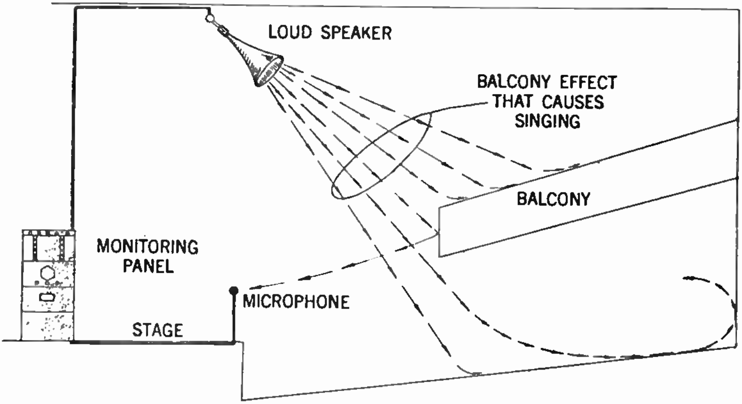


FIG. 25—By reference to fig. 24, it will be noted that placing the horn in the most advantageous position is a rather difficult task. It is nearly impossible to place the horns so that they will not have a direct throw at the edge of the balcony. This sound path is much shorter than that shown in fig. 24. Therefore if the horns are placed so that a direct path or short sound wave circuit be built up around the microphone, it will be necessary to reduce the gain of the amplifying equipment. Under the circumstances, the longer the soundpath, the greater the gain on the horns without the tendency to sing. This will explain the need of draping the walls for an inside installation. For that same reason it is also advisable to drape the outside of the buildings, bill boards, etc. on outside installations as well. It is evident that in an outside installation, consideration must be given to weather conditions to determine in so far as possible, which direction the wind may be blowing during the operation of the speakers. In addition, it is also advisable to determine as nearly as possible, the amount of outside noise sources that must be taken into account, such as trains, airplanes, heavy trucks, automobile horns, etc. Therefore arrange to place the horns as closely as possible to the group that emanates the greatest amount of noise. In this manner the greatest number of persons will be able to hear the system.

In case of excessive reverberation the following acoustic treatment is recommended:

1. Care should be taken to point loud speakers away from the microphone because of the fact that when projected sounds reach the microphone in sufficient strength, it will be reinforced again. This will give rise to a factor commonly known as "*singing*".

FIG. 26—Illustrating adjustable response type microphone. To increase pitch, push button upward; to lower pitch push button down. This adjustment according to the manufacturer will automatically take place without introducing any peaks or undesirable effects. (Courtesy The Amperite Co.)

The loud speakers will if properly directed overcome poor local acoustics, i.e., improve areas where local conditions for hearing are poor.

2. Where, as in auditoriums, it is desired to use sound reinforcement equipment, it will be desirable to use drapes or other

suitable acoustic treatment on the stage to make it relatively non-reflecting or acoustically "dead". This will aid materially in reducing the amount of sound reflected back into the microphone by adjacent surfaces and therefore, permits the use of much higher amplifications without the production of the "singing" effect already described.

3. Local sounding devices such as soundboards and the like are unnecessary when a properly designed P.A. system is used. It may introduce annoying acoustic conditions.

PUBLIC ADDRESS SYSTEM, MAINTENANCE POINTERS

Causes of Low Volume.—Low volume may be caused by one or a combination of the following:

1. *Low Line Voltage.*—This is generally common in rural communities and especially at the tail end of long transmission lines with insufficient capacity of conductors and transforming equipment. Low-tube voltage results in reduced output.

2. *Low Speaker Field Voltage.*—If the field of the speakers are improperly excited, there will be a considerable loss in volume.

3. *Open Coils in Speakers.*—The opening of a voice or field coil will result in a reduced volume especially where a series-parallel voice coil arrangement is used. In this type of connection, two or more speakers will be out of service in each case depending on the particular wiring arrangement used.

4. *Faults in Tubes.*—When weak or faulty tubes are suspected, check by analyzer to determine if the plate current consumption be of proper value. When push-pull stages are employed, both tubes should have approximately equal plate current drain.

5. *Unresponsive Microphone.*—This may be due to moisture, large temperature changes, careless handling, or packing of carbon granules. A weak microphone battery will cause a reduced current through the microphone buttons, and hence reduce the output from the microphone to the amplifiers.

Poor Sound Quality.—This may be caused by one or a combination of the following factors:

1. *Weak Tubes.* See 4, on *Low Volume.*

2. *Overloaded Speakers.*—When volume of speaker is run too high it will cause a chattering and distorted sound. The size of the speaker should in each case conform with the power requirements.

3. *Singing of Speakers.*—Cause and remedy for singing, see page 443.

4. *Faulty Microphones.*—See 5, on **Low Volume,** this chapter. In addition. try phonograph reproducer in phonograph input taps if this provision is made and note result.

5. *Field Excitation too Low.*—If the field has improper excitation, the frequency response of the speaker will naturally be poor. This is because of sluggishness of the speaker unit to lower impulses. This voltage should be checked and compared to that specified by the manufacturer.

No Sound.—When no sound is received, check for trouble among the following items:

1. A transformer or resistance coil may have become opened or short-circuited. Check for proper voltage across each suspected faulty device.

2. Check tubes. A burnt out tube (except where tubes are connected in push-pull or parallel) will interrupt the current flow.

3. *Microphone Troubles.*—See (5) *Low Volume*, this chapter.

Wiring of Conduits.—Since the energy in the microphone circuits is at a level considerably below that required in loud speaker circuits, these circuits must be run in separate conduits.

If this be not done, the difference in gain between these circuits, due to the amplifiers, will cause electrical interference and may result in a singing noise in the output of the loud speakers.

Wiring for the observer's communication system should also be run in a conduit separate from these circuits, unless this wiring be shielded. If shielded it may be run in the same conduit as that of the loud speakers, but should under no circumstances be run in the same conduit as the microphone circuits.

All microphone circuit wiring from the loud speakers and observer's communication circuit wiring should be terminated in separate terminal boxes. The circuits for microphones are usually run so that when copper shielded wire is used, the copper shield is used as the ground side of the circuit.

Wiring of Receiver Units.—In the voice circuits of receiver units, No. 14 B & S gauge twisted pair rubber covered wire generally is used. The size of the wire, however, depends upon the length of the run from the amplifier to the receiver units, the type and number of unit used, and also by the requirements of each individual unit for the operation condition presented.

The wire used must be in twisted pairs in order to provide a balanced circuit. When receiver units which require a direct current circuit for energizing the field coil are used, the wire for the power circuit may be either in a twisted pair or parallel laid.

When an alternating current power circuit is used to supply a rectifier located at the receiver then the power line should consist of a twisted pair. No. 14 B & S wire is generally used for this circuit, but the size depends again upon the length of run and number and type of receiver units.

It should also be observed that receiver circuits of the low impedance type which are used on relatively long runs, will necessitate the installation of wires of larger carrying capacity.

Wiring of Amplifying and Control Equipment.—The amplifiers and control equipment are generally mounted on steel racks and are provided with marked terminals to facilitate the making of proper connections.

When connecting the amplifiers and control equipment, it is generally desirable to use shielded wire to prevent against possible feed-back between circuits of different levels. An illustration of public address system wiring is shown in fig. 8.

When making power connections to the amplifiers (110-volt, 60 cycle A.C.) it is desirable that the power leads be run in conduit from the power source to the amplifiers. Wire used for this purpose should be rubber covered. It is also important that all power circuits be properly fused to protect the equipment.

Wiring of Communication Equipment.—The wires which should be used for connecting the various observer's communication stations to the control room proper is the same as that used in ordinary telephone work. The size of this wire may be No. 19 or 20 B & S or larger.

Rules for Antenna Wiring.—The antenna shall be erected on suitable supports for roof mounting. The horizontal distance between the supports should be 75 to 150 feet, so that an antenna of that length may be stretched between them, at a height of 25 feet from the top of the roof and remote from any metal structure rising above the level of the roof.

The antenna shall be of No. 14 gauge stranded copper wire, and shall be provided with suitable insulators. The lead in wire from the antenna shall be No. 14 gauge rubber covered. This wire shall be run to an antenna terminating panel located on the roof and an antenna transmission line shall be run from this panel to the control room in a half inch conduit and shall be terminated at the receiver panel. The lead in wire shall be brought in through the roof in an approved weather proof fitting.

The ground wire shall be run from the control room to the water pipe and shall be fastened to the pipe by an approved clamp.

An approved lightning arrester shall be installed on the outside of the building clear of all woodwork within three feet of the point where the wires enter the building.

All wiring shall be made to conform with the Underwriter's requirements.

Example.—*If by means of an input potentiometer the power output of a certain amplifier can be varied between* 0.1 *watt and* 10 *watts. What is the power range in decibels?*

Solution.—The decibel system of expressing the difference between two power levels is now coming into everyday use, and to-day it is quite common to express in decibels the range in values which a receiver can handle. It is important to note that the decibel is not a physical unit such as the "watt" or "volt" but it might rather be called a comparative unit in that it always expresses the comparison between the physical quantities. The units compared are usually those of power; thus, in comparing one amount of power with another on a decibel basis, we may refer either to the ratio between them or else to the difference between them in relation to one of the powers.

The point to note is that a given amount of power is not expressible in decibels; it is only when there is a comparison stated or implied, that recourse is made to this unit. The decibel number is thus equivalent to a ratio between two powers, the nature of the equivalent being more precisely defined as follows:

The difference between two power levels expressed in decibels is equal to ten times the common logarithm of the ratio between the two powers. Now if P_1 and P_2 be taken to represent two power values, then the difference D, decibels in their power level is given by equation.

$$D = 10 \log._{10} \frac{P_1}{P_2} \qquad (4)$$

In the present example the ratio between the two powers representing the extremes of the range is $\frac{10}{0.1}$ or 100, the common log. of which is 2. Accordingly the difference between the two power levels is 10×2 or 20 decibels which thus expresses the power range. **Note** that a power amplifier varying in output from say 3 to 300 watts would have exactly the same decibel range.

Example.—*A transformer coupled stage of audio frequency amplification incorporates a device for tone control by the use of which the effective amplification of the stage may be varied between three times and* 0.15 *times the amplification of the tube. What is the amplification range of the tone control in decibels?*

Solution.—Perhaps the simplest way of looking at the decibel is to regard it as the unit in terms of which the difference between two power levels may be measured. Taking the symbols P_1 and P_2 to represent two power values, then the difference D, decibels, in their power levels is given by—

$$D = 10\,(\log.\ P_1 - \log.\ P_2) \quad \text{.......(5)}$$

$$\text{or } 10 \log. \frac{P_1}{P_2} \quad \text{.......(6)}$$

The difference in power levels thus depend upon the ratio between the two powers. Since the decibel is defined in terms of a ratio between powers, care must be taken in applying it to measure ratios between other quantities such as currents and voltage. Where it is desired to express a ratio between voltages and decibels, first translate the voltage ratio in equivalent power ratio. This can be done by making a convention, viz: that the two voltages are arranged to operate across the same resistance R ohms, so that the resulting power dissipation may be compared.

Thus, if the difference between E_1 and E_2 volts is to be expressed in decibels, the two powers are then E_1^2 and E_2^2 volts and the power ratio is $\frac{E_1^2}{E_2^2}$.

Now substitute this for the ratio $\frac{P_1}{P_2}$ in equation (6) obtaining:

$$D = 10 \log. \frac{E_1^2}{E_2^2} \text{ i.e. } D = 20 \log. \frac{E_1}{E_2} \ldots\ldots\ldots\ldots (7)$$

In the example, voltage amplification is dealt with, which of course is quite a different matter from power amplification. Equation (7) will therefore apply,

E_1 being $3 \times M$ while E_2 is $0.15 \times M$;

$\frac{E_1}{E_2}$ is thus $\frac{3}{0.15} = 20$

Whence, $D = 20 \log. 20 = 20 \times 1.301 = 26.02$ decibels.

Example.—*A loud speaker whose inductance is* 1.15 *henries is coupled to a power tube through a condenser of* 2 *mfds. To what frequency will the combination be resonant?*

Solution.—This is obviously a simple exercise in finding the resonant frequency of a series tuning circuit and the only point calling for any remarks lies in the treatment of the units involved. When the inductance L, and the capacity C, of a series circuit are both expressed in fundamental units, for example, henries and farads, the resonant frequency in cycles per second is given by the well known formula

$$f = \frac{1}{2\pi\sqrt{L.C}}$$

In the present example, the condenser is of 2 microfarads capacity, therefore this must be expressed in terms of farads before applying the formula: evidently it is 2×10^{-6} *farads* Substituting numerical values in the formula, the following is obtained:

$$f = \frac{1}{2\pi \times \sqrt{1.15 \times 2 \times 10^{-6}}}$$

which gives $f = 105$ cycles.

Example.—*An alternating current of amplitude* 10 *milli-amperes and frequency* 750 *cycles, passes through a resistance of* 50,000 *ohms. What amount of power is dissipated in the resistance? What power would be dissipated if the frequency were increased to* 1,000 *cycles?*

Solution.—It is first necessary to obtain the root mean square (*r.m.s.*) value of the current, which is 0.707 times the amplitude or in this case 7.07 *m.a.*

It is a sound rule in working out electrical problems to express the quantities in fundamental units. In this case, express the (*r.m.s.*) values in amperes, i.e. 0.00707 amperes. Now if an (*r.m.s.*) current of I amperes flow through a resistance of R ohms the power dissipated is given by I^2R watts. Hence,

$$\text{power (W)} = (0.00707)^2 \times 50{,}000 = 2.5 \text{ watts}$$

CHAPTER 24

The Radio Compass
and
Principle of Operation

The radio compass is an instrument for observing by means of radio, the direction of a station emitting radio signals; briefly, in aerial and marine navigation, it is an instrument for taking radio bearings.

Operating Principles.—Since the radio compass is built around the *loop antenna* it is necessary to understand its principles of operation before undertaking a study of the other units.

The radio compass utilizes the directional receiving properties of the coil, which consists essentially of several turns of wire wound into a large coil. This coil will receive the radio signals with maximum intensity when the plane in which the coil is wound is in the line of the direction to the transmitting station. See fig. 1.

As may be observed from the diagram, the minimum is well defined, and the maximum is not, hence it is evident that the strength of the signal varies rapidly with the movement of the coil near minimum, but very slowly with the movement near the maximum.

It is for this reason that the minimum is utilized in observing bearings. If it were not for this, there would be great advantages in taking bearings on the maximum, on account of greater audibility and thus diminishing the interference effect.

The coil or loop antenna part of the compass operates on the principle that the amount of electronotive force induced in a vertical loop of wire by an arriving electromotive wave, depends on the angle between the plan of the loop and the wave front.

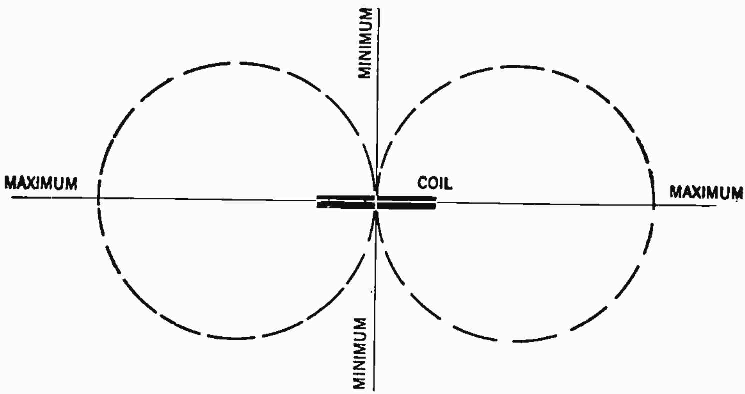


FIG. 1—Illustrating directional effect of radio waves on the loop-antenna part of the radio compass.

In a rotatable coil of practical size the voltage induced by radio signal is very small. Hence for use of such small coil for radio compass purposes, it is necessary to generate a great amplification, and it was the utilization of the multistage vacuum tube amplifier which made the instrument usable for marine and aerial navigation.

As previously asserted, the radio compass utilizes the directional receiving properties of the coil type of the antenna. To further facilitate the understanding of the instrument, an analysis of the behavior from the point of view of the magnetic field is as follows:

It is a-well known fact that the radio waves emanate from the transmitting stations in all directions, very much the same as water waves on the surface of a quiet pond when a stone is dropped in. The length of a radio wave is the distance between successive crests of the wave; the number of crests passing a given point per second is the frequency, and the product of the wave length and frequency gives the velocity of the radio wave. The product of these two factors (wave length and frequency) is always about 300,000,000 meters (186,300 miles) per second. Radio waves are accompanied by a magnetic force which is horizontal and at right angles to the direction in which the waves are traveling.

As a radio wave passes a given point the magnetic force, or field strength, varies from moment to moment from a maximum in one direction through zero to a maximum in the other direction. At a given point the cycle from maximum in one direction back to maximum in the same direction is performed in a very small fractional part of a second. For a wave length of 300 meters this cycle is performed in one-millionth of a second.

If a coil of wire is held in a fixed position, such that the lines of magnetic force thread or pass through the coil and are not parallel to it, while the magnetic field varies in intensity, as is the case with that accompanying the radio wave, an electromotive force or voltage will be induced in the coil.

Since the magnetic force is horizontal and may be thought of as forming circles around the transmitting source, the compass coil when turned with its plane parallel to the direction of the

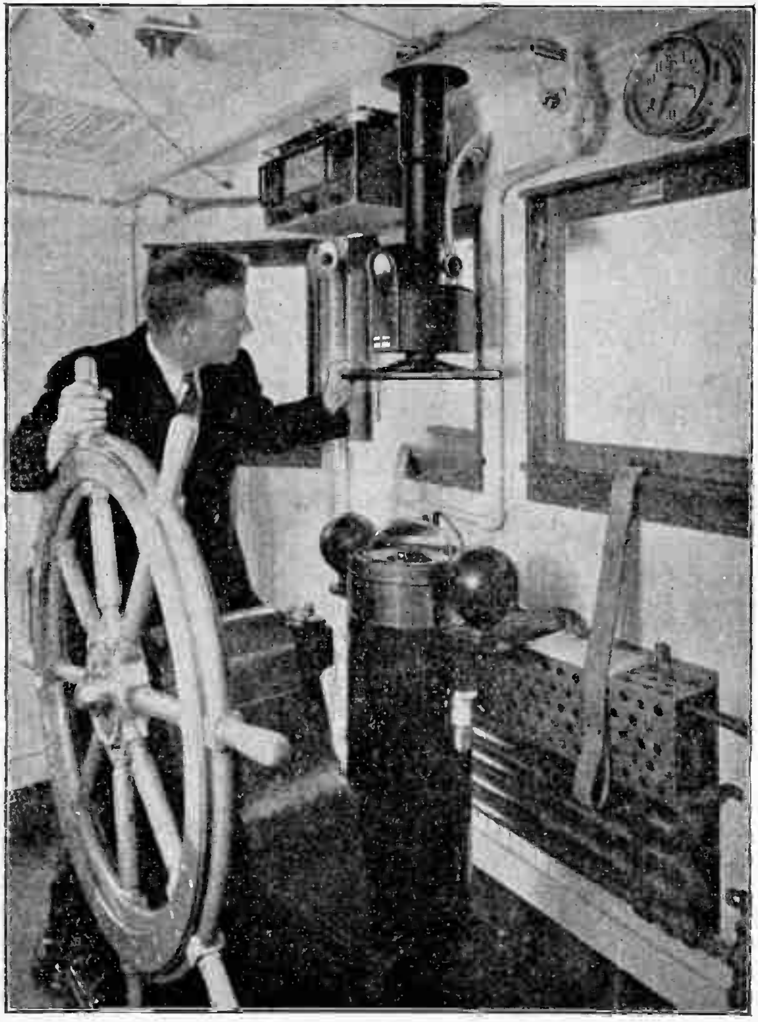


FIG. 2—Typical Marine radio compass installation. (Courtesy Western Electric Co.)

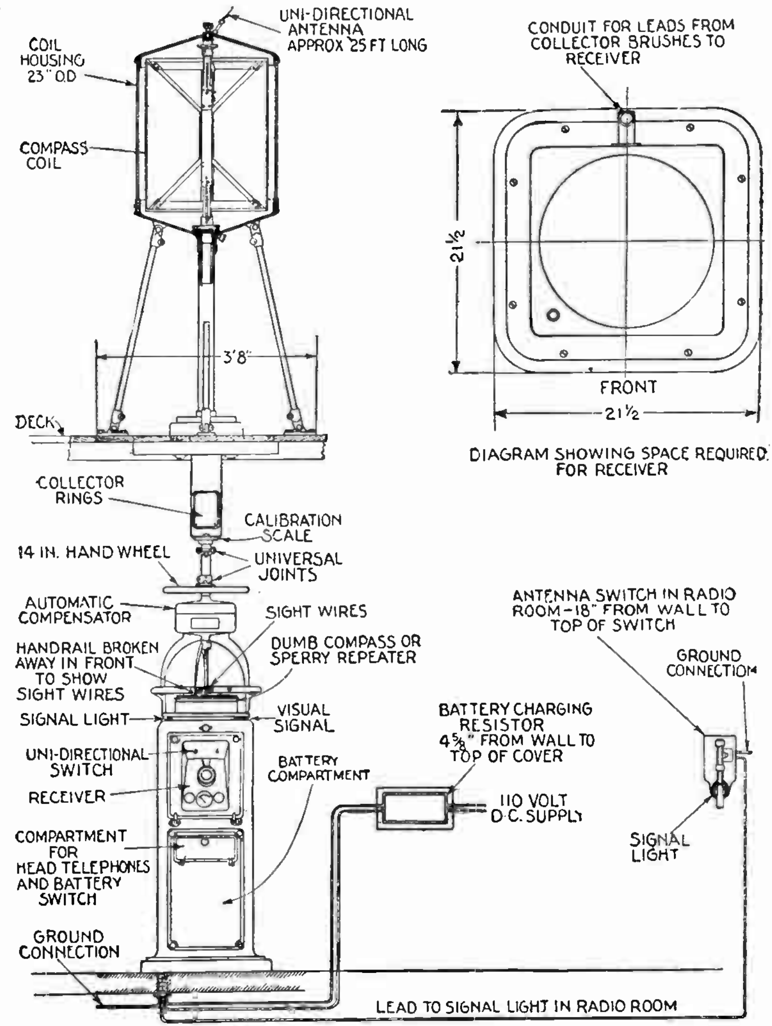


FIG. 3—Kolster radio compass installation.

transmitting station is threaded by the maximum number of magnetic lines of force, and the signal heard in the telephone receivers is a maximum. When the plane of the coil is turned at right angles to the direction of the transmitting station, no magnetic lines of force thread through the coil, and therefore no voltage and no current are induced in the coil and no signal will be heard in the telephone receivers.

The Marine Radio Compass.—A radio compass frequently found on board ships of U. S. registry was developed by F. A. Kolster and is manufactured by the Federal Telegraph Co., named variously **The Kolster Radio Direction Finder** or **The Kolster Radio Compass.**

Other radio Direction Finders have been developed by the Radio-Marine Corporation of America, the Marconi Wireless Telegraph Co., etc.

By means of this device, radio bearings can be taken in dense fog, snow storms and over distances greatly beyond the horizon with an accuracy equal to that obtained with visible sight, thus eliminating one of the greatest hazards to marine navigation.

The modern method of obtaining radio compass bearings on shipboard requires the installation of radio beacons on light vessels and light houses in the vicinity of harbor entrances and other places dangerous to navigation, the exact locations of which are shown on all sailing charts.

Operation of Unit.—With reference to the electrical circuit fig. 4, the theory and operation of the unit as developed by the U. S. Bureau of Standards is as follows:

The variable condenser C_1 together with coil L_1 form the main receiving circuit which is tuned to the signaling wave length.

Connected across the condenser C_1 either directly or through the potential transformer P, is the vacuum tube amplifying and detecting apparatus.

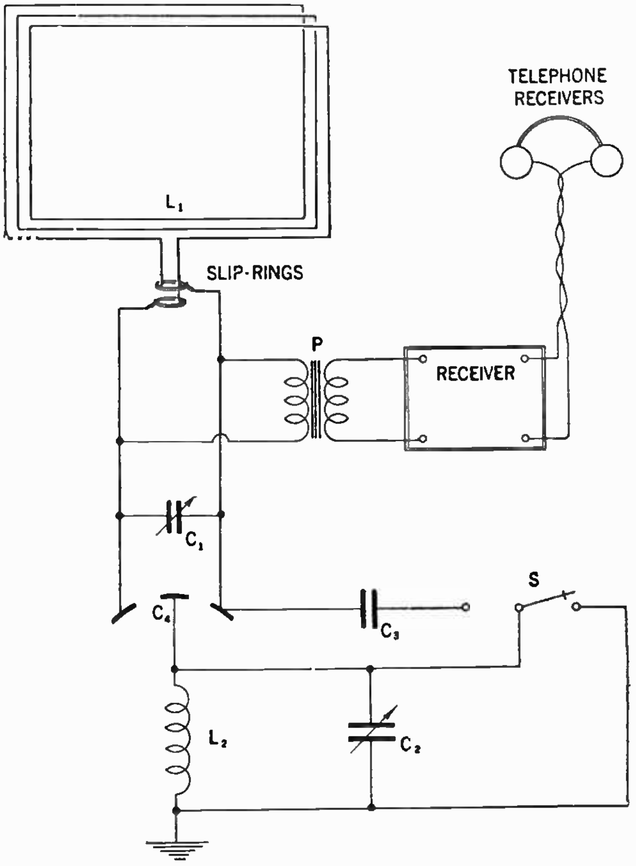


FIG. 4—Circuit of Kolster radio direction finder.

As developed by the U. S. Bureau of Standards this receiver consists of a three-stage radio-frequency amplifier, a detector and a two-stage audio frequency amplifier made up as a unit with a minimum number of operating adjustments. However, the receiver may be of any standard design.

The telephone receivers are located at a distance from the magnetic compass to avoid any effect upon the compass due to the magnets within the telephone receivers.

The auxiliary circuits of the direction finder are controlled by switch S. With the switch closed to the right, the middle plates of the double condenser C_4 are directly grounded.

The double condenser is utilized to bring about electrical symmetry of the coil system with respect to the earth. In other words by adjusting the middle plates of the condenser C_4, to the right or left the earth connection is brought to the electrical midpoint of the coil system, and the signal received in telephones, results only from the energy directly received in coil L_1.

With the switch closed to the left a small condenser C_3 is connected across half of the double condenser C_4, and the inductance L_2 and tuning condenser C_2 are inserted in the ground lead.

Under these conditions the coil system is no longer electrically symmetrical with respect to earth, and received energy enters the coil circuit L_1C_1 indirectly through the tuned ground circuit, of which the capacity of the complete coil system to earth forms a part.

By proper adjustment, a complete uni-directional effect can be obtained.

In the practical operation of the direction finder, all tuning adjustments remain set for the wave length of the signaling station. Switch S is closed to the right when observing the line of direction of a given signaling station and to the left when it is desired to determine the sense of direction.

In other words, to determine the line of direction of a station, the coil system which is directly grounded at its electrical midpoint by throwing switch *S*, to the right, is rotated to the position of critical silence at which time the plane of the coil is normal to the direction of the approach of the signaling wave.

To determine the sense of direction of the station, switch *S* is closed to the left and the coil rotated to the position of maximum signal intensity at which time the plane of the coil is in direction of approach of the signaling wave and pointed toward the signaling station as indicated by an index pointer for that purpose.

Bellini Radio Compass.—Another type of radio compass known as the Bellini direction finder, is shown in fig. 5.

The frame consists of the loop *L* and condenser C_1 and C_2. The vertical antenna consists of the grounded center of the loop and the two condensers C_1 and C_2 which are grounded through the tuning condenser C_3.

Operation.—To obtain a bearing the switch *S* is closed and the loop tuned to the incoming signals. The false vertical effect of the loop is practically eliminated by grounding the center point of the loop through the variable resistor *R*. The sharpening effect of the minimum due to the elimination of the remaining vertical effect is accomplished by varying condensers C_1 and C_2.

To obtain the sense of true direction, the switch is opened and the vertical antenna tuned by means of condenser C_3, by varying the resistance *R*, it is possible to obtain the conventional heart-shaped diagram.

Dependable bearings can be obtained only by precise adjustments of condenser C_1 and C_2. The presence of tube damping across the loop is detrimental in that it limits the range and selectivity of the set.

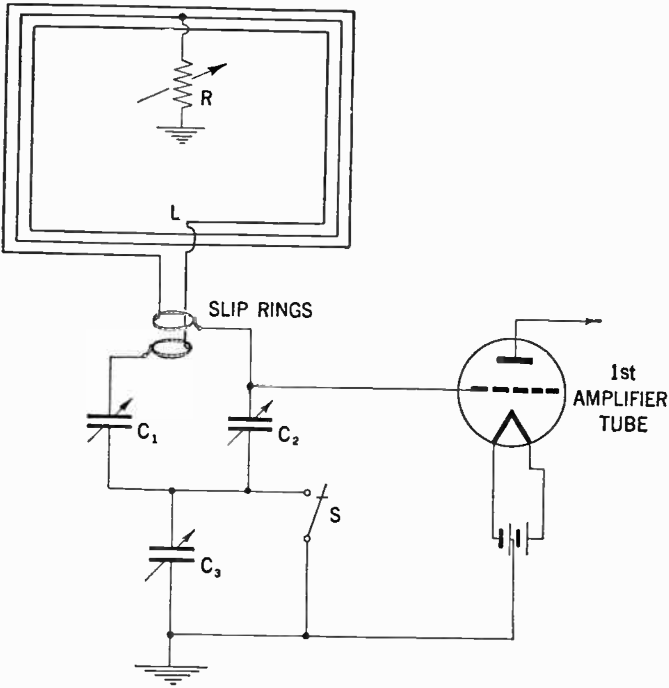


FIG. 5—Circuit of Bellini Radio direction finder.

The frame supporting the loop is square in shape, each side being approximately 32 inches long and ten turns are wound for a wave length of 300 to 1100 meters.

The energy from the frame to the amplifier is transferred similarly to the previously discussed Kolster type direction finder by means of slip rings.

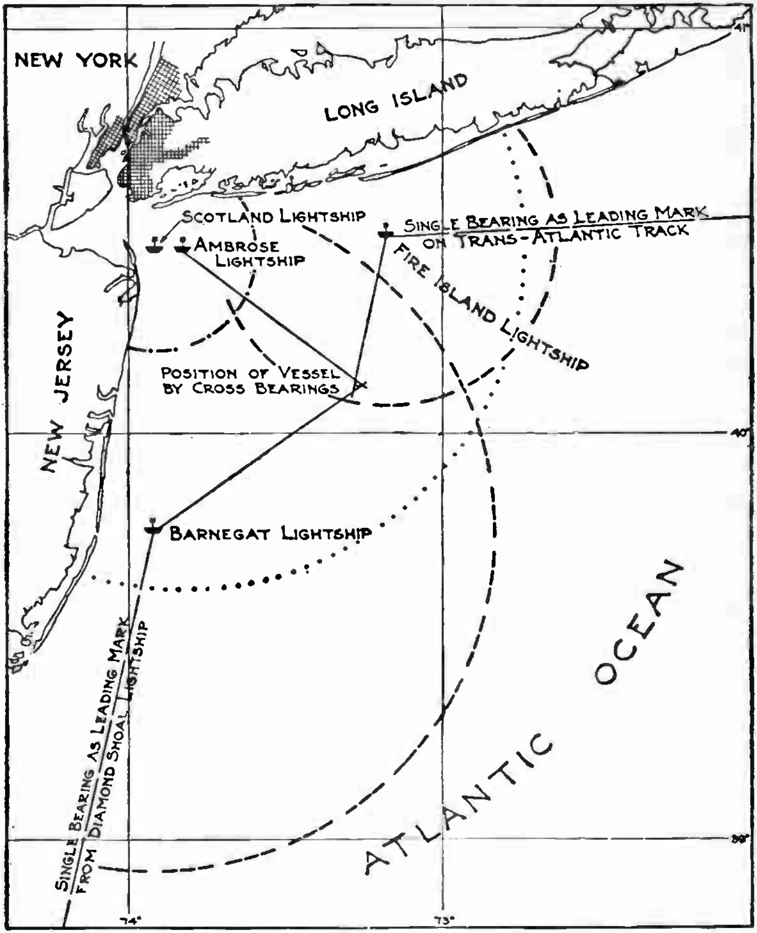


FIG. 6—Illustrating the use of radio beacons in navigation. When approaching New York, the location of four radio beacons as shown, makes it possible to obtain radio bearings, and thus at any instant the position of the vessel will be obtained. The arcs of circles indicate the characteristics of the radio beacons, and the radius shown is approximately half the ordinary range.

A typical shipboard compass installation is shown in fig. 2. When the coil is rotated by means of the hand wheel, the characteristic signal from the signaling station will be heard in the telephone with varying degrees of sharpness until the plane of the coil is at right angle to the direction of the incoming waves at which point the signaling fades out completely.

The position of silence is very sharp and hence indicates with great accuracy the line of direction of the incoming waves.

By means of cross bearings as indicated in chart, fig. 6, on two or more stations or by several bearings on a single station with the distances logged between bearings, the position of the vessel can be determined by simple triangulation with an accuracy equal to sight bearings on visible fixed objects.

Example on Cross Bearings Obtained by Radio Compass from Two Adjacent Radio Beacons.—With reference to fig. 7 showing two beacon transmitters T_1 and T_2, the bearings on ship S may be computed by the navigator who reads the ship's head and corrects for deviation and variation as follows:

1. Ship's head as read by the magnetic compass	$=45°$	$= \quad 45°$
Variation obtained from chart	$=10°E$	$=+10°$
Deviation obtained from correction table	$=\ \ 2°E$	$=+\ \ 2°$
True ship's head relative to true North		$= \quad 57°$
2. Radio beacon T_1 as read on radio compass	$=$	$272°$
Correction from QE* curve for 92°	$=$	$-\quad 1.°5$
Radio bearing on T_1 relative to ship's fore and aft line	$=$	$270.°5$

Thus, bearing on T_1 relative to true north = true ship's head + corrected radio bearing $=57°+270.°5=327.°5$. This gives position line T_1OY from radio beacon T_1.

*QE—Quandrantal error calibration curve. A curve representing the deflection of radio bearings due to the unequal distribution of metal on the ship.

3. Radio beacon T_2 as read on radio compass	=	223.°5
Correction from QE curve for 223°	= +	9.5
Radio bearings on T_2 relative to ship's fore and aft line	=	233°

Thus the bearings on T_2 relative to true north = True ship's head and corrected radio bearings = 57° + 233° = 290°. This gives position line T_2OX from radio beacon T_2, and the intersection of the two lines at O is the ship's position.

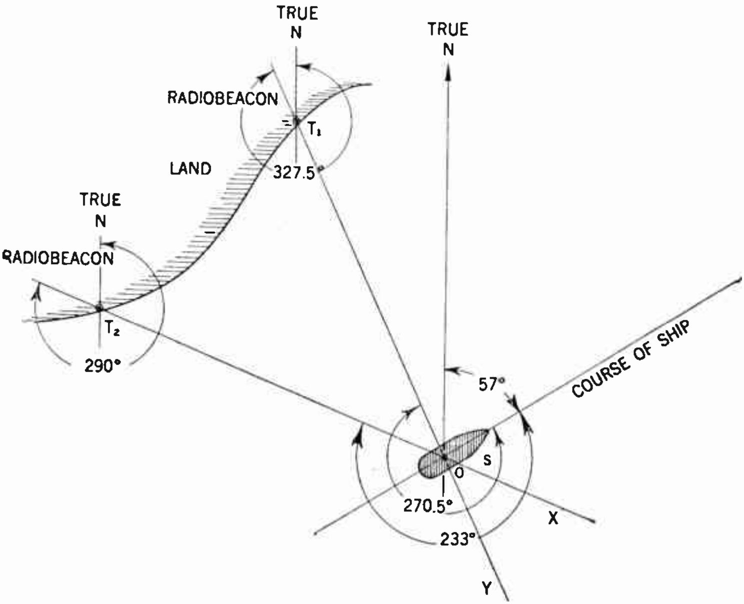


FIG. 7—Diagram illustrating method of computing ship's location by means of radio direction finder. In this illustration the following assumptions should be noted.

1. That the radio bearings are taken very rapidly, so that the distance covered by the ship between observations are negligible.

2. That the distances between the ship and the radio beacons are less than 100 miles and hence no convergency has been considered.

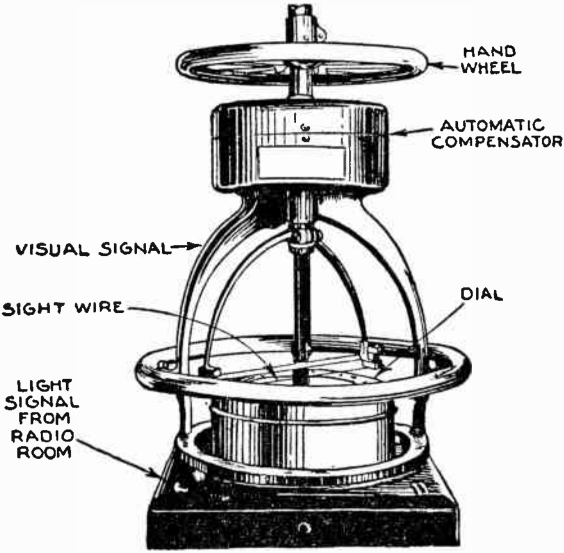


FIG. 8—Kolster compass and compensator arrangement.

CHAPTER 25

Radio Beacons*

Radio beacons as pertaining to marine radio navigation, are simply *radio stations* installed at lighthouses, on light-ships, or at other points shown on charts for the radial dispatch of radio signals for the guidance of ships.

By means of the radio compass, (see page 500) it is hence possible for the ship navigator to ascertain his position at any time when within receiving distance of the radio beacon.

As the radio compass aboard ships are usually designed to enable the operator to take radio bearings without outside assistance, the general problem and practice in navigation becomes very much the same when using radio bearings as they are with visual bearings on lighthouses and other known objects.

The practical difference between the two being that with the availability of the radio beacon much greater distances can be covered under all conditions of visibility.

As previously asserted, the radio beacons are located at definite points clearly marked on the chart, and send out signals in all directions similar to that of light beams sent out by the lighthouse.

*The radio beacons in the United States are erected and maintained by the U. S. Department of Commerce, Lighthouse Service as a part of its system of aids for the navigation of ships.

Another similarity is that as the light beams may be distinguished from one another by definite characteristics, so has each radio beacon a definite signal.

Location Methods.—The common method of ascertaining the location of a ship equipped with radio compass is by means of cross bearings using two or more radio beams as shown in fig. 1 or by visual and radio bearings in combination.

Of course the usual principles apply, as to employing stations which will give good intersections, and as to allowing for the

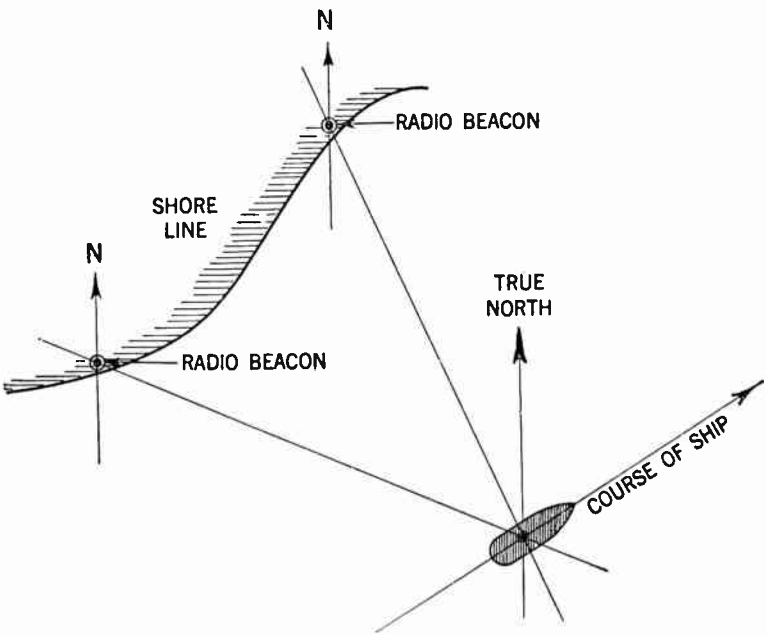


FIG. 1—Illustrating method of ascertaining location of ship, by means of radio compass aboard ship and shore radio beacons.

distance run between the times of taking bearings if the interval is appreciable. A typical example on how to obtain radio bearings is shown on page 506.

The ship's location may also be established by bearings on a single radio beacon using the customary method of taking two or more bearings at sufficiently different azimuths, and plotting these in combination with the distance and course run between bearings.

Indirect use of radio bearings in navigation is also possible. For example a vessel equipped with a radio compass and knowing its own position will be able to assist other vessels by means of radio bearings. Thus, where a vessel seeking another in distress is unable to locate it because of inaccurate reported position, neither having a radio compass, a third vessel so equipped will be able to guide the rescuing vessel by the utilization of radio bearings.

Time Schedules for Sending of Radio Beacon Signals.—Generally radio beacon signals when operating are sent for one minute out of each three minutes. Subject to this they are operated continuously during fog and low visibility, and they are also transmitted on regular time schedules regardless of fog.

Power and Range of Radio Beacon Signals.—The distance of availibility of ranges, considered desirable for radio beacons vary greatly with the purpose of the respective stations. In this country the stations are divided into three general classes:

Class A, primary station, with power approximately 500 watts, with a range of 200 to 300 miles.

Class B, intermediate power 100 to 200 watts, with a range of 100 to 150 miles.

Class C, low power 5 to 50 watts with a range of 10 to 50 miles.

However, the actual range at which signals can be picked up and bearings taken, may under favorable conditions exceed the aforementioned distances.

Although it is possible with present day equipment to greatly exceed these distances, the practical limitations are:

1. The power required may cause a considerable amount of interference.
2. A small error in the direction of a bearing is much magnified in a derived position at a great distance.
3. The possible deviation of radio bearings, particularly as regards the various types of transmission, has not been fully investigated at great distances.

It is at present, considering the above, much more important to develop accurate and dependable direction finding apparatus on ships to be used for distances of 200 miles, than to seek for the possibility of bearings at greater distances.

Radio Beacon Equipment.—As the location of radio beacons in the United States in nearly all instances has been established at existing light stations, and as the space required for the transmitting apparatus is comparatively small, they are usually housed within the light emitting station, and generally no additional buildings are necessary.

The equipment of a radio beacon station comprises the following:

1. Radio transmitter
2. Automatic code machine
3. Power supply equipment consisting of a generator. a battery or both
4. Antenna
5. Synchronizing clock

6. Radio receiver
7. Automatic warning devices.

On account of the importance of continuity of service, all apparatus as far as practicable, are installed in duplicate, with means for switching from one transmitter, generator or code machine to another in case of trouble.

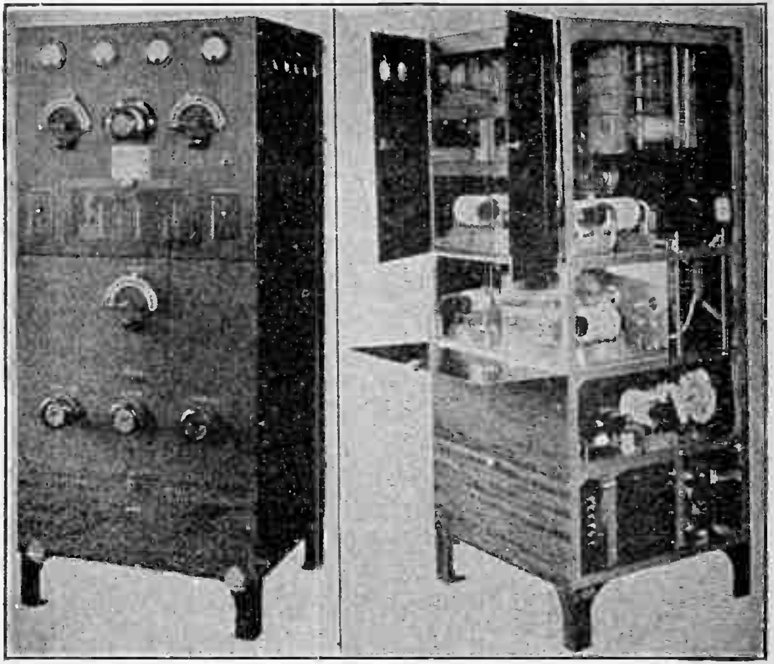


FIG. 2—Standard 200 Watts Marine Radiobeacon transmitter.

Transmitter.—Transmitters of late design are generally of the so-called master-oscillator power-amplifier type, usually employing a 7½ watt tube as master oscillator, following with

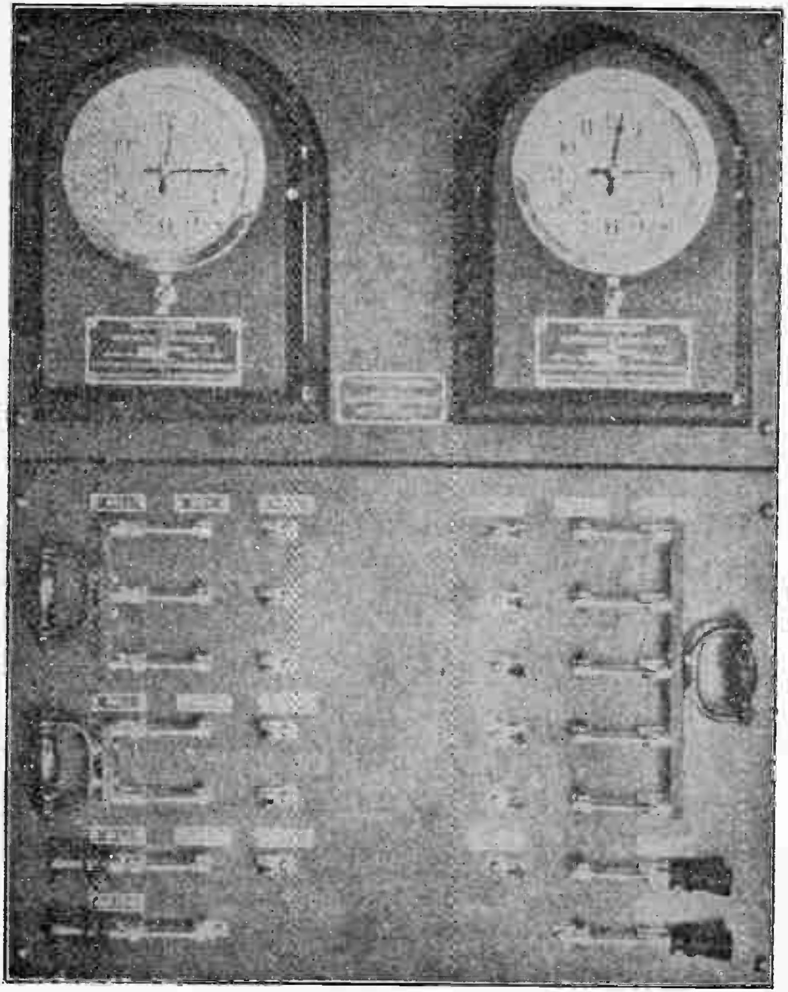


FIG. 3—Radiobeacon Synchronizer, complete with Switchboard, Installation in duplicate.

one or more 50 watt and 250 watt tubes as intermediate and final power amplifiers.

The plate supply is usually obtained from a 110 volt, 60 cycle, alternating current source through suitable tube rectifying circuits, employing rectifiers of the mercury-vapor type. The filament current in nearly all cases is supplied by a separate motor generator or rotary converter to secure better voltage regulation, and is usually 60 cycle *a.c.* current to obtain uniform filament evaporation.

Code Machine.—The code machine is entirely automatic in its operation and provides for the sending of the station characteristics.

The code is formed by a series of combination of short and long segments of a revolving code wheel, making short or long contacts as the wheel is revolved to produce dots and dashes. This wheel is revolved by an electric motor through suitable reduction gears which also drive a contacting cam designed to open or close the circuit, so that any desired combination of "on" or "off" operating intervals may be obtained.

Power Supply.—The location of radio beacons usually is a determining factor as to power supply to be used, and commercial current is employed when available. However, when location prohibits the use of commercial current, internal combustion or steam engines with electric generators are provided.

In case of power failure a duplicate source of supply is utilized to provide against possible interruption of service.

On practically all ship stations as well as on land stations where the storage of gasoline utilized in prime movers for generating equipment would constitute a fire hazard, storage batteries are used as a source of power.

Synchronizer for Radio Beacons.—This apparatus has been designed to automatically control the sending intervals of a radio beacon, and to synchronize the sending intervals of several stations in a group so that they will not overlap.

The actual work of synchronizing is accomplished through control of the "on" and "off" periods of the transmitter by accurate clocks. Two types of clocks are used to accomplish this, the larger number being of the marine escapement type which are serviceable alike at ship and shore stations. Pendulum clocks are also used at a considerable number of land stations. Both types of control clocks are equipped to close an electric contact at the beginning of each minute. This contact is in series with the windings of an electric solenoid or a similar device, which when the contact is closed advances the drum, carrying the other and larger electrical contacts one step at a time.

This multicontact drum, called a synchronizer or secondary clock, is also divided into minutes, or spaces corresponding to minutes, and makes one complete revolution in an hour. It is this drum that provides that the radio beacon signal shall be emitted for exactly one minute and be silent for two minutes. It is also feasible to select any other "on" and "off" arrangement so long as the changes occur at even-minute intervals. Incidentally, this multi-contact drum which is advanced at minute intervals by an accurate clock, provides a ready means of closing and opening other circuits in addition to those controlling the "on" and "off" minute periods, thus furnishing the means by which any radio beacon station can be made fully automatic.

For example, one contact can start a gasoline driven electric generator, another contact can place the transmitter in operation, while another controls the duration of the characteristic signal period, the operation for 15 minutes in each hour.

Although the control clocks are accurate and sturdy, it is necessary to provide for correction and adjustment against a standard time signal. An attempt to permanently fix the electrical contacting mechanism to the clock time train and depend on regulating the clock to correct for accumulated errors, was found to require too frequent adjustment of the clock.

Instead of this, the contactor itself in the clock is made adjustable, so that the instant of contact can be advanced or retarded manually as necessary to allow for accumulated clock error. This adjustment is made by a suitable device without opening the clock. This provides a ready means whereby the attendant at the radio beacon station can listen in on the other radio beacon stations in the synchronized group and correct at once for any errors. This is done twice a day. For this purpose one station in each group is taken as a master station, to which the clocks at the other stations are adjusted. The clock at the master station is adjusted twice a month from the standard time signals.

Warning Device.—Automatic operation of radio beacons is at present being provided in many locations.

In order to insure operation without the constant attendance of the keeper, a positive warning device has been developed whose function it is to notify the keeper in case of failure of any part of the radio-beacon system.

The function of the radio-beacon transmitter system is to induce an *r.f.* current in the antenna, and the warning device being actuated by the antenna current, automatically sounds a warning, in case the antenna current for some reason is being interrupted.

The device operated by sounding a gong or horn whenever the aforementioned antenna current (radio signals) stops for a longer period than two minutes, this being the normal silent period.

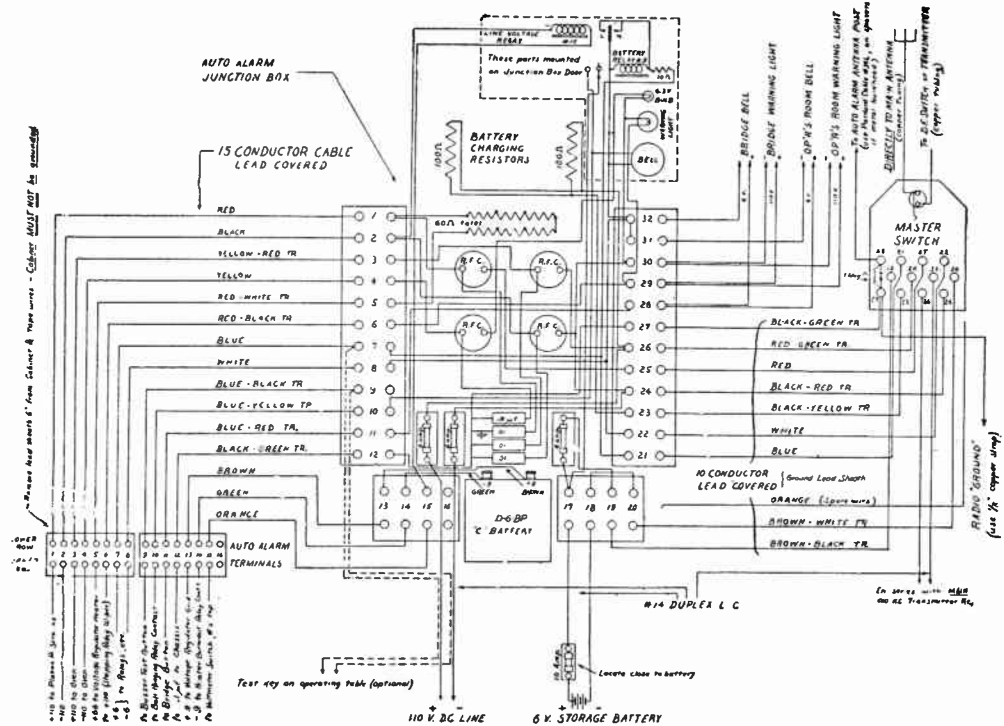


FIG. 4—External Wiring Diagram of *AR*-8600 auto alarm unit, shown on page 521.

CHAPTER 26

Automatic Radio Alarm

An automatic alarm is a device used to enable a ship in distress to summon aid at any time by radio from a nearby vessel, and especially during those periods when the radio operator on the nearby vessel might not be "on watch."

Special regulations governing this distress signal and the number of operators which their installation shall release are now in force.

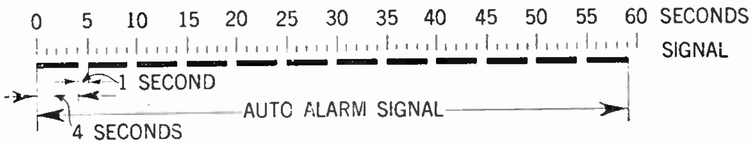


FIG. 1—Standard auto alarm signal.

The function of this distress signal is to actuate an automatic receiving device on the vessel in the vicinity of the ship in distress and by means of bells or other signal producing apparatus, call attention to the fact that a distress call is being transmitted.

This special distress signal only supplements and does not supersede the conventional SOS call, and is known as the *automatic alarm signal* and the special receiving apparatus is called the *auto alarm.*

Auto Alarm Signal Characteristics.—The auto alarm signal is transmitted by the ship in distress just prior to sending the normal SOS signal. This signal consists of a series of dashes and spaces, each dash having a duration of four seconds and each space between dashes a duration of one second. Twelve such dashes and spaces can be transmitted during one minute. (See fig. 1)

The auto alarm is designed to operate bells after a certain number of consecutive dashes and spaces are being correctly received.

Foreign Practice as Compared with F.C.C. Requirements.—Foreign practice sometimes require the arrangement of bells to ring when three consecutive dashes and spaces pass through the receiver, whereas the U. S. Federal Cummunication Commission (F.C.C.) requirements are based on ringing of the bells after four consecutive dashes and spaces are correctly received.

It is obvious that the four-dash cycle considerably minimizes the possibility of false alarm, since the chances are quite remote for accidental combination of signals to repeat themselves four times to imitate the alarm signal. In this connection it may be mentioned that the current designs of American auto alarms may be easily arranged to accept either the three or four dash cycle and in any case no International operating difficulties occur since the vessels in distress always send twelve or more dashes.

A single master switch to place the auto alarm in service is required which must be so arranged that power cannot be applied to the alarm circuits unless the main antenna is connected to the alarm receiver and having an interlocking feature to prevent the ship transmitter from being keyed unless the auto alarm receiver is turned off.

Basic Elements of the Automatic Radio Alarm.*—The complete radio alarm consists of two main parts namely the radio receiver and the selector unit.

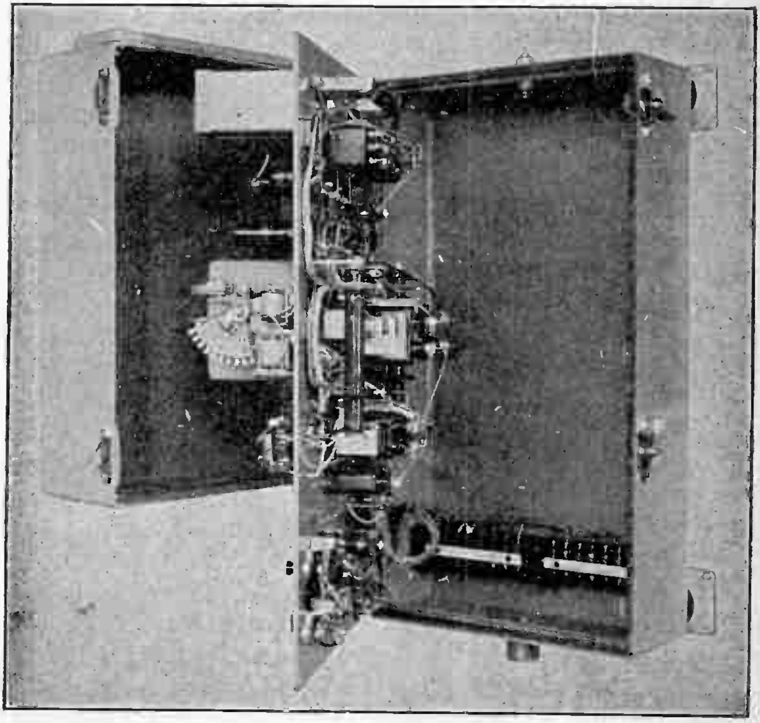


FIG. 2—Type AR-8600 auto alarm with cover and panel open.

*An auto alarm designed by the Radio Marine Corp. of America and generally referred to as the Model AR-8600 is described on the following pages.

The radio receiver forming a part of the alarm must be designed to possess uniform sensitivity over a frequency range from 487.5 to 512.5 *k.c.* The normal distress frequency is 500 *k.c.* but provision must be made for the auto alarm receiver to accept signals outside tnis exact frequency, thereby permitting some variation in the adjustment of the radio transmitter on the vessel in distress.

The band width of the alarm receiver must also be fixed as an integral part of the design, and not be adjustable by the operator.

Warning Apparatus.—Since it is necessary that the auto alarm when connected in the circuit to operate unattended for several hours, some means must be devised to indicate when operation is not normal.

During abnormal atmospheric conditions for example, prolonged static of high level may tend to "hold over" some of the relays in the selector unit. Hence it is necessary to arrange for a warning light or its equivalent to indicate to the bridge that the radio operator is required to readjust the sensitivity control.

At other times vacuum tubes in the alarm may burn out, and when this occurs, a "no current" relay is utilized to energize warning bells located on the bridge. Failure of the source of energy which rings the bells is shown by a continuous burning of warning light placed alongside the bells, in a position where they must be observed.

After the radio signal passes through the receiver it controls the selector mechanism. To allow for reasonable variations in timing of the alarm signal the selector must be designed to accept dashes having a duration of 3.5 to 4.5 seconds and spaces of from 0.1 to 1.5 seconds. The question of operation through interfering signals in the 487.5 to 512.5 *k.c.* band as well as the possibility of false alarm must also be considered when determining the selector timing tolerances.

It is necessary also that the alarm function through a reasonable amount of interference on the same wave length as the distress signals. This interference may produce two effects on the

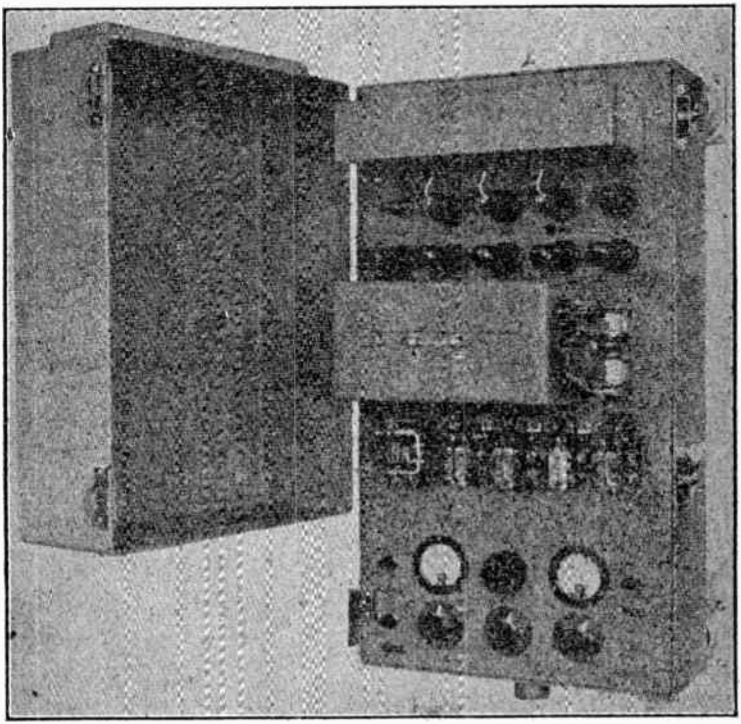


FIG. 3—Type AR-8600 auto alarm with panel closed and cover open.

selector, one of which is to prolong the normal four-second alarm signal in case the interference appears at just the correct time to add to the desired signal, the second effect of interference is to "fill in" the normal one second spaces.

If the spaces are completely filled in at the correct time the selector functions to reject the signals and it will do the same if interference unduly prolongs the desired dashes.

False Alarms.—The false alarm possibility is determined by a combination of three main factors, namely:

1. Accidental combinations of signals or noise equivalent to the alarm signal.
2. Timing tolerances of the selector.
3. The number of dashes and spaces which are selected to ring the bells.

The Selector Unit.—Under normal conditions, 16 hours per day or approximately 5,800 hours per year of operation is necessary, hence the selector unit to be most reliable should have as few moving parts as possible.

As previously mentioned the Standard automatic alarm signal is composed of 12 dashes and spaces, but the alarm bells are to be actuated after the receipt of four dashes with tolerances of 3.5 to 4.5 seconds and spaces with tolerances of 0.1 to 1.5 seconds.

Thus if the space between the first and second dashes is completely filled with interference, the alarm would be actuated at the end of the sixth dash. If interference prolongs the length of any dash beyond 4.5 seconds, or completely fills in the space between dashes, the mechanism used for selection would be restored to normal. Thus, of the 12 dashes comprising the signal, four consecutive dashes having a space at the beginning and ending of the group, as well as between dashes, must be received before the alarm bells will ring.

The obvious advantage of a 12 dash signal is that it permits more chances of the alarm being actuated under severe conditions of interference both from the standpoint of prolonging the dashes and filling in the spaces.

The aforementioned dash and space tolerances seemingly impose difficult terms for the selector response. For example, four dashes and the intervening three spaces might vary in total elapsed time between 14.3 and 22.5 seconds.

Obviously the selector must check individual dashes and spaces since any attempt to use the sum would result in the false alarm probability being greatly increased.

The schematic circuits of the receiver and selector units are shown in fig. 4.

Elapsed time of signal duration is measured by *RC* circuits connected in the grid circuit of individual selector tubes.

The principle utilized is the familiar one of current decay in a series *RC* circuit.

With reference to fig. 4 warning relay No. 8 being connected in series with the tube heaters across the ship's 110 volt line, will cause the alarm bell to ring when any one of the tube heaters burn out, or when voltage failure occurs.

Warning relay No. 9 is connected across the storage battery through a series resistor. Failure of the battery supply will allow relay No. 9 to de-energize and turn on the warning lights at each bell location point. Warning of power failure is therefore obtained except for simultaneous failure of both the 110 volt ship line supply and the storage battery.

The following is a summary of warnings indicating various conditions when using auto alarm apparatus heretofore described:

1. *Bells ringing* may be caused by:
    - *a*. Receipt of auto alarm signal.
    - *b*. Receipt of a false auto alarm signal caused by a fortuitous combination of static and keyed interference.
    - *c*. Loss of ship's line voltage.
    - *d*. Tube heater burn-out.

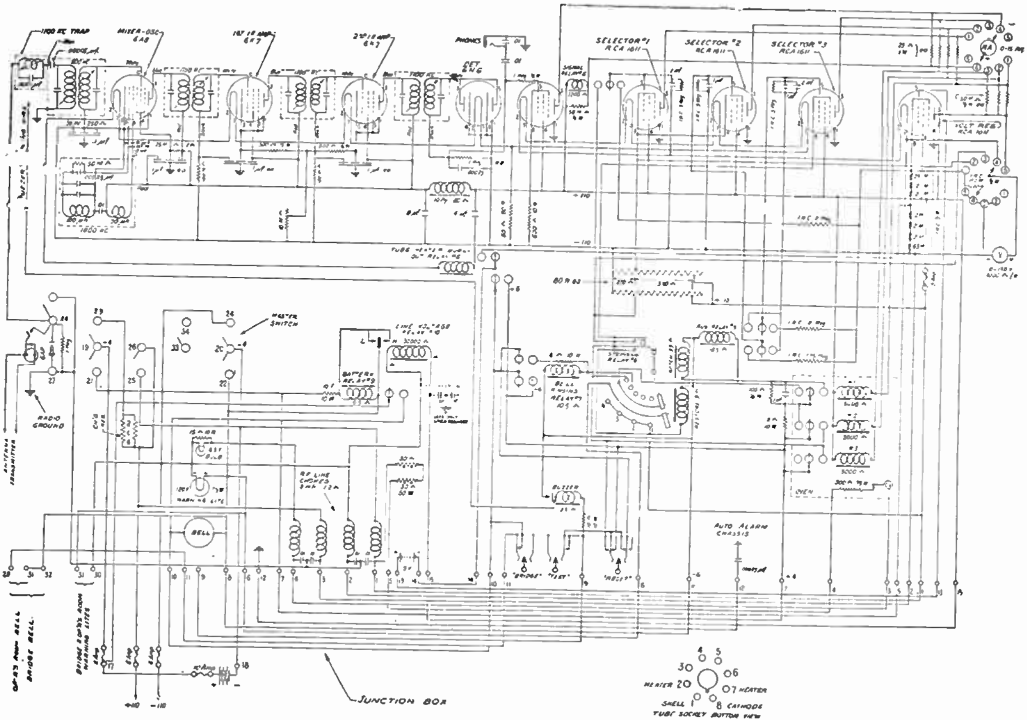


FIG. 4—Complete schematic circuit diagram of AR-8600 auto alarm unit.

2. *Warning lights burning continuously* are caused by:

   a. Receipt of a continuous signal from a transmitter whose key is being held down for a period considerably greater than 4.5 seconds.

   b. Sensitivity control set too high for the prevailing noise level.

   c. Loss of 6 volt battery supply.

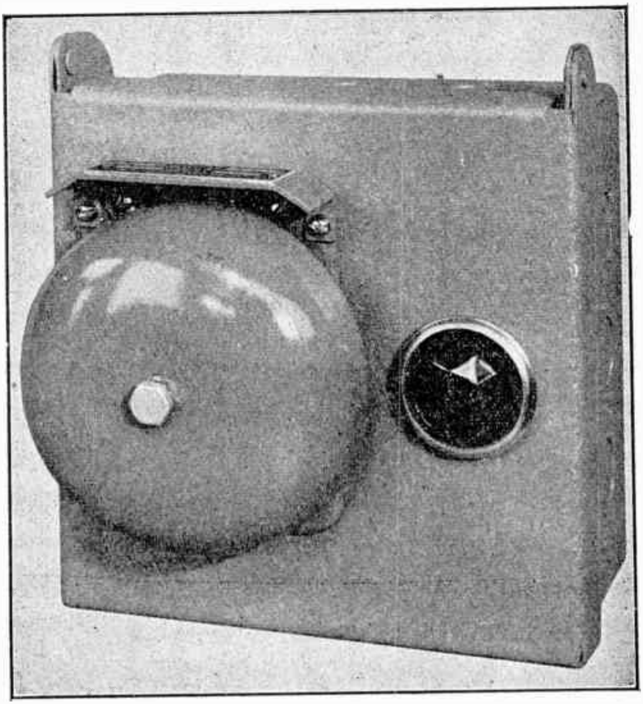


FIG. 5—View of warning light and bell located on bridge of ship.

3. *Warning lights burning intermittently* are caused by:
   a. Occasional long bursts of static.
   b. Transmitter testing using dashes slightly longer than 3.5 seconds.
   c. Heavy 500 *k.c.* interference caused by several telegraph transmitters transmitting at the same time.

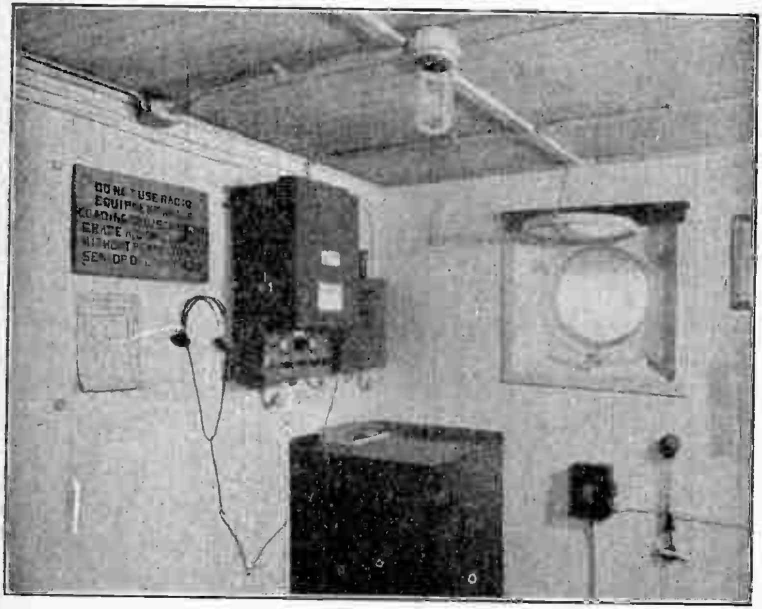


FIG. 6—Typical shipboard installation showing location of auto alarm unit and associated equipment.

Warnings as under 3, are to be expected and indicate that the auto alarm is functioning correctly. Warnings as under 1 and 2, should be investigated as to their cause.

The following gives a summary as to procedure to be followed in order to properly operate and maintain the auto alarm as given on the instructions accompanying the equipment.

ADJUSTMENTS TO BE MADE BY RADIO OPERATOR BEFORE GOING OFF WATCH

On the front cover of the auto alarm there will be found printed instructions which read as follows:

IMPORTANT INSTRUCTIONS

"*TO TEST ALARM:* Close master switch. Set sensitivity control to approximately 40. Using radio room clock transmit alarm signal with test push button on auto alarm. Bells will ring after four correct dashes and spaces. See instruction book for further details."

"*TO ADJUST SENSITIVITY CONTROL:* Set scale at 0. Set current switch at 4. Meter will read about 7.5 M.A. Turn sensitivity control to right until average meter reading due to noise, static. etc., is about 1 M.A. less than maximum value. Listen with phones. Incoming signals will cause signal relay to chatter slightly and meter reading to fall toward zero. If sensitivity is set too high for prevailing noise level, warning lights will indicate need for lower setting. Do not set sensitivity control lower than necessary as weak distress calls may not be received."

When testing the auto alarm with the test buzzer and push button the operator should observe that the milliammeter reading falls to zero or nearly so each time the test button is depressed. Close this button quickly several times and observe that the radio relay, whose armature click may be heard, follows the keying speed. Each time a correct four second dash and space are sent with the test buzzer, it may be observed that the stepping relay advances one position. If there is considerable radio interference or static during the time the alarm is being tested, it will be observed that the restore coil on the stepping relay is also energized, thereby preventing the stepping relay from advancing further. This condition will occur during testing whenever static or interference completely fills the spaces between dashes so that the normal auto alarm signal is distorted The position of the sensitivity control, during the test of the auto alarm, may be used as an approximate check on the sensitivity of the receiver and the correct performance of all tubes. If it is found necessary to advance the sensitivity control beyond approximately 40 to 50 on the scale, it may be inferred that one of the tubes in the radio receiver part of the circuit is defective. After a little experience with the alarm, using the headphones plugged into the jack and by observing the operation of the radio relay on incoming signals, the operator may reach an approximate determination as to whether or not the receiver sensitivity is normal In other words on the average shipboard antenna it should not be necessary to advance the sensitivity control to the extreme right in order to make the radio relay operate with the average incoming signal.

SENSITIVITY CONTROL ADJUSTMENT

A clear understanding of the results to be expected from various settings of the sensitivity control is necessary in order to adjust this control to the optimum or most favorable position. For example if the sensitivity control is turned to the extreme right (100 on the dial) or nearly so, it may be found that the average noise level and static will cause the radio relay to hold over for long periods of time, or to chatter or vibrate steadily When this occurs the adjustment is not a favorable one, for not only will the warning light be illuminated frequently whenever static or noise persists for 3.5 seconds or more, but also a real alarm signal will be more apt to have its dashes prolonged and its spaces filled in, with such an adjustment. On the other hand if the sensitivity control is adjusted too far to the left, that is toward zero on the scale, then only very strong signals will operate the auto alarm, and a distress call from a distant ship might be missed. The optimum adjustment will be found to be that which gives a reading on the milliammeter (with no incoming signals) which is approximately one milliampere *less than* the reading obtained when the volume control is at zero. With such an optimum adjustment the radio relay may close occasionally from short bursts of static or from ordinary code signals. The operator should keep in mind that if the sensitivity control is set too high the radio relay will vibrate constantly, which is an undesirable adjustment. The officers on the bridge will have instructions to summon the radio operator whenever the warning light on the bridge is illuminated for periods of five minutes or more. When the sensitivity is set at 100 or maximum, a signal strength of approximately 200 microvolts will operate the auto alarm. At a dial setting of 50 (midscale) a signal of approximately 1000 microvolts is required. At 0 setting of the sensitivity control a signal strength of 20,000 microvolts is required.

FAULTS WHICH WILL CAUSE SOUNDING OF THE AUDIBLE ALARM

1—False alarm. Accidental combination of static or other interference may occasionally cause the stepping relay to advance to its fourth position, which will lock in the bell ringing relay and cause the bells to ring continuously. Bells will stop when reset push button is depressed on auto alarm panel.

2—Filament burnout. If any one of the vacuum tube filaments (heaters) should burn out, or if one of the 30 ohm series filament resistors in the junction box should burn out, the *filament burnout relay* on the auto alarm panel will have its coil de-energized, which will close the back contacts, and cause the bells to ring. Bells can only be stopped from ringing by replacing the defective tube, or resistor or by opening the master switch.

3—Low or high line supply voltage. If the 110 volt shipboard supply is reduced below normal or increased above 120 volts, the *line voltage relay* in the junction box will operate, which will short out the coil on the six volt relay, causing the bells to ring. The bells will continue ringing until line voltage is restored to normal or until master switch is opened.

4—If the six volt battery approaches discharge and its voltage falls below about 4.5 volts, the back contacts will close on the *six volt relay*, causing the bells to ring continuously until a suitably charged battery is placed in circuit or until the master switch is opened.

5—If the one-half ampere fuse on the auto alarm panel or any of the fuses in the junction box should be blown, the bells will ring continuously until the fault is corrected or unless the master switch is opened. The one-half ampere fuse will blow in case of tube shorts or condenser breakdown in the receiver-selector unit.

OPERATION OF WARNING LIGHTS

The purpose of the warning lights as explained previously is to provide a visual indication whenever prolonged static or other interference holds the radio relay open. After 3.5 seconds the stepping relay will advance one position and remain there as long as the interference is continuous. An auxiliary set of contacts on the stepping relay will close a circuit to the three warning lights to indicate this condition. The remedy is to readjust the sensitivity control to a slightly lower setting so that the stepping relay drops back to its normal or zero position.

PROCEDURE TO BE FOLLOWED WHEN ALARM BELLS RING

1—If alarm bells ring momentarily, then stop ringing, and repeat this cycle frequently, the difficulty is most likely due to low, high or variable line voltage. Go to the radio room, open the door of the junction box and observe the line voltage relay contacts. Also measure the line voltage by placing the voltmeter switch in position five on the auto alarm panel. If the voltage is much below 100 volts, it will be observed that the line voltage relay "left" contact is closed, causing the bells to ring Higher than normal line voltage will cause the "right" contact to make on the relay, also ringing the bells. This condition of low, variable, or high line voltage should be brought to the attention of the proper ship's officer.

2—Alarm bells ringing continuously. Go to the radio room and depress the reset button on the auto alarm. If this stops the bells from ringing a pair of phones should be immediately plugged into the phone jack to determine if an alarm signal has been transmitted by a vessel in distress. If the bells do not stop ringing when the reset button is depressed the fault may be low line voltage, high line voltage, low six volt battery supply, filament burnout, or blown fuses. Filament burnout may be immediately determined by placing the voltmeter switch in position four, where a reading of 100 volts or more will be obtained instead of the normal reading of approximately 60 volts. A blown one-half ampere plate fuse or 110 volt line fuse may be quickly determined by observing if any reading is obtained on the voltmeter with the switch in position five. No reading will be obtained if these fuses are blown. If the six volt battery is low this should be checked with the three scale voltmeter carried in the radio room as a part of standard safety of life at sea equipment.

3—When troubles which cause the bells to ring continuously cannot be located quickly, it is desirable to disconnect the bridge bell and operator's bell temporarily to avoid undue annoyance to the ship's personnel. This may be done by removing the lead (blue with red tracer) which will be found on terminal 28 on the vertical right hand terminal block of the junction box. After the trouble has been corrected the operator should make certain that the lead to terminal 28 is firmly reconnected, and he should make a test with the bridge and the operator's room to insure that the bells are again functioning normally.

LOG ENTRIES

The following instructions with regard to log entries should be carefully observed as they are required by the Federal Communications Commission.

1—While the ship is at sea the auto alarm shall be tested by means of the testing device supplied, at least once every 24 hours, the timing of the dashes to be made by reference to the sweep seconds hand of the station's clock. Bridge bell and warning light and operator's room bell and light must show correct operation when this test is made. A statement that the foregoing has been fulfilled must be inserted in the ship's official deck log and the radio log daily.

2—If the warning light is illuminated for a continuous period of five minutes or more, the operator shall record in the radio log the time when he was called by the bridge, the time when he goes to the radio room to investigate the difficulty, the reason for the warning lights burning, and a statement as to the adjustments found necessary to restore normal operation.

3—If the bells ring, the operator should record in the radio log the time of the occurrence and the time when he arrives at the radio room to investigate the reason for the bells ringing. A record should also be made in the log to explain what caused the bells to ring, such as actual alarm, false alarm, filament burnout, low line voltage, low battery voltage, blown fuses, etc.

4—Vacuum tube and battery information to be entered in log. Each vacuum tube initially supplied in the auto alarm is dated at the time of installation. If any tube becomes defective the operator should remove the tube and make an entry in the log to indicate the date the tube was removed and replaced and the tube socket from which it was taken. The defective tube should not be destroyed, but should be returned to the radio company responsible for the maintenance of the auto alarm. The new tube which is used to replace the defective tube should be dated by the operator. This may be done by scratching the date on the metal shell of the tube with the point of a knife or other sharp tool.

The 9 volt "C" battery (type D6BP) mounted in the junction box is provided with a label to record the date when installed, and also the date when it should be replaced. If for any reason the operator finds it necessary to replace the "C" battery with his spare "C" battery, he should enter this fact in the log, recording when the old "C" battery was taken out, when the new one was replaced and on the label of the new battery he should write the date when installed. The "C" battery should be replaced when it falls below 8.5 volts.

GENERAL MAINTENANCE AND REPAIRS AT SEA

If normal operation of the auto alarm cannot be obtained, the radio operator should proceed as follows:

IMPORTANT: Do not remove relay cover or oven cover on the auto alarm panel or work with tools around any of the parts unless the master switch is in the "off" position.

1—Check with three range radio room voltmeter to determine if the 110 volt line voltage and six volt battery power exists across the appropriate input terminals in the junction box. If correct readings are obtained make similar measurements across the proper terminals of the receiver-selector unit. Refer to T-351.

2—Make certain that all leads on the junction box terminals from number 1 to 32 inclusive are tight and making good connections.

3—Relay contacts should be checked and cleaned, if necessary, to insure proper contact. To clean contacts use the special burnishing tool which is furnished, taking care not to remove too much contact material with the burnisher.

4—If defective tubes are suspected, they should be replaced *one at a time*, starting with the 6-A-8 tube, always returning good tubes to the same socket from which they were removed. This will avoid confusion in locating a defective tube. Type 1611 tubes may be checked for emission by placing them successively in the second socket from the left in the lower row of tubes. This is the radio relay tube socket and the plate current of this tube may be read by the milliammeter with the switch in position number four. Normal tubes with 100 volts line should show a plate current with no incoming signal of approximately 7 milliamperes or more. When checking tubes all tube sockets must be filled, otherwise bells will ring.

5—Each selector circuit may be checked by sending a test signal through the auto alarm and successively placing the "current" switch in position 1, 2 and 3. In position 1 after a long dash a current of approximately 8 to 10 milliamperes will be obtained. In position 2 after a long dash a similar value will be obtained. To check selector number 3 place the switch in position 3, send a 4 second dash with the test buzzer and then observe after about 5 seconds that the meter reads momentarily a value of approximately 6 milliamperes. The third selector tube shuts off its own plate current after it checks a space and for this reason only a momentary meter reading will be obtained.

6—It is possible to check various voltages in the junction box and on the various component units back of the auto alarm panel by referring to diagram T-351, and by using the three range voltmeter which is carried in the radio room. Such a voltage analysis will enable the operator to determine if open circuits or poor connections exist in various parts of the circuits.

7—The switch contacts on the master switch should be checked occasionally to insure that they are making good connection, removing any corrosion or oxidation which may have taken place.

8—Normal operation of the oven heater will be indicated by intermittent operation of the small pilot light mounted on the back of the junction box cover. This pilot light is provided to enable the radio operator to determine that the oven circuit is operating normally whether or not the auto alarm is on watch.

9—If for any reason the auto alarm 6 volt battery becomes discharged the operator should substitute one of the radio room 6 volt storage batteries temporarily. The auto alarm battery should then be placed on charge from the standard radio room "A" battery charger. The operator should determine why the auto alarm battery became discharged. The auto alarm master switch is arranged to place the 6 volt battery on charge at a rate of approximately 2 amperes whenever the master switch is in the "off" position. This charging rate is sufficient to keep the alarm battery fully charged if the alarm is "on watch" for a period of 18 hours daily. In other words 6 hours charging in each 24 hours will keep the battery in good condition. If either or both battery charging resistors at the top of the junction box should become defective, standard 110 volt 100 watt lamps may be used as a substitute.

10—When replacing the 9 volt "C" battery, make certain that the green lead connects to the negative terminal and the brown lead to the positive terminal. No current is taken by the "C" battery, therefore if early "C" battery replacement is necessary look for shorts or leakage. A voltmeter connected in *series* with one of the "C" battery leads should show no reading for normal operation.

11—If plate current is obtained through each selector relay as explained under "5" above and the stepping relay does not operate, inspect the contacts on the selector relay in the oven.

Remove oven cover screws and carefully withdraw the oven cover *straight out* to prevent breakage of the thermometer. Relay contacts may now be examined and cleaned if necessary.

12—Note that the 6 volt storage battery has two fuses in the positive side of the circuit, a 6 ampere glass fuse in the junction box and also an external 10 ampere fuse installed near the battery. Short circuits in the 6 volt circuits in the auto alarm or junction box will normally cause the 6 ampere glass fuse to blow. Short circuits in the wiring to the warning bells will cause blowing of the external 10 ampere fuse. This arrangement allows the warning bells to ring when the 6 ampere fuse is blown. Both fuses should be inspected in case of trouble. Always use the specified ratings when replacing fuses.

13—The line voltage relay will also cause the bells to ring if the polarity of the 110 volt shipboard line is reversed. The voltmeter on the receiver-selector unit in switch position 5 will also indicate this condition by reading in the reverse direction.

TYPICAL READINGS OF CURRENT AND VOLTAGE FOR NORMAL AUTO ALARM OPERATION

The following readings are based on an average line voltage of 100 volts. Higher line voltages will give slightly higher readings.

CURRENT SWITCH

Position 1—First selector relay closes at approximately 4 M.A.
Position 2—Second selector relay closes at approximately 6.5 M.A.
Position 3—Third selector relay closes momentarily at approximately 6.5 M.A.
Position 4—Signal relay plate current is 7.5 M.A. with no incoming signal. With signals, lower values, down to zero, will be obtained.
Position 5—Not used.

VOLTMETER SWITCH

Position 1—Grid charging voltage 52 volts.
Position 2—Grid bias on selector tubes 1 and 2, 29 volts.
Position 3—Grid bias on third selector tube, 29 volts.
Position 4—Heater voltage 60 volts.
Position 5—Reads ship's line voltage.

When going off watch the operator should always leave the "current" switch in position 1 and the "voltage" switch in position 5. If the current switch is left in position 4 the milliammeter will follow all incoming signals, causing unnecessary wear and tear on the instrument.

TESTING AUTO ALARM UNDER SEVERE STATIC CONDITIONS

Occasionally when static is very severe the sensitivity control cannot be advanced far enough to permit the test buzzer to actuate the receiver without causing the radio relay to "block" from the static. To test the alarm under these conditions place a temporary short circuit between the AA terminal and ground terminal on the master switch. After the test the short circuit should be removed and the sensitivity control adjusted to optimum for the prevailing noise level.

UNDERSTANDING SELECTOR ACTION BY OBSERVING RELAYS

1—Transmit "V"s or other code signals with test buzzer. Radio relay will follow keying and milliammeter in position 4 will show a lower reading each time buzzer is operated. No other relays will operate.

2—Transmit one four second dash. Radio relay will operate instantly and after 3.5 seconds number 1 selector relay in oven will close, auxiliary relay will close, "notch" coil will be energized and stepping relay will advance one position. This checks if dash is long enough.

3—Transmit one dash of 5 seconds or more. Same action as under "2" above will take place and in addition number two selector relay in oven will close and "restore" coil on stepping relay will be energized. When long dash is broken stepping relay will return to zero or normal position. This checks overlong dashes.

4—Transmit one four second dash to advance stepping relay one position and then break this dash. After approximately 5 seconds "restore" coil will click and stepping relay will return to zero. This checks spaces.

5—Transmit four correct 4 second dashes separated by 1 second spaces and watch the stepping relay move up with each dash, finally causing the bell ringing relay to lock in when the fourth dash is broken. Note that each dash, including the fourth dash must be followed by a space to lock in the bell ringing relay. If the fourth dash (or any other dash) is too long the restore coil is energized on the stepping relay

PREVENTING OVERCHARGE OF 6 VOLT BATTERY

When the ship is in port or drydock or if the auto alarm is in use for only a few hours each day, the 6 volt storage battery may become overcharged. To avoid this use one charging resistor if the alarm is in use only a short time daily. In port or in drydock remove both charging resistors by unscrewing from sockets.

CHAPTER 27

Short Wave Receiver Principles

As short waves permit the reception at much greater distances than that with longer waves, regularly employed by commercial broadcasting stations, it has become the practice to transmit important programs simultaneously on both long and short waves.

Generally a radio program received at a frequency at or above 1,500 *k.c.* is classed as *short wave reception*, and the simultaneous transmitting and receiving of radio waves at or above 1,500 *k.c.* is classed as *short wave communication.*

Short wave communication at present is carried on at wavelengths down to 5 meters or 60 megacycles (60,000,000 cycles per second) although it is now becoming apparent that in the near future the *ultra short wave* range of from 5 down to 1 meter, 60 to 300 megacycles will be considered as familiar and useful territory.

However, as the radio tube design is so closely associated with the utilization of *ultra high frequencies* it is apparent that the exploration of the frequency band of between 60 to 300 megacycles will have to wait for the research laboratories, who in this case must lead the way for successful operation.

The problems introduced in the design of equipment by the attempt to raise the limitations of high frequencies of the order mentioned above can best be appreciated by speaking in terms of wave-lengths.

The wave-length determines directly in the same units the approximate maximum physical size which the equipment to produce that frequency may attain. This results from the fact that the greatest speed at which energy may be sent along an electrical circuit is the same as that of the electro-magnetic energy in space—the velocity of light or approximately 300,-000,000 meters* per second.

In practical circuits, however, due to the fact that inductance and capacitance lowers the speed of electrical energy, this speed is never reached.

From this it follows that the circuits then must be smaller in extent than the wave-lengths and the tubes themselves will be very small in physical size.

Wave Length and Frequency.—Since as stated the electro-magnetic energy and flux lines move with the velocity of light of approximately 186,300 miles or 300,000,000 meters per second, the distance between two successive maxima of electric strain directed in the same direction, or as usually expressed,

$$\text{Wave length (in meters)} = \frac{300{,}000{,}000}{\text{Frequency (in cycles per second)}} \quad (1)$$

$$\text{or Frequency (in cycles per second)} = \frac{300{,}000{,}000}{\text{Wave length (in meters)}} \quad (2)$$

From the formula it is apparent that the shorter the wave length the higher is the frequency.

*A unit of length in the metric system: It represents approx. a ten-millionth part of a quadrant of the earth's meridian measured from the equator to the pole through Paris; one hundred centimeters or 39.37 inches.

For example, if the wave length be one meter (which is not at present a practical wave length) the corresponding frequency is 300,000,000 cycles, 300,000 kilo-cycles (*k.c.*) or 300 mega-cycles per second.

In general usage, however, "per second" is usually omitted, it being generally understood that so many kilocycles (*k.c.*) or so many megacycles always include the prefix per second.

Example.—*What are the frequencies for wave lengths of* 5, 25 *and* 100 *meters?*

Solution.—Substituting 5 in formula (2)

$$\text{Frequency} = \frac{300,000,000}{5} = 60,000,000 \text{ cycles}$$

60,000 kilocycles or 60 megacycles.

Similarly substituting 25 and 100 in formula (2), 12 and 3 megacycles respectively are obtained.

In order to facilitate the transformation of wave length in meters to frequency in kilocycles or vice versa, a table supplied by the courtesy of the Bureau of Standards is found on pages 539 to 542.

This table is based on the factor 299,820 meaning that the value of the aforementioned speed of light instead of being 300,000 kilometers per second is more closely 299,820 kilometers per second.

The odd and even columns in this table are related to each other; that is the first column is related to the second, the third column to the fourth and so on. Fundamentally the numbers in the odd columns first, third, fifth, etc. refer to wave-lengths in meters. These columns are continuous numerically from 10 to 10,000 meters.

It is obvious from the previous discussion that the frequency corresponding to 10 meters is equivalent to a frequency of

29,982 kilocycles and that the frequency corresponding to 10,000 meters is equivalent to 29.982 kilocycles.

The table is also reversible. The designations for frequency in kilocycles (*kc*) and wave length (*m*) are placed at the top of each column.

From this table it is also possible to determine frequencies and wave-lengths above or below the values included. Thus the frequency corresponding to 5 meters may be determined by selecting the number 50 in the first column and reading it as 5. The answer is 59,960 kilocycles or 59.96 megacycles. In the same manner for 2.5 meters one would select the number 250 in the first column and read it as 2.5. The answer in this case is 119,900 *k.c.* or 119.9 megacycles.

In all cases it is merely a matter of shifting the decimal point to its correct place.

High Frequency Reception.—Due to inductance and capacitance effects between coils and wires, the requirements of receivers for short waves are different, from that of ordinary receivers. This is on account of the high frequencies associated with short waves.

In a short wave receiver all wires from grids and plates of tubes should be kept short and well separated. It has been found to be good practice to utilize buss bars in the wiring, as well as metal panels, well grounded—this in order to mitigate the ever present hand-capacity when tuning.

Most short wave set designers do not fully appreciate the fact that the entire success of their receivers depend upon how smoothly and easily they can control regenerative action of the detector tube.

Hence the control of regeneration in the detector stage is an important factor for successful short wave reception.

Relations of natural wavelength in meters (*m*) to frequency in kilocycles (*k.c.*). (Tables are reversible.)—(*continued*)

m.	*kc.*	*m.*	*kc.*	*m.*	*kc.*	*m.*	*kc.*	*m.*	*kc.*
10	29,982	510	587.9	1,010	296.9	1,510	198.6	2,010	149.2
20	14,991	520	576.6	1,020	293.9	1,520	197.2	2,020	148.4
30	9,994	530	565.7	1,030	291.1	1,530	196.0	2,030	147.7
40	7,496	540	555.2	1,040	288.3	1,540	194.7	2,040	147.0
50	5,996	550	545.1	1,050	285.5	1,550	193.4	2,050	146.3
60	4,997	560	535.4	1,060	282.8	1,560	192.2	2,060	145.5
70	4,283	570	526.0	1,070	280.2	1,570	191.0	2,070	144.8
80	3,748	580	516.9	1,080	277.6	1,580	189.8	2,080	144.1
90	3,331	590	508.2	1,090	275.1	1,590	188.6	2,090	143.5
100	2,998	600	499.7	1,100	272.6	1,600	187.4	2,100	142.8
110	2,726	610	491.5	1,110	270.1	1,610	186.2	2,110	142.1
120	2,499	620	483.6	1,120	267.7	1,620	185.1	2,120	141.4
130	2,306	630	475.9	1,130	265.3	1,630	183.9	2,130	140.8
140	2,142	640	468.5	1,140	263.0	1,640	182.8	2,140	140.1
150	1,999	650	461.3	1,150	260.7	1,650	181.7	2,150	139.5
160	1,874	660	454.3	1,160	258.5	1,660	180.6	2,160	138.8
170	1,764	670	447.5	1,170	256.3	1,670	179.5	2,170	138.1
180	1,666	680	440.9	1,180	254.1	1,680	178.5	2,180	137.5
190	1,578	690	434.5	1,190	252.0	1,690	177.4	2,190	136.9
200	1,499	700	428.3	1,200	249.9	1,700	176.4	2,200	136.3
210	1,428	710	422.3	1,210	247.8	1,710	175.3	2,210	135.7
220	1,363	720	416.4	1,220	245.8	1,720	174.3	2,220	135.1
230	1,304	730	410.7	1,230	243.8	1,730	173.3	2,230	134.4
240	1,249	740	405.2	1,240	241.8	1,740	172.3	2,240	133.8
250	1,199	750	399.8	1,250	239.9	1,750	171.3	2,250	133.3
260	1,153	760	394.5	1,260	238.0	1,760	170.4	2,260	132.7
270	1,110	770	389.4	1,270	236.1	1,770	169.4	2,270	132.1
280	1,071	780	384.4	1,280	234.2	1,780	168.4	2,280	131.5
290	1,034	790	379.5	1,290	232.4	1,790	167.5	2,290	130.9
300	999.4	800	374.8	1,300	230.6	1,800	166.6	2,300	130.4
310	967.2	810	370.2	1,310	228.9	1,810	165.6	2,310	129.8
320	936.9	820	365.6	1,320	227.1	1,820	164.7	2,320	129.2
330	908.6	830	361.2	1,330	225.4	1,830	163.8	2,330	128.7
340	881.8	840	356.9	1,340	223.7	1,840	162.9	2,340	128.1
350	856.6	850	352.7	1,350	222.1	1,850	162.1	2,350	127.6
360	832.8	860	348.6	1,360	220.4	1,860	161.2	2,360	127.0
370	810.3	870	344.6	1,370	218.8	1,870	160.3	2,370	126.5
380	789.0	880	340.7	1,380	217.3	1,880	159.5	2,380	126.0
390	768.8	890	336.9	1,390	215.7	1,890	158.6	2,390	125.4
400	749.6	900	333.1	1,400	214.2	1,900	157.8	2,400	124.9
410	731.3	910	329.5	1,410	212.6	1,910	157.0	2,410	124.4
420	713.9	920	325.9	1,420	211.1	1,920	156.2	2,420	123.9
430	697.3	930	322.4	1,430	209.7	1,930	155.3	2,430	123.4
440	681.4	940	319.0	1,440	208.2	1,940	154.5	2,440	122.9
450	666.3	950	315.6	1,450	206.8	1,950	153.8	2,450	122.4
460	651.8	960	312.3	1,460	205.4	1,960	153.0	2,460	121.9
470	637.9	970	309.1	1,470	204.0	1,970	152.2	2,470	121.4
480	624.6	980	303.9	1,480	202.6	1,980	151.4	2,480	120.9
490	611.9	990	302.8	1,490	201.2	1,990	150.7	2,490	120.4
500	599.6	1,000	299.8	1,500	199.9	2,000	149.9	2,500	119.9

Relations of natural wavelength in meters (*m*) to frequency in kilocycles (*k.c.*). (Tables are reversible.)—(*continued*)

m.	kc.	m.	kc.	m.	kc.	m.	kc.	m.	kc.
2,510	119.5	3,010	99.61	3,510	85.42	4,010	74.77	4,510	66.48
2,520	119.0	3,020	99.28	3,520	85.18	4,020	74.58	4,520	66.33
2,530	118.5	3,030	98.95	3,530	84.94	4,030	74.40	4,530	66.19
2,540	118.0	3,040	98.62	3,540	84.70	4,040	74.21	4,540	66.04
2,550	117.6	3,050	98.30	3,550	94.46	4,050	74.03	4,550	65.89
2,560	117.1	3,060	97.98	3,560	84.22	4,060	73.85	4,560	65.75
2,570	116.7	3,070	97.66	3,570	83.98	4,070	73.67	4,570	65.61
2,580	116.2	3,080	97.34	3,580	83.75	4,080	73.49	4,580	65.46
2,590	115.8	3,090	97.03	3,590	83.52	4,090	73.31	4,590	65.32
2,600	115.3	3,100	96.72	3,600	83.28	4,100	73.13	4,600	65.18
2,610	114.9	3,110	96.41	3,610	83.05	4,110	72.95	4,610	65.04
2,260	114.4	3,120	96.10	3,620	82.82	4,120	72.77	4,620	64.90
2,630	114.0	3,130	95.79	3,630	82.60	4,130	72.60	4,630	64.76
2,640	113.6	3,140	95.48	3,640	82.37	4,140	72.42	4,640	64.62
2,650	113.1	3,150	95.18	3,650	82.14	4,150	72.25	4,650	64.48
2,660	112.7	3,160	94.88	3,660	81.92	4,160	72.07	4,660	64.34
2,670	112.3	3,170	94.58	3,670	81.70	4,170	71.90	4,670	64.20
2,680	111.9	3,180	94.28	3,680	81.47	4,180	71.73	4,680	64.06
2,690	111.5	3,190	93.99	3,690	81.25	4,190	71.56	4,690	63.93
2,700	111.0	3,200	93.69	3,700	81.03	4,200	71.39	4,700	63.79
2,710	110.6	3,210	93.40	3,710	80.81	4,210	71.22	4,710	63.66
2,720	110.2	3,220	93.11	3,720	80.60	4,220	71.05	4,720	63.52
2,730	109.8	3,230	92.82	3,730	80.38	4,230	70.88	4,730	63.39
2,740	109.4	3,240	92.54	3,740	80.17	4,240	70.71	4,740	63.25
2,750	109.0	3,250	92.25	3,750	79.95	4,250	70.55	4,750	63.12
2,760	108.6	3,260	91.97	3,760	79.74	4,260	70.38	4,760	62.99
2,770	108.2	3,270	91.69	3,770	79.53	4,270	70.22	4,770	62.86
2,780	107.8	3,280	91.41	3,780	79.32	4,280	70.05	4,780	62.72
2,790	107.5	3,290	91.13	3,790	79.11	4,290	69.89	4,790	62.59
2,800	107.1	3,300	90.86	3,800	78.90	4,300	69.73	4,800	62.46
2,810	106.7	3,310	90.58	3,810	78.69	4,310	69.56	4,810	62.33
2,820	106.3	3,320	90.31	3,820	78.49	4,320	69.40	4,820	62.20
2,830	105.9	3,330	90.04	3,830	78.28	4,330	69.24	4,830	62.07
2,840	105.6	3,340	89.77	3,840	78.08	4,340	69.08	4,840	61.95
2,850	105.2	3,350	89.50	3,850	77.88	4,350	68.92	4,850	61.82
2,860	104.8	3,360	89.23	3,860	77.67	4,360	68.77	4,860	61.69
2,870	104.5	3,370	88.97	3,870	77.47	4,370	68.61	4,870	61.56
2,880	104.1	3,380	88.70	3,880	77.27	4,380	68.45	4,880	61.44
2,890	103.7	3,390	88.44	3,890	77.07	4,390	68.30	4,890	61.31
2,900	103.4	3,400	88.18	3,900	76.88	4,400	68.14	4,900	61.19
2,910	103.0	3,410	87.92	3,910	76.68	4,410	67.99	4,910	61.06
2,920	102.7	3,420	87.67	3,920	76.48	4,420	67.83	4,920	60.94
2,930	102.3	3,430	87.41	3,930	76.29	4,430	67.68	4,930	60.82
2,940	102.0	3,440	87.16	3,940	76.10	4,440	67.53	4,940	60.69
2,950	101.6	3,450	86.90	3,950	75.90	4,450	67.38	4,950	60.57
2,960	101.3	3,460	86.65	3,960	75.71	4,460	67.22	4,960	60.45
2,970	100.9	3,470	86.40	3,970	75.52	4,470	67.07	4,970	60.33
2,980	100.6	3,480	86.16	3,980	75.33	4,480	66.92	4,980	60.20
2,990	100.3	3,490	85.91	3,990	75.14	4,490	66.78	4,990	60.08
3,000	99.94	3,500	85.66	4,000	74.96	4,500	66.63	5,000	59.96

Relations of natural wavelength in meters (*m*) to frequency in kilocycles (*k.c.*). (Tables are reversible.)—(*continued*)

m.	*kc.*	*m.*	*kc.*	*m.*	*kc.*	*m.*	*kc.*	*m.*	*kc.*
5,010	59.84	5,510	54.41	6,010	49.89	6,510	46.06	7,010	42.77
5,020	59.73	5,520	54.32	6.020	49.80	6,520	45.98	7,020	42.71
5,030	59.61	5,530	54.22	6,030	49.72	6,530	45.91	7,030	42.65
5,040	59.49	5,540	54.12	6,050	49.64	6,540	45.84	7,040	42.59
5,050	59.37	5,550	54.02	6,050	49.56	6,550	45.77	7,050	42.53
5,060	59.25	5,560	53.92	6,060	49.48	6,560	45.70	7,060	42.47
5,070	59.13	5,570	53.83	6,070	49.39	6,570	45.63	7,070	42.41
5,080	59.02	5,580	53.73	6,080	49.31	6,580	45.57	7,080	42.35
5,090	58.90	5,590	53.64	6,090	49.23	6,590	45.50	7,090	42.29
5,100	58.79	5,600	53.54	6,100	49.15	6,600	45.43	7,100	42.23
5,110	58.67	5,610	53.44	6,110	49.07	6,610	45.36	7,110	42.17
5,120	58.56	5,620	53.35	6,120	48.99	6,620	45.29	7,120	42.11
5,130	58.44	5,630	53.25	6.130	48.91	6,630	45.22	7,130	42.05
5,140	58.33	5,640	53.16	6,140	48.83	6,640	45.15	7,140	41.99
5,150	58.22	5,650	53.07	6,150	48.75	6,650	45.09	7,150	41.93
5,160	58.10	5,660	52.97	6,160	48.67	6,660	45.02	7,160	41.87
5,170	57.99	5,670	52.88	6,170	48.59	6,670	44.95	7,170	41.82
5,180	57.88	5,680	52.79	6,180	48.51	6,680	44.88	7,180	41.76
5,190	57.77	5,690	52.69	6,190	48.44	6,690	44.82	7,190	41.70
5,200	57.66	5,700	52.60	6,200	48.36	6,700	44.75	7,200	41.64
5,210	57.55	5,710	52.51	6,210	48.28	6,710	44.68	7,210	41.58
5,220	57.44	5,720	52.42	6,220	48.20	6,720	44.62	7,220	41.53
5,230	57.33	5,730	52.32	6,230	48.13	6,730	44.55	7,230	41.47
5,240	57.22	5,740	52.23	6,240	48.05	6,740	44.48	7,240	41.41
5,250	57.11	5,750	52.14	6,250	47.97	6,750	44.42	7,250	41.35
5,260	57.00	5,760	52.05	6,260	47.89	6,760	44.35	7,260	41.30
5,270	56.89	5,770	51.96	6,270	47.82	6,770	44.29	7,270	41.24
5,280	56.78	5,780	51.87	6,280	47.74	6,780	44.22	7,280	41.18
5,290	56.68	5,790	51.78	6,290	47.67	6,790	44.16	7,290	41.13
5,300	56.57	5,800	51.69	6,300	47.59	6,800	44.09	7,300	41.07
5,310	56.46	5,810	51.60	6,310	47.52	6,810	44.03	7,310	41.02
5,320	56.36	5,820	51.52	6,320	47.44	6,820	43.96	7,320	40.96
5,330	56.25	5,830	51.43	6,330	47.36	6,830	43.90	7,330	40.90
5,340	56.15	5,840	51.34	6,340	47.29	6,840	43.83	7,340	40.85
5,350	56.04	5,850	51.25	6,350	47.22	6,850	43.77	7,350	40.79
5,360	55.94	5,860	51.16	6,360	47.14	6,860	43.71	7,360	40.74
5,370	55.83	5,870	51.08	6,370	47.07	6,870	43.64	7,370	40.68
5,380	55.73	5,880	50.99	6,380	46.99	6,880	43.58	7,380	40.63
5,390	55.63	5,890	50.90	6,390	46.92	6,890	43.52	7,390	40.57
5,400	55.52	5,900	50.82	6,400	46.85	6,900	43.45	7,400	40.52
5,410	55.42	5,910	50.73	6,410	46.77	6,910	43.39	7,410	40.46
5,420	55.32	5,920	50.65	6,420	46.70	6,920	43.33	7,420	40.41
5,430	55.22	5,930	50.56	6,430	46.63	6,930	43.26	7,430	40.35
5,440	55.11	5,940	50.47	6,440	46.56	6,940	43.20	7,440	40.30
5,450	55.01	5,950	50.39	6,450	46.48	6,950	43.14	7,450	40.24
5,460	54.91	5,960	50.31	6,460	46.41	6,960	43.08	7,460	40.19
5,470	54.81	5,970	50.22	6,470	46.34	6,970	43.02	7,470	40.14
5,480	54.71	5,980	50.14	6,480	46.27	6,980	42.95	7,480	40.08
5,490	54.61	5,990	50.05	6,490	46.20	6,990	42.89	7,490	40.03
5,500	54.51	6,000	49.97	6,500	46.13	7,000	42.83	7,500	39.98

Relations of natural wavelength in meters (*m*) to frequency in kilocycles (*k.c.*). (Tables are reversible.)

m.	kc.	m.	kc.	m.	kc.	m.	kc.	m.	kc.
7,510	39.92	8,010	37.43	8,510	35.23	9,010	33.28	9,510	31.53
7,520	39.87	8,020	37.38	8,520	35.19	9,020	33.24	9,520	31.49
7,530	39.82	8,030	37.34	8,530	35.15	9,030	33.20	9,530	31.46
7,540	39.76	8,040	37.29	8,540	35.11	9,040	33.17	9,540	31.43
7,550	39.71	8,050	37.24	8,550	35.07	9,050	33.13	9,550	31.39
7,560	39.66	8,060	37.20	8,560	35.03	9,060	33.09	9,560	31.36
7,570	39.61	8,070	37.15	8,570	34.98	9,070	33.06	9,570	31.33
7,580	39.55	8,080	37.11	8,580	34.94	9,080	33.02	9,580	31.30
7,590	39.50	8,090	37.06	8,590	34.90	9,090	32.98	9,590	31.26
7,600	39.45	8,100	37.01	8,600	34.86	9,100	32.95	9,600	31.23
7,610	39.40	8,110	36.97	8,610	34.82	9,110	32.91	9,610	31.20
7,620	39.35	8,120	36.92	8,620	34.78	9,120	32.88	9,620	31.17
7,630	39.29	8,130	36.88	8,630	34.74	9,130	32.84	9,630	31.13
7,640	39.24	8,140	36.83	8,640	34.70	9,140	32.80	9,640	31.10
7,650	39.19	8,150	36.79	8,650	34.66	9,150	32.77	9,650	31.07
7,660	39.14	8,160	36.74	8,660	34.62	9,160	32.73	9,660	31.04
7,670	39.09	8,170	36.70	8,670	34.58	9,170	32.70	9,670	31.01
7,680	39.04	8,180	36.65	8,680	34.54	9,180	32.66	9,680	30.97
7,690	38.99	8,190	36.61	8,690	34.50	9,190	32.62	9,690	30.94
7,700	38.94	8,200	36.56	8,700	34.46	9,200	32.59	9,700	30.91
7,710	38.89	8,210	36.52	8,710	34.42	9,210	32.55	9,710	30.88
7,720	38.84	8,220	36.47	8,720	34.38	9,220	32.52	9,720	30.85
7,730	38.79	8,230	36.43	8,730	34.34	9,230	32.48	9,730	30.81
7,740	38.74	8,240	36.39	8,740	34.30	9,240	32.45	9,740	30.78
7,750	38.69	8,250	36.34	8,750	34.27	9,250	32.41	9,750	30.75
7,760	38.64	8,260	36.30	8,760	34.23	9,260	32.38	9,760	30.72
7,770	38.59	8,270	36.25	8,770	34.19	9,270	32.34	9,770	30.69
7,780	38.54	8,280	36.21	8,780	34.15	9,280	32.31	9,780	30.66
7,790	38.49	8,290	36.17	8,790	34.11	9,290	32.27	9,790	30.63
7,800	38.44	8,300	36.12	8,800	34.07	9,300	32.24	9,800	30.59
7,810	38.39	8,310	36.08	8,810	34.03	9,310	32.20	9,810	30.56
7,820	38.34	8,320	36.04	8,820	33.99	9,320	32.17	9,820	30.53
7,830	38.29	8,330	35.99	8,830	33.95	9,330	32.14	9,830	30.50
7,840	38.24	8,340	35.95	8,840	33.92	9,340	32.10	9,840	30.47
7,850	38.19	8,350	35.91	8,850	33.88	9,350	32.07	9,850	30.44
7,860	38.14	8,360	35.86	8,860	33.84	9,360	32.03	9,860	30.41
7,870	38.10	8,370	35.82	8,870	33.80	9,370	32.00	9,870	30.38
7,880	38.05	8,380	35.78	8,880	33.76	9,380	31.96	9,880	30.35
7,890	38.00	8,390	35.74	8,890	33.73	9,390	31.93	9,890	30.32
7,900	37.95	8,400	35.69	8,900	33.69	9,400	31.90	9,900	30.28
7,910	37.90	8,410	35.65	8,910	33.65	9,410	31.86	9,910	30.25
7,920	37.86	8,420	35.61	8,920	33.61	9,420	31.83	9,920	30.22
7,930	37.81	8,430	35.57	8,930	33.57	9,430	31.79	9,930	30.19
7,940	37.76	8,440	35.52	8,940	33.54	9,440	31.76	9,940	30.16
7,950	37.71	8,450	35.48	8,950	33.50	9,450	31.73	9,950	30.13
7,960	37.67	8,460	35.44	8,960	33.46	9,460	31.69	9,960	30.10
7,970	37.62	8,470	35.40	8,970	33.42	9,470	31.66	9,970	30.07
7,980	37.57	8,480	35.36	8,980	33.39	9,480	31.63	9,980	30.04
7,990	37.52	8,490	35.31	8,990	33.35	9,490	31.59	9,990	30.01
8,000	37.48	8,500	35.27	9,000	33.31	9,500	31.56	10,000	29.98

Among the various methods in use, one is to use a variable condenser from one side of the tickler coil to ground as shown in fig. 2 and also have a variable resistor to vary the plate voltage applied to the plate of the detector tube.

In case when a transformer stage is used following the detector it is often found that the placing of a fixed condenser across the primary of the transformer or from the plate side of the transformer to the ground will greatly assist in stabilizing the circuit and facilitate regeneration control.

In case where two audio stages are employed, the common audio howl may be eliminated by the connection of a small 100,000 ohms resistor across the secondary of the first audio transformer.

When the short wave receiver is operated from *a.c.* current, the line power supply should be well filtered. Transformer, inductors and condensers should have a static shield.

As the short wave receivers are very sensitive in tuning, vernier dials should be employed.

Types of Short Wave Receivers.—Generally short wave receivers are governed by the same construction principles as that associated with ordinary broadcast band receivers previously discussed.

Referring to figs. 1 to 4, Chapter 14, a short wave receiver may consist of various arrangements from a simple single tube regenerative detector circuit to an elaborate super-infra regenerative type.

Short Wave Tuning.—One of the first things to be experienced by the short wave beginner, is the picking up of broadcast stations which cannot be located on available charts showing channel assignments.

What actually occurs is that the harmonics of stations operating in the regular broadcast band is received. Each harmonic has a definite wave, just as much so as the broadcast stations' fundamental carrier wave. A harmonic must have exactly twice, three times, five times, nine times, etc., the frequency of the fundamental (corresponding respectively to 1/2, 1/3, 1/5, 1/9 and so on) wave length. Many of these harmonics can be heard on any short wave receiver.

When one of them is picked up and the station identified, it is only a matter of division to determine the exact wave to which the receiver is tuned. By checking a number of these harmonics, with the known short wave stations, it is a simple matter to draw up a calibration curve for each coil of any short wave set.

Simple Short-wave Receiver.—A simple single tube super-regenerative receiver circuit is shown in fig. 1. To those familiar with the Armstrong super-regenerative arrangement, the diagram will more or less explain itself. It will be noted that one of the chief drawbacks with this circuit is the poor selectivity, which together with the enormous *r.f.* amplifying properties, make this disadvantage even more serious.

In order to overcome this short-coming, a form of pre-selector circuit is employed which is coupled to the grid circuit by a small capacity condenser; it is advantageous for this to be variable.

This may sound rather unreasonable for short-wave reception where all possible losses should be avoided, but in practice it makes little difference to a super-regenerative receiver, where the sensitivity is very high.

All of the tuned circuits and associated parts including the tube which is of the screen-grid type are completely screened—on top as well. This is very important if the selectivity gained by additional tuned circuits is to be realized, since a super-regenerative receiver will pick up on the coils and wiring to a surprising extent, even though screened all around, and an aerial often makes little or no difference to the rectified output.

In order to avoid extra coil changing, the aerial coil can be tapped to cover the required wave-length bands, while the grid coil can be interchangeable; or two of the common dual-range short-wave coils can be utilized. Efficiency of coils is not so very important. Coils wound on any old forms wil' give satisfactory results

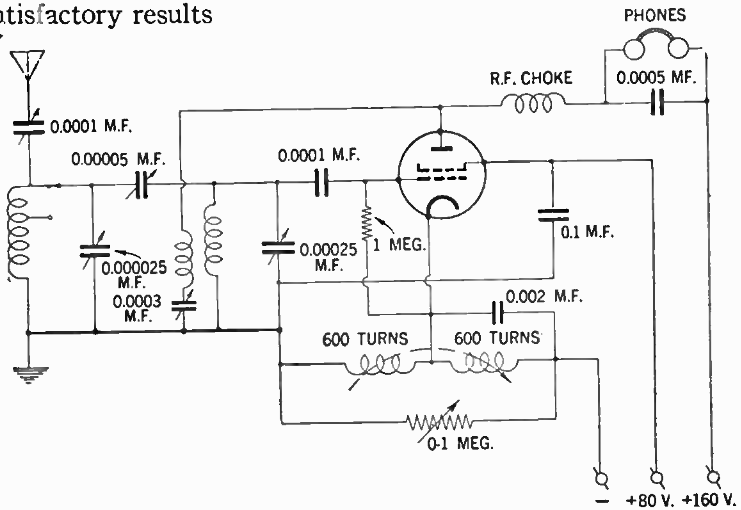


FIG. 1—Schematic diagram of a single tube super-regenerative short-wave receiver.

It must be clearly understood that a receiver of this type requires considerable practice and patience before the best results can be obtained.

The strength of the quencher oscillations (controlled by the variable resistance) has an important bearing on the performance of the receiver, and the best strength can only be found by trial, and may vary with different wave-lengths.

For those who want to get the utmost out of a single tube, there is nothing to compare with the super-regenerative circuit, and with improved selectivity, it bids fair to rival many of the smaller superheterodyne arrangements.

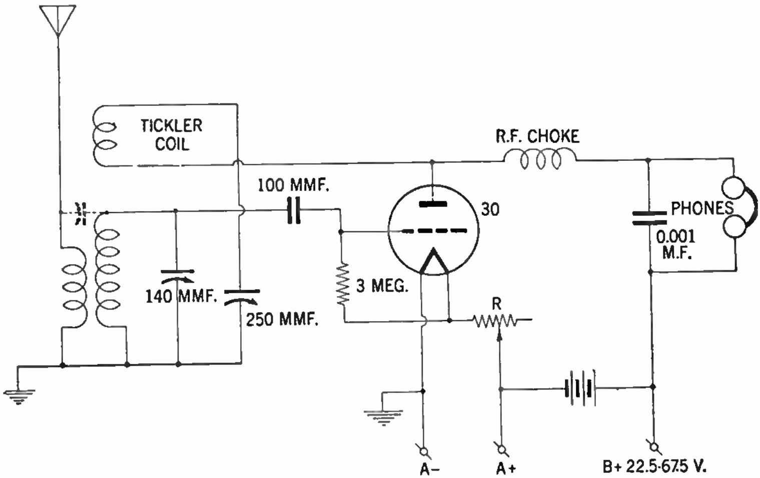


FIG. 2—Schematic diagram of a single tube regenerative detector short-wave receiver. For best results the choke (*r.f.c.*) should be carefully chosen for use at high frequencies, with its natural resonant period in the lower frequency and below 1,500 *k.c.*

Distance Ranges of Various Wave-lengths.—All radio wave transmission takes place by the propagation of a **Ground-Wave** along the ground, or a **Sky-Wave** reflected or refracted from the Kennelly-Heaviside layer, or by both means.

Radio waves are subject to absorption both in the ground and in the ionized upper atmosphere. Ground-wave absorption generally increases with the frequency and is reasonably constant with time over a given path at a given frequency; it varies for earth of different conductivities and dielectric constants.

Sky-wave absorption, however, is not constant with time frequency and path; it appears to be maximum in the broadcast band (550-1,500 kilocycles) decreasing with change in frequency in either direction.

During the day-time this absorption of the sky-wave is so great that there is practically no sky-wave, from frequencies, somewhat below and above the broadcast band, the specific limits however vary with the seasons. Therefore sky-wave propagation in the day time is only noticeable in the lower and higher frequency ranges. In the night, however, sky-wave propagation takes place on all waves except extremely high frequencies.

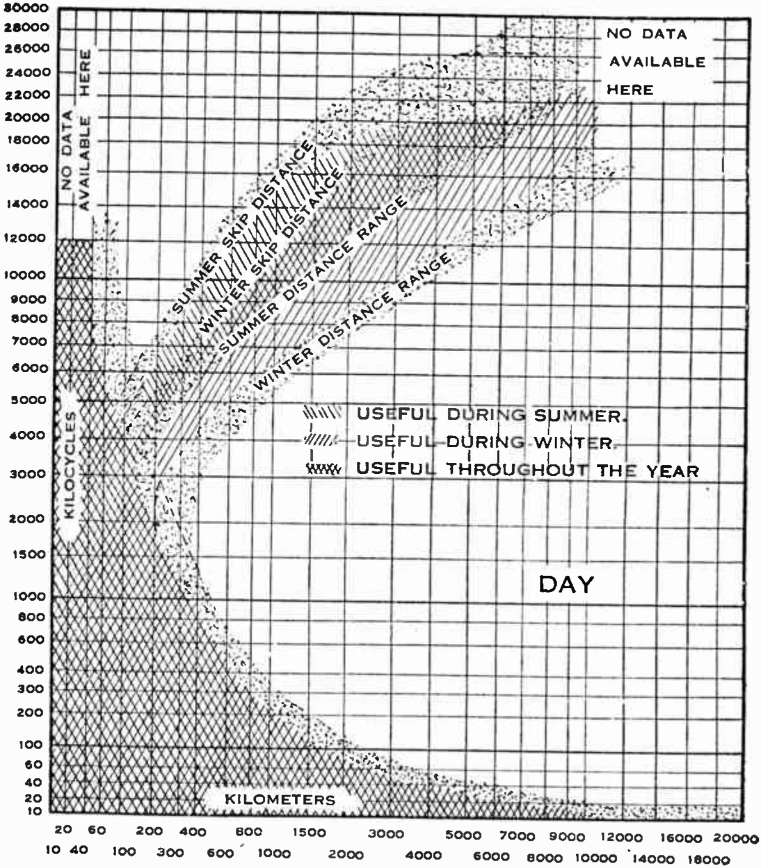
Other Influences Affecting Sky-Wave Propagation.—Sky-wave propagation is also materially influenced by condition and changes in ionization of the Kennelly-Heaviside layer.

Daily variation of daylight and darkness in the path of the waves (see charts, pages 548 and 549) and also factors such as latitude, season of the year, magnetic and solar disturbances have been found to influence this ionization.

Long-Distance Reception.—High-frequency reception at great distances is due entirely to the sky-wave. However, above a certain frequency which may be as low as 4,000 kilocycles as shown on chart, page 548, no appreciable portion of the sky-wave radiation is reflected back from the Kennelly-Heaviside layer in a certain zone surrounding the transmitter.

In the area bounded by the inner edge of this skipped zone, the receiver wave may be composed of both the ground-wave and the sky-wave, the sky-wave being appreciable on frequencies up to about 6,000 kilocycles in the summer and 12,000 kilocycles in the winter. The sky-wave intensity in this area is ordinarily much less at night than in the day. The outer boundary of the skipped zone is commonly referred to as the **Skip-**

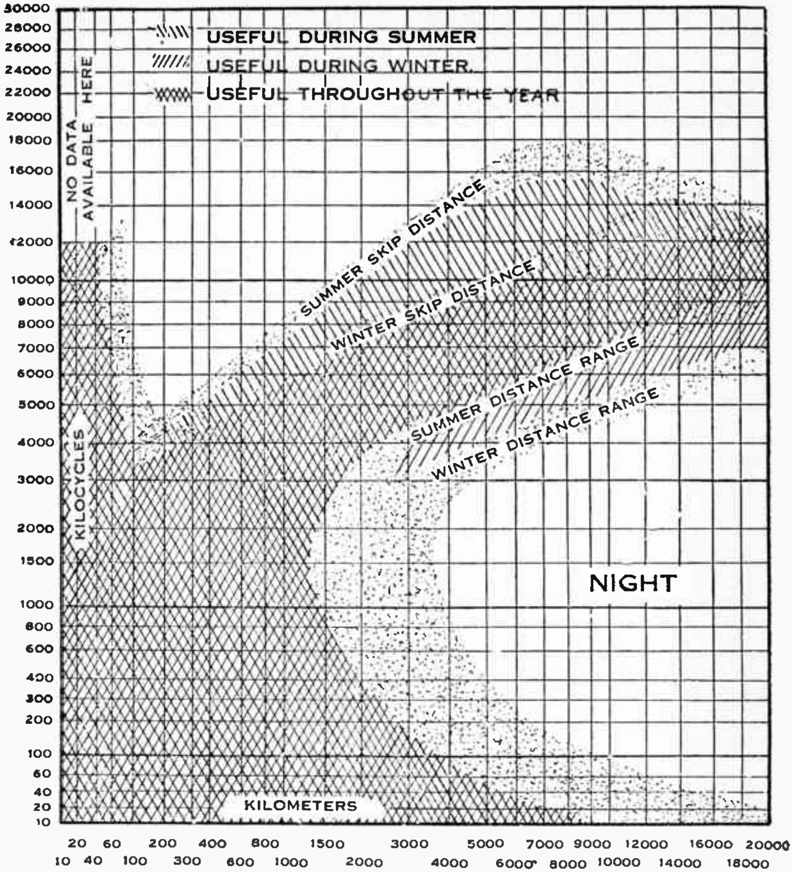
APPROXIMATE DISTANCE RANGES OF RADIO WAVES THROUGHOUT THE FREQUENCY RANGE



Width of shaded boundaries indicates variations of averages reported by different observers.

The scales of abscissas and ordinates are cubical (i.e., numbers shown are proportional to cube of distance along scale, or, distance along scale is proportional to cube root of numbers). This was chosen because it spaces the data satisfactorily. Obviously a linear scale would crowd the low values too much and a logarithmic scale would crowd the high values too much. The graphs shows the limits of distance over which practical communication is

APPROXIMATE DISTANCE RANGES OF RADIO WAVES THROUGHOUT THE FREQUENCY RANGE



possible. They are based on the lowest field intensity which permits practical reception in the presence of actual background noise. For the broadcasting frequencies this does not mean satisfactory program reception. The limiting field intensity is taken to be 10 micro-volts per meter for frequencies up to 2,000 kilocycles to about 1 micro-volt per meter at 20,000 kilocycles. When atmospherics or other sources of interference are great, for example in the tropics, much larger received field intensities are required and the distance ranges are less.

distance. This distance increases with the frequency and varies daily and seasonally. Beyond the skip-distance, the sky-wave radiation is received with useful intensity.

The graphs given on pages 548 and 549 showing the distances for good reception during the day and the night, for summer and winter season as found by test and recorded by the United States Bureau of Standards. The graphs assume the use of about 5 *K.W.* radiated power, and non-directional antennas.

For transmission over a given path, received intensity is proportional to the square root of the radiated power, but there is no simple relation between the range and either radiated power or received field intensity.

How High Frequency Reception Is Affected by Day, Night and Seasonal Changes.—Reception on higher frequencies (above 12 megacycles) is generally more satisfactory during the day than at night, on frequencies below 6 megacycles, however, the reverse is usually true.

Except in rare instances, frequencies above 12 megacycles can be heard only when the path between the transmitting station and the receiver lies entirely in daylight. It has also been found that frequencies from 6.5 to 15 megacycles are received best when either the transmitter or receiver lies in darkness, but not both.

The time of the day must also be taken into consideration in high frequency reception. The handy chart shown on page 551 gives the corresponding time in all parts of the globe, and will be of valuable help in determining the time and whether it is day or night at the transmission point.

For example, when it is 8 P.M. in New York and 7 P.M. in Chicago, it is 9 A.M. in Melbourne; 1 A.M. the next day in London and 2 A.M. of the next day in most of Europe. During those hours, of course, the European broadcasting stations are

YESTERDAY — TODAY

Longitude	Place																									
EAST 180°	FIJI ISLANDS	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
165°	NEW ZEALAND (Standard Time Ad'd Half Hr)	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
150°	EASTERN AUSTRALIA	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
135°	JAPAN	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2
120°	CHINA, WESTERN AUSTRALIA, PHILIPPINE ISLANDS	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1
105°	SIAM, BATAVIA, SINGAPORE	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
90°	CALCUTTA (India Standard Time Subtract Half Hr)	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
75°		10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
60°	MAURITIUS	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
45°	ARABIA, MADAGASCAR	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
30°	EUROPEAN (Eastern Time)	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
15°	EUROPEAN (Middle Time)	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
LONGITUDE 0°	EUROPEAN (Western Time)	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
15°	ICELAND, CANARY ISLANDS	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
30°	AZORES	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
45°	EASTERN BRAZIL	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2
60°	NEW FOUNDLAND	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1
75°	UNITED STATES (Eastern Standard Time)	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
90°	UNITED STATES (Central Standard Time)	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
WEST 105°	UNITED STATES (Mountain Standard Time)	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
120°	UNITED STATES (Pacific Standard Time)	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
135°		8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
150°	ALASKA, SOCIETY ISLANDS	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
165°	HAWAIIAN ISLANDS (Standard Time Subtract Half Hr)	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
180°	FIJI ISLANDS	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

TODAY — TOMORROW

CHART SHOWING CORRESPONDING TIME FOR ALL PARTS OF THE GLOBE

European (Eastern Time) = European part of Russia, Finland, Egypt, South Africa.

European (Middle Time) = Norway, Sweden, Germany, Poland, Czecho-slovakia, Austria, Italy, Switzerland.

European (Western Time) = England, France, Holland, Belgium, Spain.

The above chart shows the character of the intervening zones (day or night) to be bridged between the points of transmission and reception, as well as the corresponding time difference between the point of reception and any other part of the World.

***Example on How to Use Chart.*—Assume the radio amateur lives in Chicago. At 5 P.M. he wants to know what time it is in Japan. Follow the 5 opposite central standard time and travel upward until intersection is made with the line "reading" Japan which is 8. Which means 8 o'clock A.M. the next day. The change of date naturally is due to the crossing of the international date line. The black bands on the chart indicates approximately dark hours of the day.**

seldom operating. Hence on the American continents, tuning for stations in Europe must be done during the afternoon or early evening. Australian stations, however, will be received in the early morning.

In addition, the season of the year also affects reception. Better reception on the higher frequencies may generally be excepted during the summer months and better reception at 6 megacycles and above during the winter months.

Although reception on *higher frequencies* generally is very little affected by atmospheric or static, and good results may be had in mid-summer even during a thunder storm. The same, however, is not true of so-called man-made static, such as trolleys, dial telephones, motors, electric fans, automobiles, airplanes, electrical appliances, flashing signs, oil burners, etc., which create far more interference on high frequencies than they do on ordinary broadcast frequencies.

As an example of the interpretation of the table on effect of time, day and season of the year on high frequency transmission assume that you are in New York and that the time is 1 P.M. mid-summer, and that you tune in a station in Chicago on approximately 15 megacycles (20 meters wave length). Assume now, that this station transmits a continuous program and that your receiver is left tuned in. Several hours later the signal will fluctuate excessively and finally will fade out entirely or become unintelligible. This can be accounted for by the fact that, at mid-summer, the "skip distance" is approximately 400 miles at noon and increases to 2,500 miles at midnight. Chicago is approximately 600 miles from New York and is one hour later in time; therefore, some few hours after noon, in Chicago, the "skip distance" will have so increased that reliable reception on 15 megacycles cannot be obtained in New York.

It is also well to note that in midwinter, the "skip distance" for 15 megacycles is approximately 900 miles at noon and becomes infinity at midnight—showing that reliable reception could not be effected at this frequency between Chicago and New York; therefore, if you, located in New York, became accustomed during the summer, to receiving a regular 15 megacycle program at noon from Chicago, then as winter came on, the period of time during which reliable communication could be effected, would decrease until at no time could a signal be heard. The reverse would be true the following spring.

Example.—*If 10 k.c. be taken as the necessary frequency "spread" of a broadcasting station, how many stations could be operated on wave lengths between—*

a. 100 *and* 600 *meters*

b. 3 *and* 8 *meters.*

Solution.—All that is needed here is to express the various specified wave-lengths as frequencies. The frequency corresponding to a wave-length of λ meters is given by $\frac{3\times10^8}{\lambda}$ cycles per second.

The first band of broadcasting stations will thus have frequencies between 3,000 and 500 *k.c.* This range occupies a band of 2,500 *k.c.* so that it would accommodate $\frac{2{,}500}{10}$ or 250 stations.

The second group of stations will occupy that part of the frequency "spectrum" between 100,000 and 37,500 *k.c.*, i.e. a band of 62,500 *k.c.* it would thus provide for 6,250 stations. It is interesting to note that the second group could contain 25 times the number of stations in the first, i.e. it has provisions for exactly 6,000 more stations.

This illustrates in a very striking manner the possibilities offered by the short waves in overcoming the congested state of the ether in present day broadcasting. With growing technical advancement the vexed problem of quality and interference may ultimately be solved along these lines.

CHAPTER 28

Coil Calculations

Coil Design Calculations.—It has been shown on page 49 that any inductance in combination with a certain capacitance will start to resonate (be in resonance with) at a certain definite frequency, which frequency may readily be found by the expression—

$$f=\frac{159{,}000}{\sqrt{C\times L}} \quad (1)$$

from which

$$C=\frac{(159{,}000)^2}{f^2\times L} \quad (2)$$

and

$$L=\frac{(159{,}000)^2}{f^2\times C} \quad (3)$$

In a more convenient form for calculation purposes, formulas (2) and (3) may be written—

$$C=\frac{2.528\times 10^{10}}{f^2\times L} \quad (4)$$

and

$$L=\frac{2.528\times 10^{10}}{f^2\times C} \quad (5)$$

In the preceding formulas (f) denotes the frequency in cycles per second, (C) the capacitance in micro-farads and (L) the inductance in micro-henries.

The formula for the natural wave-length in meters at which resonance takes place

$$\lambda = 1{,}885\sqrt{C \times L} \quad \text{(6)}$$

in another form the above equation may be written

$$C = \frac{\lambda^2}{3.55 \times 10^6 \times L} \quad \text{(7)}$$

and

$$L = \frac{\lambda^2}{3.55 \times 10^6 \times C} \quad \text{(8)}$$

L and C again represents the inductance and capacity of the circuit in micro-henries and micro-farads respectively.

The formula for the inductance of the helical single layer coil is—

$$L = \frac{0.2 \times A^2 \times N^2}{3A + 9B + 10C} \quad \text{(9)}$$

Where L = Inductance in micro-henries

N = Total number of turns

A = Inside diameter of coil in inches

B = Length of winding in inches

C = Radial depth of coil in inches (which value may be omitted for single layer coils)

This formula will be of assistance and is preferred to the cut and try methods which are often found to be of little help when exact values of inductance are required.

Sometimes it may be most convenient to use an existing coil form in which case the diameter is given, the only trouble being then, to determine the number of turns of a certain wire or the length the wire would occupy.

Under those conditions a method which has been found to be most convenient for obtaining the value of N, is as follows:

1. Determine the size of wire to be used after a careful consideration of current to be carried and the wave bands to be covered.

2. Decide upon the number of turns per inch that will be used. (A consultation of any wire table will give the factors under 1 and 2.)

3. Now express (B) as ratio between the total number of turns (N) and the number of turns per inch (K) or

$$B = \frac{N}{K} \quad \text{(10)}$$

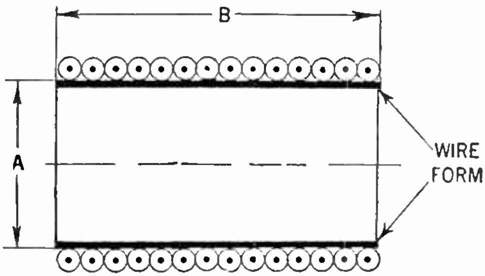


FIG. 1—Cross-section of single layer coil.

Example.—*What is resonant frequency of a circuit having an inductance of* 200,000 *micro-henries with a series condenser of* 20 *micro-farads?*

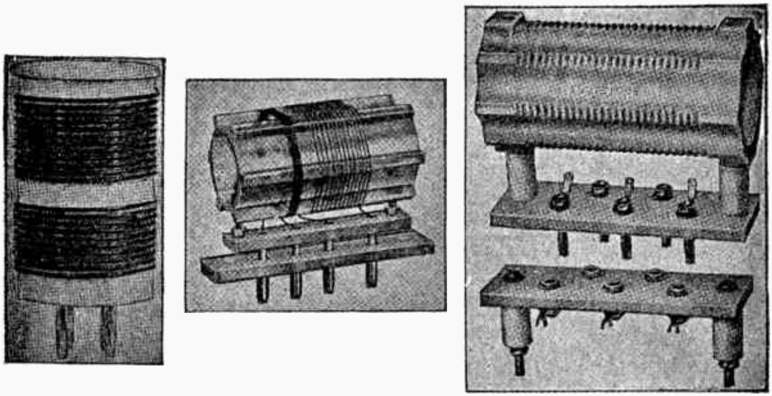
Solution.—This example provides a simple exercise in using formula (1). With the inductance and capacitance in micro-henries and micro-farads given, the only unknown is the frequency (f) at which the combination will become resonant, thus:

$$f = \frac{159{,}000}{\sqrt{20 \times 200{,}000}} = \frac{159}{2} \text{ or } 79.5 \text{ cycles per second.}$$

Example.—*What inductance is required in the secondary winding of a radio-frequency transformer, when it is to tune to a wave-length of* 600 *meters, and the variable condenser is set at its maximum capacitance which is* 0.00025 *micro-farads?*

Solution.—From equation (8) page 556 is obtained—

$$L = \frac{600^2}{3.55 \times 10^6 \times 0.00025} = 406 \text{ micro-henries}$$



FIGS. 2, 3 and 4—Showing arrangement of typical coils and coil forms.

Example.—*Assume that a coil is to be wound on a coil form of one inch diameter with a required inductance of* 240 *micro-henries. The coil is to be employed on a short-wave receiver for reception on* 160 *meters, and it is hence decided to use No.* 32 *enamel wire close wound. The wire table gives the number of turns per linear inch as* 120. *From this data it is required to find the total number of turns* (N).

Solution.—In the present example with reference to equation numbers (9) and (10) the only unknown term is the total number of turns (N) of the coil. This problem offers a simple application on the formula for coil design calculations, and it is advisable that before proceeding with our calculations, to put down all the known factors enumerated in the present example, thus:

Diameter of coil $(A) = 1$ inch

Number of turns per linear inch $(K) = 120$

Length of winding $(B) = \frac{N}{K} = \frac{N}{120}$

Inductance of coil in micro-henries $(L) = 240$

Applying the known factors to equations (9) and (10) we obtain—

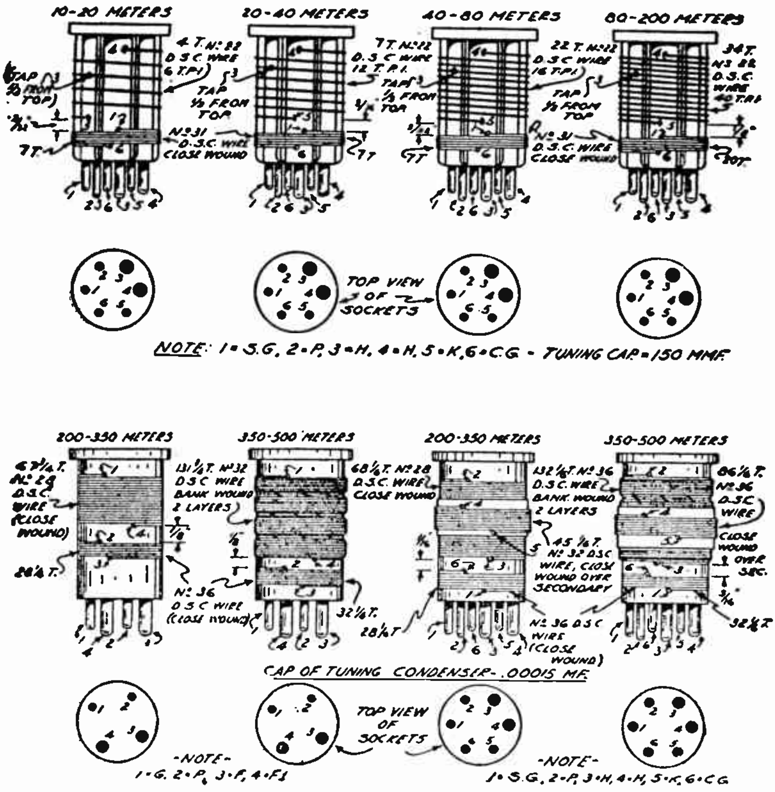
$$L = 240 = \frac{0.2 \times N^2}{3 + \frac{9N}{120}} = \frac{24N^2}{360 + 9N}$$

which after dividing both sides of the equation by 24 and rearrangement of terms becomes—

$$N^2 - 90N - 3600 = 0$$

or $\quad N = 45 \pm \sqrt{45^2 + 3600} = 45 \pm 75$

from which the positive root equals 120 turns.



FIGS. 5 to 12—Data for standard short and medium wavebands plug in coils, showing arrangement of windings.

CHAPTER 29

Frequency Modulation (F.M.)

Fundamental Principles.—The method of transmitting speech and music by radio is universally effected by varying the amplitude of the radio waves by the waves of sound which strike the microphone.

By means of another and until quite recently, neglected method, the frequency of radio waves is made to vary while the amplitude remains constant. This is known as *Frequency Modulation*, and is presently employed by numerous transmitting stations operating under the Armstrong patents.

Wave-Lengths Used.—Whereas in the regular broadcasting band wave-length of from 500 to 1,500 *k.c.* are employed, a frequency modulated wave takes a part in the frequency spectrum of from 42 to 200 *m.c.* At present regular assignments are from 42 to 50 *m.c.* (Mega-cycles).

Assuming a maximum frequency deviation for each F.M. station of 200 *k.c.* that is 100 *k.c.* on each side of the carrier, it is evident that one locality would accommodate 8/0.2 or 40 stations. This illustrates the advantage of frequency modulation in opening new and uncrowded channels for broadcasting.

Distances covered by F.M. transmitters.—Frequency modulated transmitting stations are designed to cover a number of square miles surrounding the station with a program signal of sufficient strength to cover that area. This service area is determined by the Federal Communication Commission (F.C.C.) and varies from 3,000 square miles up to 20,000 square miles.

Thus, the radial reception limits from the transmitting station are $\sqrt{\frac{3{,}000}{\pi}} = 31$ miles, and $\sqrt{\frac{20{,}000}{\pi}} = 80$ miles approximately.

Station Call Letters.—A new type of station call letters has been originated for frequency modulation which does the twofold job of telling where the station is on the dial and where the station is located geographically.

The first letter (see dial chart, fig. 1) indicates on which side of the Mississippi River the station is located; W for East and K for West. The two numbers give the station frequency. Since all F.M. stations are within the 42 to 49.9 megacycle

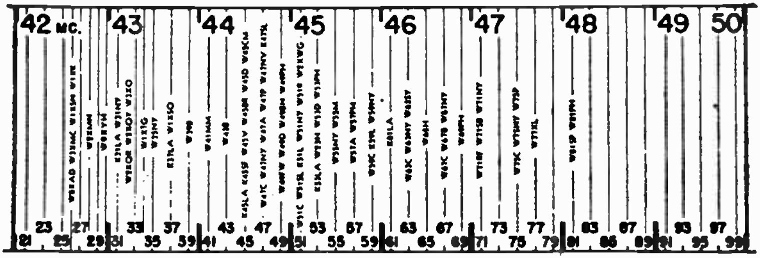


FIG. 1—Frequency modulation part of the radio spectrum with dial position of stations in operation and under construction. Due to possible changes in frequency assignment, the above chart may not be assumed correct, but serves to illustrate the present location of certain stations. For correct location of your F.M. station consult the Federal Communications Commission or licensed station officials.

band the "40" is common to all stations. Hence, only the unit and decimal part of the frequency are given in the call. Thus "67" means 46.7 megacycles and "99" means 49.9 megacycles. The last letter or letters represent the City where the station is located; "N.Y." stands for New York and "C" for Chicago, etc.

Comparison of the Two Systems.—In the conventional system of reception, most interfering noises are amplitude modulated and so receivers designed to receive amplitude modulated signals also receive radio interference.

Frequency modulated signals received on sets designed exclusively for such reception would give greater freedom from interference. This is the most vital point in the system.

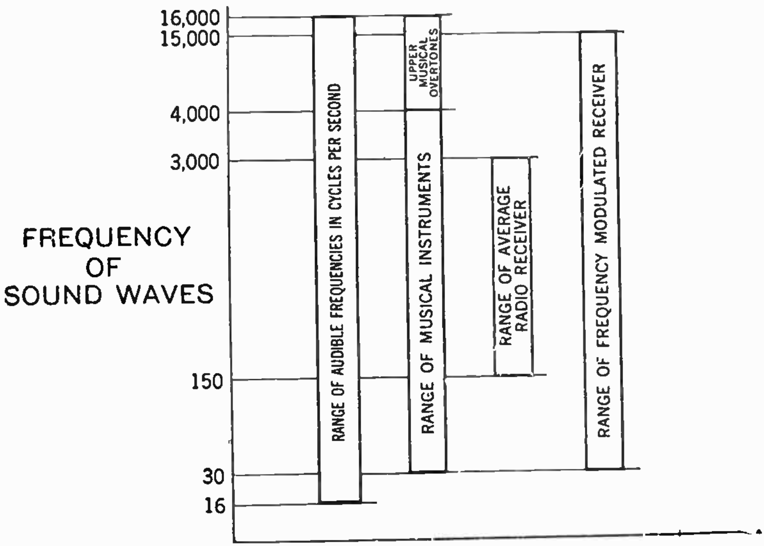
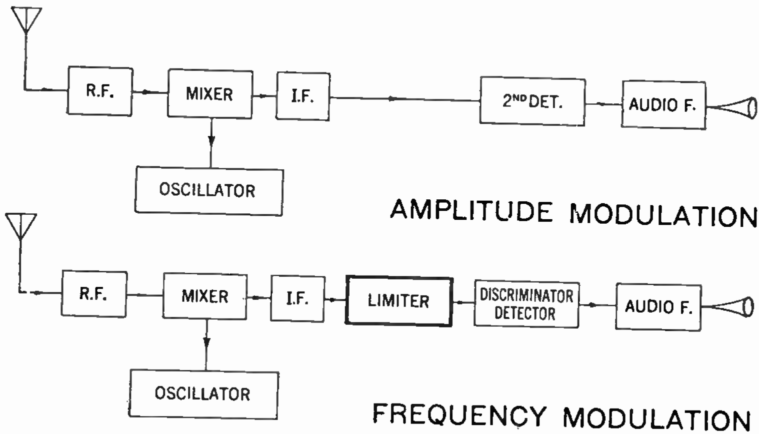


FIG. 2—Diagram illustrating comparative tone coverages of average amplitude modulated and frequency modulated receiver.

The advantages in reception when using frequency modulation are:

1. Freedom from static interference.
2. A greatly extended musical range. (See fig. 2.)

The main difference between the amplitude and frequency modulated receiver is apparent from block diagrams figs. 3 and 4.



FIGS. 3 and 4—Receiver block diagrams showing sequence of amplitude modulated and frequency modulated stages.

With reference to diagrams, both types may have a radio frequency stage, the primary function of which is to provide adequate selectivity and voltage gain.

A converter stage, consisting of a single tube functioning as mixer and oscillator, or two separate tubes performing these functions is common to both circuits.

The Intermediate Frequency Amplifier.—Though an intermediate frequency amplifier of one or more stages is also common to both, the intermediate frequency amplifier in a frequency modulated receiver differs from that of an amplitude modulated one by reason of its wide-band characteristics.

In an amplitude modulated receiver the intermediate frequency amplifier is designed to reject a signal more than 10 to 15 *k.c.* from that to which the amplifier is tuned, whereas the intermediate frequency amplifier in a frequency modulated receiver is designed to pass a signal without appreciable attenuation, as much as 100 *k.c.* on either side of the frequency to which the intermediate frequency transformers are aligned.

There are various methods employed to obtain this bandwidth. In some instances, the primary and secondary windings are over-coupled to broaden out the response curve.

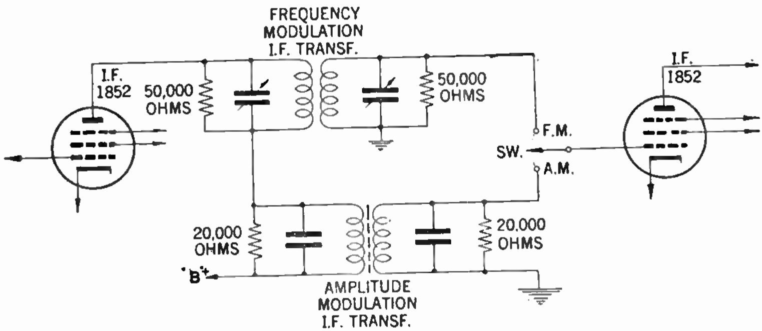


FIG. 5—Illustrates use of resistive loading to broaden response characteristics.

The great majority of frequency modulated receivers, however, employ shunt resistors, to load up either or both of the primary and secondary windings to obtain the required 150 to 200 *k.c.* band-width. In some early receivers as well as several frequency modulation adapters both primary and secondary of the intermediate frequency transformers are shunted by resistors as indicated by fig. 5.

The values of these shunt resistors varies with each receiver model, and depends upon transformer design and degree of loading required in each case to secure the band-spread. Resistor values from 10,000 to 50,000 ohms are most commonly used for this purpose.

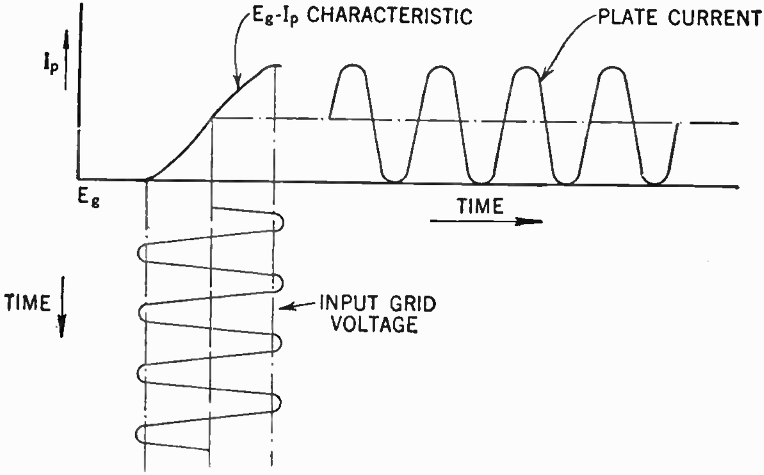


FIG. 6—Shows action of limiter in clipping modulation peaks beyond linear portion of characteristic.

The Limiter Stage.—Again referring to our block diagram fig. 4 a limiter stage is shown. This is essentially an intermediate frequency stage, and consists of one or two amplifier tubes so arranged as to deliver constant output regardless of wide variation in signal input.

The tubes employed as limiters are usually of the pentode type, having sharp cut-off characteristics, and operated at low plate and screen-voltages, so that plate current cut-off occurs with relatively small grid bias or signal input.

Normal signal input will swing the grid voltage considerably above and below the linear portion of the tubes characteristic curve.

Positive peaks beyond the range of the limiter tube will be clipped by grid-bias limiting, whereas negative signal peaks will be clipped due to plate current cut-off. In this manner, variations in signal delivered to the limiter which are greater than the operating limits of the tube are clipped and have no effect on plate current.

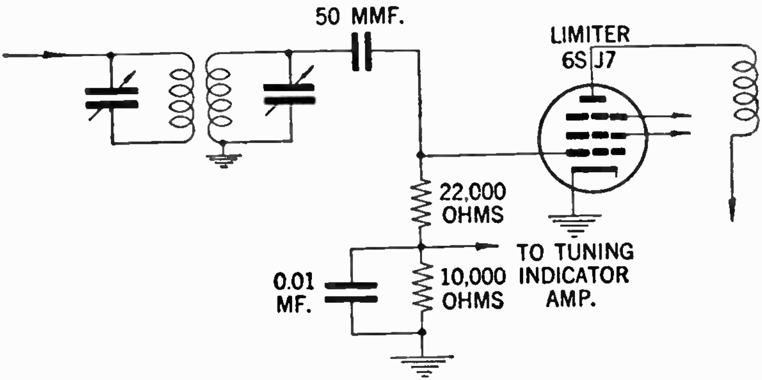


FIG. 7—Limiter circuit used in certain Stromberg Carlson frequency modulation receivers.

Since static and noise disturbances, primarily produce amplitude changes in the signal, as do tube noises, the clipping of the amplitude changes removes the disturbing effects but leaves the frequency modulated signal unaltered. This action is illustrated in fig. 6.

For complete noise elimination, it is essential that the signal voltage appearing at the limiter grid be sufficiently great to swing the grid bias to plate current cut-off and saturation points.

Limiter tubes are generally operated at zero bias or with small bias voltage. The limiter circuit shown in fig. 7 is representative of a great many frequency modulation receivers.

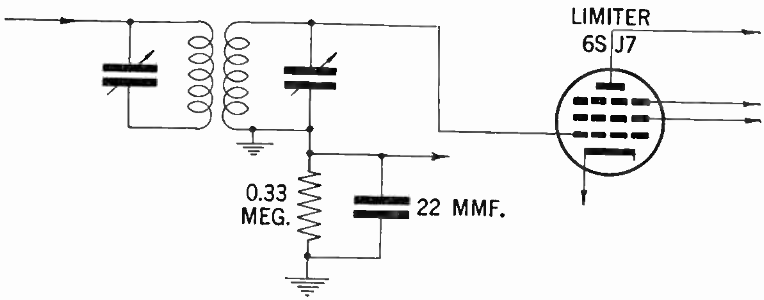


FIG. 8—Limiter circuit employed in certain General Electric frequency modulation receivers.

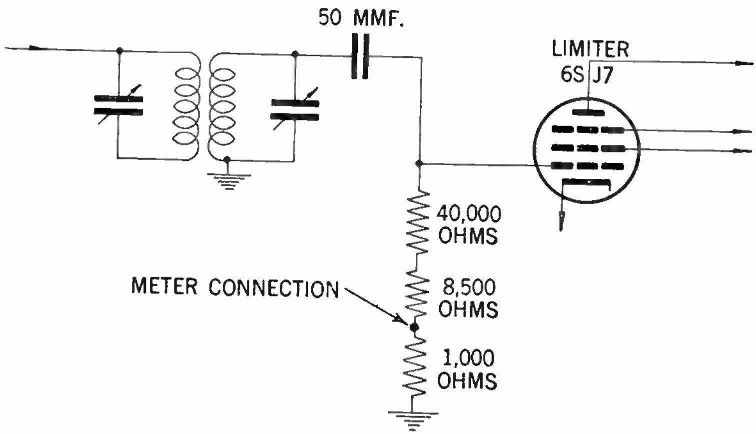


FIG. 9—Limiter circuit used in certain Pilot frequency modulation receivers. Terminal indicates connection for indicating instrument.

Another limiter circuit is shown in fig. 8. In this circuit the load resistance is connected in the secondary return, the tube being supplied with a small initial negative bias.

Circuit fig. 9 shows a low value resistor connected in series with the limiter load resistor so that an indicating meter may be conveniently connected.

Circuit fig. 10 shows how two tubes may be arranged in cascade to operate more efficiently as limiters.

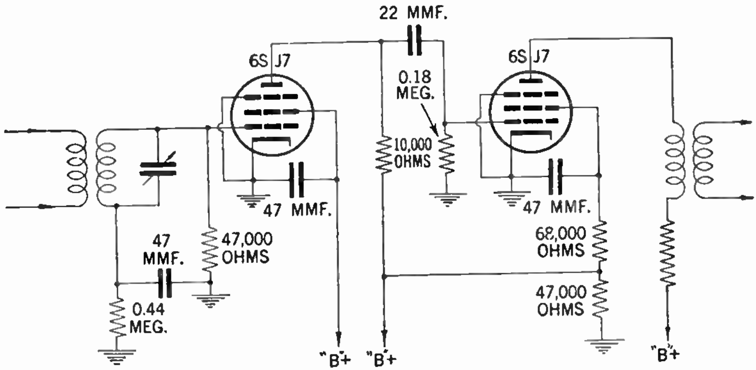


FIG. 10—Double limiter circuit employed in certain General Electric frequency modulation receivers to obtain more effective action.

The Discriminator.—The last important point of difference between the amplitude modulated and frequency modulated receiver concerns the second detector or demodulator.

In the frequency modulated receiver, a discriminator detector as shown in fig. 11 is employed. The discriminator consists of a push-pull diode detector in which opposing voltages developed across load resistors are equal and opposite so long as the carrier frequency rest at the intermediate frequency.

The resultant voltage across the two load resistors, from point A, to ground is zero and no audio voltage is developed.

When the signal impressed upon the discriminator transformer is frequency modulated, due to phase changes as a result of both magnetic and capacity coupling, the voltage drops across the load resistors will be unequal as the frequency varies above and below the intermediate frequency with modulation.

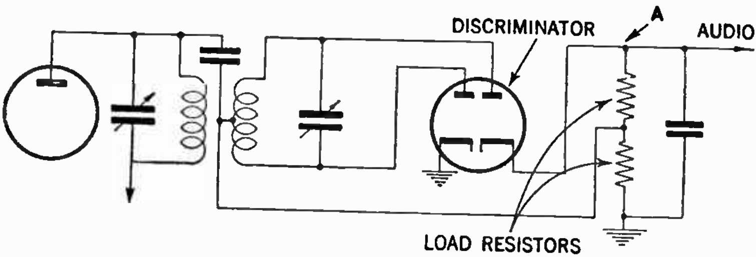


FIG. 11—Typical discriminator circuit. The demodulator of the frequency modulation receiver.

The resultant voltage measured across both diode load resistors will then be equal to the difference between the voltages developed across each, and will vary in polarity from point A, to ground as the modulation swings the frequency higher and lower than the resting or resonant frequency. The degree of modulation or frequency swing, determines the magnitude of the voltage and the number of times per second, or rate at which the intermediate frequency signal swings above and below the resonant frequency, produces the audio signal.

Need of Antenna for F.M. Receivers.—Frequency modulated receivers like any other type of receiver will perform better if equipped with a good outdoor antenna. Most F.M. receivers are now equipped with built-in antennas which perform quite satisfactorily when the receiver is well within the service range of the stations that are to be received.

A special F.M. dipole short wave antenna however, will do much to improve reception if correctly dimensioned and erected. Considering the length of the units we may recall that this depends upon the frequency of operation.

If it be desired to erect an antenna capable of tuning over the entire frequency modulation band, it is best to select a medium frequency and design the antenna for this. In this case an antenna of moderately low "Q" or one that is not critically resonant to any one frequency is recommended.

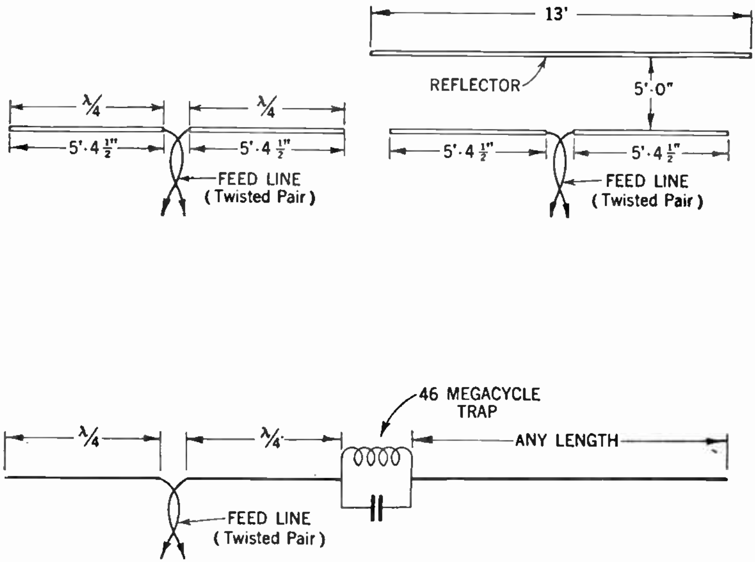
It has been found that within certain limits the larger the diameter the lower the "Q" of the antenna. A conductor for this purpose should have a diameter of not less than 3/8 ins. and be in the form of a tube rather than a solid conductor.

The thickness of the walls of the tubes are not particularly important—the main point is that the rods are of sufficient mechanical strength to support themselves properly, as well as to withstand eventual wind and ice or snow pressure in the particular location in which they are erected.

Tubing of diameters of from one to three ins. may be used although such large diameter is not necessary. Hard drawn tubing of copper, brass or aluminum are satisfactory.

Di-pole antennas are broadly directional on the side and have a sharp minimum reception point on the ends. Theoretically, the pick-up of antennas will be at maximum when the line of the di-poles are at right angles to the line between the receiver and the station.

Reflections and intervening objects occasionally change this and the di-pole should be rotated for maximum signal from the weakest station if this does not interfere with the reception of other F.M. stations.



FIGS. 12 to 14—Typical frequency modulation antennas with dimensions for di-pole types. A practical method in erection of antennas of this kind is shown on page 596. Di-pole antennas may be erected either horizontally or vertically. If the transmitting di-pole elements are mounted vertically, the transmissions are said to be vertically polarized. In this event best reception is obtained with a vertical receiving antenna which receives vertically polarized waves best. Likewise, a horizontal antenna producing horizontally polarized waves is best received by a horizontal antenna. Fig. 14 illustrates a combination frequency modulation-amplitude modulation antenna used when it is desired to combine the frequency modulation and regular broadcast band antenna. This can be accomplished in several ways. Some antenna manufacturers are selling units which consist of a long wire section connected to the open end of one di-pole through a wave trap resonated at 46 megacycles. This trap isolates the long antenna section from the ordinary frequency modulation di-pole for the 40 to 50 megacycle range, but permits the full length of the wire to operate on the broadcast band.

Another important consideration when installing an F.M. antenna is to erect the di-pole as high as possible. This is because of the quasi-optic nature of ultra-high frequencies (tendency to follow the line of sight between the transmitter and the receiver). The extra length of transmission line required and possible loss in the two conductor feed-line will be more than compensated for by the greater signal.

A table giving the approximate length of di-pole for various frequencies is given below.

F.M. Band Megacycles	Meters λ	Meters $\lambda/4$	Length of Di-pole (Single Rod)
40	7.500	1.875	6′– 1 13/16″
41	7.320	1.830	6′– 3/64″
42	7.140	1.780	5′–10 5/64″
43	7.000	1.750	5′– 8 7/8″
44	6.820	1.705	5′– 7 1/8″
45	6.667	1.667	5′– 5 3/4″
46	6.520	1.630	5′– 4″
47	6.400	1.600	5′– 2 3/4″
48	6.250	1.560	5′– 1 7/16″
49	6.120	1.530	5′– 1/4″
50	6.000	1.500	4′–11 1/16″

The method used in calculation of a typical antenna is best understood by considering the following:

Example.—*It is desired to calculate the required dimension for a quarter wave di-pole unit antenna capable of tuning to a frequency of* 43.5 *megacycles.*

Solution.—This problem simply involves a calculation of the wave length corresponding to a frequency of 43.5 megacycles. The relations between wave length in meters and frequency is written:

$$\lambda = \frac{3 \times 10^8}{F}$$

Where λ = wave length in meters

F = frequency in cycles per second

Remembering that 43.5 megacycles equals 43,500,000 cycles, a substitution of values gives:

$$\lambda = \frac{300{,}000{,}000}{43{,}500{,}000} \text{ or } 6.896 \text{ meters}$$

The length of each di-pole unit then is 6.896/4 = 1.7241 meters, which translated into inches becomes 1.7241 × 39.37 = 67.878 ins. or 5 ft. 7⅞ ins. approximately.

CHAPTER 30

Radio Testing

It is of the utmost importance that the serviceman, in order to intelligently cope with the various faults liable to develop in radio sets should be provided with the necessary testing instruments, of which there are a great variety available (some of which have very desirable characteristics).

The selection of instruments described in this chapter however, are by no means essential for intelligent servicing of radio sets.

Testing instruments to be of value to a radio serviceman must have the following features:

1. They should be easily portable.

2. They should be ruggedly constructed so that instruments will not be damaged or their calibration changed in transport.

3. The instruments must be designed to stand considerable overloads without damage, as in service work it is often difficult to estimate the exact magnitude of the measurements being taken.

The following instruments are required to properly service any radio set:

1. A volt-ohm milliammeter for measuring voltage, resistance and current.

2. Analyzer with the necessary selector switches and analyzer cable with adapters.

3. Output meter.

4. All-wave oscillator.

5. Capacity meter.

6. Inductance meter.

7. Tube tester.

This equipment may be supplemented by a cathode-ray oscillograph, a vacuum tube voltmeter, etc., and hence will provide the serviceman with equipment necessary to successfully cope with almost any servicing problem.

Analyzers and How to Use Them.—The fundamental purpose of an analyzer is to locate trouble in receivers without undue waste of time and without disturbance to the wiring of the radio set.

A modern analyzer consists of various resistances, capacitances, inductances and meters, which by means of switches are connected to the circuit whose values it is desired to verify, and mounted in a compact cabinet to facilitate transportation.

Preliminary Pointers.—However, before analyzing the radio set for trouble, it is well to consider possibilities of trouble in the installation itself. The aerial may be grounded or touching foreign parts; the aerial connection may be corroded; or the lead-in wire itself possibly broken inside its insulation. The lightning arrester may be leaky or short-circuited. A poor ground connection is also a frequent cause of trouble due to interference with reception from outside causes. If, by disconnecting the aerial and ground the noise disappears, the trouble is undoubtedly located outside the set.

If it be evident that the trouble is inside the radio set itself, a careful examination of the wiring connections and interior parts of the set is next in order. The condition of soldered joints should be examined to be sure that there is a good electrical connection.

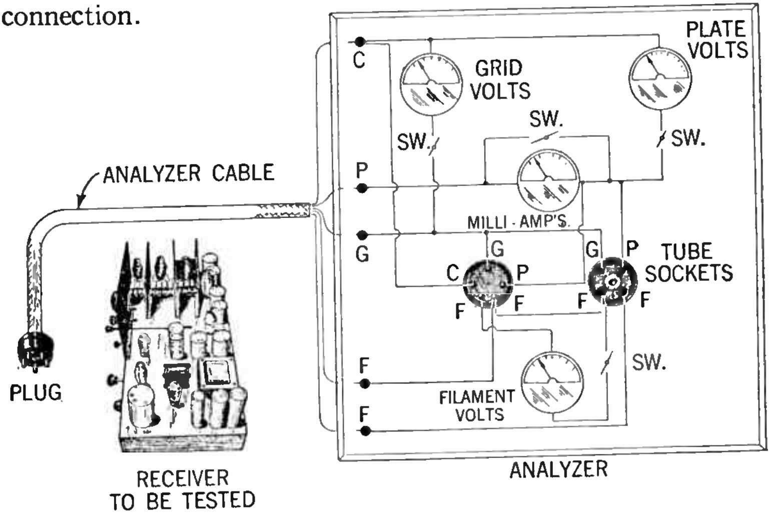


FIG. 1—Principal parts of a simple analyzer. The performance of the test is as follows: After a preliminary investigation of possible outside sources of trouble such as faulty or grounded aerials, open soldering joints, broken parts, etc., remove tube to be tested from set to proper socket in analyzer, and insert analyzer plug in place of the tube removed from set. Test the tubes one by one, starting with the antenna stage and proceed until the power amplification stage is reached. This test will indicate the location of troubles in the various circuits or in the tubes as well as in their power supply.

It should be noted that the insulation of the wiring be not cut or frayed where it passes through metal, around the edges of tube socket contacts, etc. The tube socket fingers should be clean and tight. The possibility of variable condenser plates touching should be checked. A visual inspection of this kind may quickly locate the cause of the trouble.

Electrical Tests.—The first electrical check on the set should be on the power supply to insure a normal supply of voltage to the various circuits in the radio set.

If the set be a battery operated type, check the condition of the various batteries by making use of the tip jacks on the analyzer and the test leads supplied with it. If the set be supplied with power from an alternating current house lighting circuit, measure the line voltage to be sure that it is correct for the set as indicated on the name plate of the radio set. The various batteries should give approximately their rated voltage readings with the radio set connected and turned on. If the batteries are low they should be re-charged or replaced.

Having checked the source of power to the radio set, the next step is to check the current and voltage supplied to each tube. A suggested method is to check the tubes in the order in which the signal passes through them. That is, start with the antenna stage and end with the power amplifier stage.

After making preliminary tests and a visual inspection and finding everything in good order, the electrical tests should be made. These electrical tests will show the location of troubles in the various circuits, in the tubes and in the power supply to them.

First, place the radio set as near as possible in good operating condition. If battery operated, all batteries should be properly connected. If power operated, connect to the proper power circuit. Turn on the set and make such adjustments as are normally necessary to bring in a good signal.

In general, all electrical tests should be made with the volume control in the maximum volume position, since this position generally gives the optimum distribution of currents and voltages through the various circuits in the radio set. A second set of readings with the volume control in the average working position is often helpful in locating trouble. This second set of readings is the current and voltage values in the various circuits under average conditions and should compare favorably with the first set. Radical differences should be checked up for a possible source of trouble.

In a battery operated set all batteries should be checked; any which are low in voltage should be replaced before proceeding with a more detailed analysis of the radio set.

Selection of Voltmeter Scales.—It is advisable when reading direct current voltages to set the selector switch on the range which will give the smallest deflection of the instrument which can be read satisfactorily. While this may seem to be contrary to general practice, the fact that many modern radio receivers have individual voltage divider networks for each tube, allows the current drawn by the voltmeter to throw the voltage applied to the tube somewhat in error.

It is obvious that a network supplying three milliamperes plate current to a tube will be upset to a considerable extent by connecting a voltmeter to it which requires one milliampere full scale. Consequently, deflections of less than half scale, as would be obtained on a higher range, will introduce less error than deflections of approximately full scale on a lower range, since the latter require considerably more current from the voltage divider network. When a difference in voltage indicated on the instrument scale exists as the range selection is changed, the indication read on the highest full scale voltage should be taken as the more accurate.

Selection of Current Scales.—In reading current always take the reading on the range which will give the largest possible deflection. By doing this the greatest possible accuracy will result.

Testing a Triode.—For a complete analysis of a triode for example, it is necessary to measure the following values:

1. Plate voltage
2. Plate current
3. Grid voltage
4. Grid current
5. Filament voltage.

In addition where cathode screen grid or pentode tubes are being tested, it is necessary to measure—

6. Cathode voltage
7. Screen grid voltage.
8. Screen grid current.

A complete outline of the above tests is given on pages 588 to 593

Test Oscillators and Their Use.—The fundamental use of a test oscillator is to replace the broadcast signal for test and adjustment of radio receivers. Of special importance to the servicemen are the following uses:

Alignment of *IF*, *RF* and oscillator padding circuits. Checking the condition of tubes. To determine the gain in any part of radio receivers. For testing *a.v.c.* circuits. For checking selectivity.

Alignment Procedure.—Unless the manufacturer of the receiver instructs otherwise the following sequence should be followed in the alignment of a radio set:

1. The various tuned circuits of the *IF* amplifier are first aligned properly at the intermediate frequency for which the amplifier was designed.

2. The oscillator tracking condenser should then be adjusted at about 1,400 *k.c.* so that it tracks properly at the high frequency end of the dial. Adjust the padding condenser at about 600 *k.c.* so that it tracks at the low frequency end of the dial.

3. Align the radio frequency, the pre-selector, amplifier or tuned circuit last.

If double spot or image suppression circuit be employed in the receiver, the manufacturer's instructions should be consulted for the proper procedure. Maximum transfer of energy in output is only obtained when every section is synchronized properly.

Use of Output Meters.—To determine the condition of tubes feed the signal from the oscillator to the aerial and ground connections of the receiver. Connect an output meter to the radio set; substitute new tubes for those in the radio set, one at a time and if the output meter indicates a greater value when each new tube is placed in the set, the original tube should be replaced.

To determine the gain in any part of the receiver, connect output meter as before and feed signal to aerial connection of radio set. Adjust oscillator to a high output and move the oscillator aerial connection to each succeeding *RF* or *IF* stage, noting the drop in the output voltage as shown on the output meter. Always use the proper frequency and proper scales for the output meter.

To check *a.v.c.* to determine when it is functioning properly, wide changes in the alignment with a large signal voltage will produce no appreciable change in output.

To check selectivity feed a signal of low value to aerial and ground connections, tune oscillator to perfect resonance, move oscillator signal dial until signal disappears. Note number of kilocycles between resonance and inaudibility.

Capacity Measurements.—On account of the fact that capacitors very frequently give rise to trouble in *a.c.* receivers, it is necessary to be able to measure and compare the value received by that as given in the manufacturer's circuit diagram. Hence it is important that the serviceman should understand the theory of capacity values and how they are derived.

The dial of most *a.c.* milliammeters are calibrated to read directly in microfarads (*M.F.*). The capacitive reactance of a condenser in ohms is given by the following formula:

$$X_c = \frac{1,000,000}{2 \times \pi \times f \times C_{m.f}} \text{ohms} \ldots\ldots\ldots\ldots\ldots (1)$$

When a 60 cycle current is used ($f=60$) and C is measured in microfarads, this formula then becomes:

$$C_{m.f} = \frac{2,650}{X_c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From this last equation it is possible to calibrate an *a.c.* milliammeter to read directly in capacity.

If any other frequency than 60 cycles is used, the result obtained in equation 1 or 2, must be multiplied by the fraction $\frac{F}{f}$, where (F) is 60 cycles and (f) is a cycle of the current being used. For example, if a 50 cycle current be used, then the values of equations 1 or 2 must be multiplied by $\frac{60}{50}$ or 1.2.

Before using any instruments designed for use on 60 cycles, on any other frequency, one must make sure that the equipment will function at the new frequency.

How to Make Capacity Measurements When the Capacitor Be Shunted by a Non-Inductive Resistor.—In *a.c.* receivers it is very frequently desired to obtain the values in microfarads when an ohmic resistor is shunted by a condenser as shown in fig. 2.

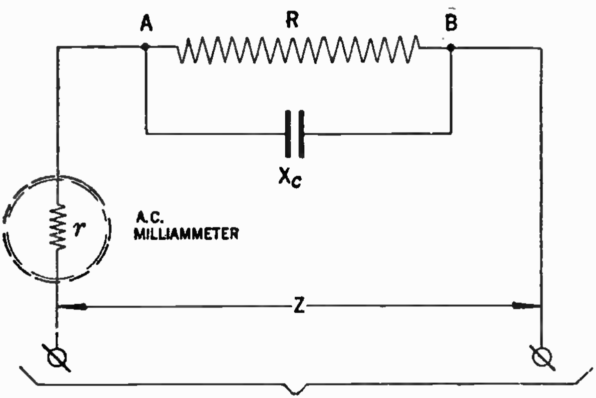


FIG. 2—Connection for measurement of capacity when capacitor is shunted by a non-inductive resistor.

The impedance Z, of the above circuit combination is obtained by the following formula:

$$Z=\sqrt{r^2+\frac{(R+2r)RX_c^2}{R^2+X_c^2}} \qquad \text{(3)}$$

in which r = Resistance of the *a.c.* milliammeter in ohms

R = Resistance of the shunt resistor in ohms

X_c = The reactance of the capacitor to be measured in ohms

Z = The impedance of the circuit combination, in ohms.

The X_c values as used in formula (3) are the effective resistance values of capacitors given by formula (1).

From the above mathematical relationship, curves may be plotted as shown in chart, fig. 3. In this chart the resistance value from 500 to 5,000 ohms and capacitors from 0.1 to 15 microfarads are covered. The chart is used as follows:

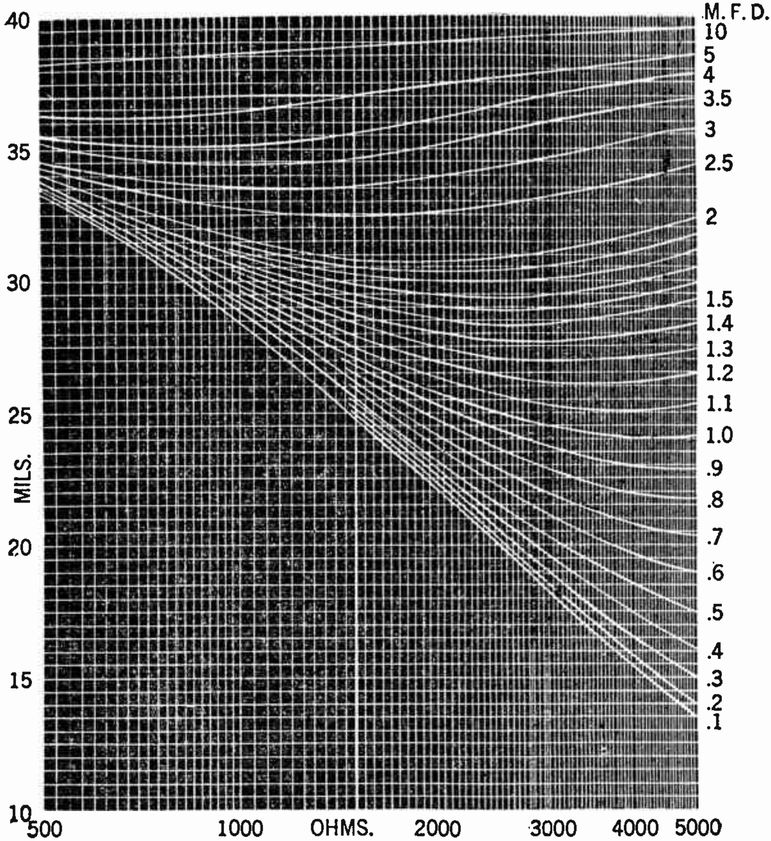


FIG. 3—Parallel resistance-capacity chart. Charts may conveniently be designed to suit individual requirements.

The value of r, is the resistance of the meter being used.

The value of R is obtained by an ohmmeter (*d.c.*). The *a.c.* milliammeter reading is obtained by placing it across the points A and B of fig. 2 as indicated.

The intersection of the line corresponding to the *a.c.* milliammeter readings and the resistance given by the ohmmeter will intersect on one of the curves and following this curve out, the value of the condenser in microfarad is obtained.

Example.—*If the* a.c. *milliammeter reads* 30 *M.A., and the resistance* (R) *is found by the ohmmeter to be* 2,500 *ohms, what is the value of the condenser?*

Solution.—Following the curve fig. 3 at the intersection of the 30 *M.A.* and the 2,500 ohms line shows the value of C to be 1.82 microfarads.

Inductive Measurements.—Inductance values may be obtained in a manner similar to that already described in capacity measurements. It should however be remembered that inductive reactance is vectorially positive whereas capacitive reactance is negative, and that the larger the value of the inductive reactance the lower will be the reading of the *a.c.* milliammeter. Also the larger the capacitive reactance the higher will be the reading of the *a.c.* milliammeter.

The formula for the inductive reactance (X_L) in ohms is:

$$X_L = 2\pi f L \text{ ohms} \qquad (4)$$

or if $f = 60$ cycles, then

$$L = \frac{X_L}{377} \text{ henries} \qquad (5)$$

When i = the *a.c.* current in amperes
e = Impressed *a.c.* voltage
R = Resistance of *a.c.* meter in ohms
X_L = Effective resistance of the inductor in ohms

then the formula for current is as follows:

$$i=\frac{e}{\sqrt{R^2+X_L^2}} \qquad (6)$$

The reading of the *a.c.* milliammeter may conveniently be referred to a chart computed from equation (4) from which the value of the inductance can be found similarly as previously shown.

If 50 cycles is used instead of 60 cycles the results should be multiplied by $\frac{60}{50}$ or 1.2.

Commercial Type Analyzers

Weston Model 665 Selective Analyzer.—The external view of this instrument is shown in fig. 4. and its internal connection diagram in fig. 5.

The instrument is principally a volt-ohm-milliammeter for both *a.c.* and *d.c.* service.

All voltage ranges are available at the pin jacks, and by means of socket selector units may be had through the plug. They are 0–1/2.5/5/10/25/100/250/500/1,000 volts, either *a.c.* or *d.c.* The individual ranges are selected by means of the large selector switch. A reading cannot be had till either the *d.c.* or *a.c.* push button at the bottom of the panel is pressed. These are locking types and should be returned to their original position after each test is completed.

All current ranges are available at the pin jacks and are also available for current measurements at the socket by means of the socket selector units. These ranges are 0–/2.5/5/10/25/50/-100/250/500 milli-amperes, *d.c.* only.

Resistance measurements may be had with test leads and the various ohmmeter pin jacks, as a point-to-point tester. Also by means of a socket selector unit, resistance measurements may be taken between any two socket prongs or a socket prong and ground.

A very useful feature in this instrument is that it may easily be converted into a complete analyzer by addition of the 666 socket selector shown in fig. 6, thus bringing the tube socket connections to the analyzer circuit.

With reference to the **Tube Base Chart** shown on page 591 the various measurements should be made as follows:

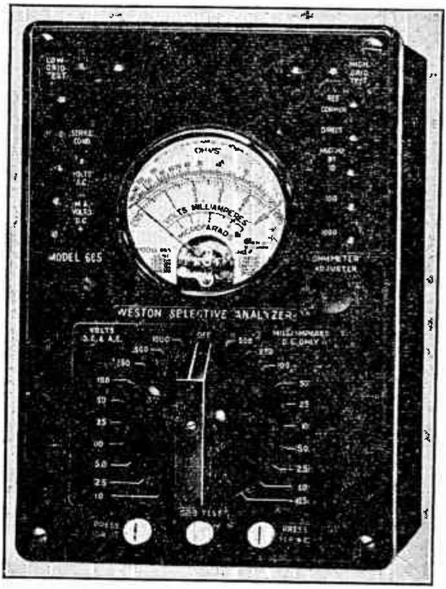


FIG. 4—Front view of Weston Model 665 selective analyzer.

Heater Voltage.—This is read between 1 and 4 on 4 prong tubes; 1 and 5 on 5 prong tubes; 1 and 6 on 6 prong tubes, and 1 and 7 on 7 prong tubes. However, it is advisable to check with the tube base chart because no fixed rule for the location of any terminal can be given.

Plate Voltage.—The plate is generally terminal No. 2 and for heater type tubes this voltage would be read between plate and cathode and for filament type between plate and negative filament. Since the plate and cathode terminal are not in the same locations for all type tubes, reference to the tube base chart is suggested.

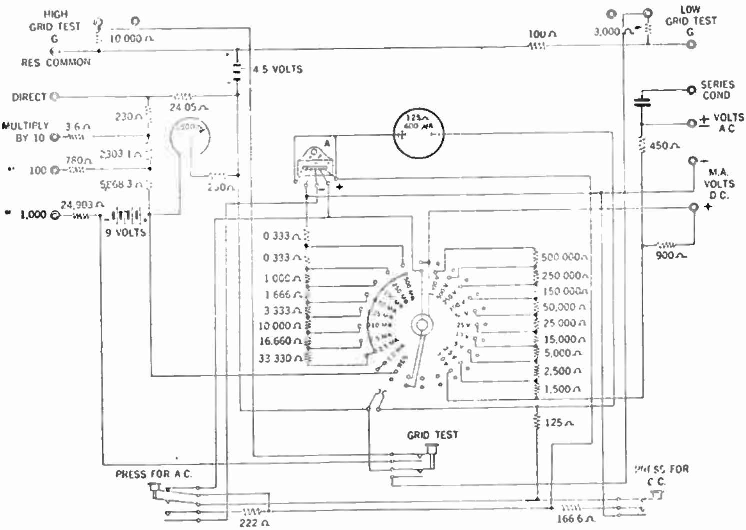


FIG. 5—Internal connection diagram of Weston Model 665 selective analyzer.

Grid Voltage.—There are a number of grids such as control, screen, suppressor, anode, etc. For heater type tubes the voltage is measured from the cathode to the desired grid and for filament type tubes from the negative filament to the desired grid. Reference to the tube base chart will give the correct location of the various grids for the tube in question.

Reference should be made to the service manual of the radio set being tested for the determination of the correct values of grid and plate voltage.

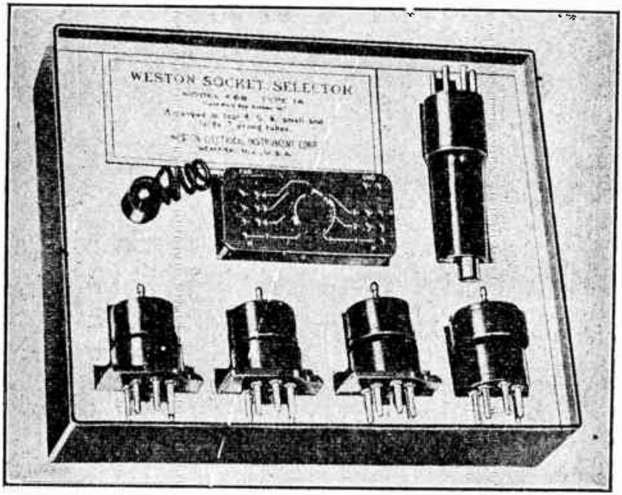


FIG. 6—Socket selector for use with Weston Model 665 analyzer.

Plate Current.—A pair of leads are plugged into the M.A. pin jacks on the panel; the other ends of these leads are placed in the two jacks opposite the plate terminal on the socket selector unit. The dial switch is turned to the desired milliampere range. This will give a plate current reading on the milliammeter. It is necessary to hold down the "Press for D.C." button.

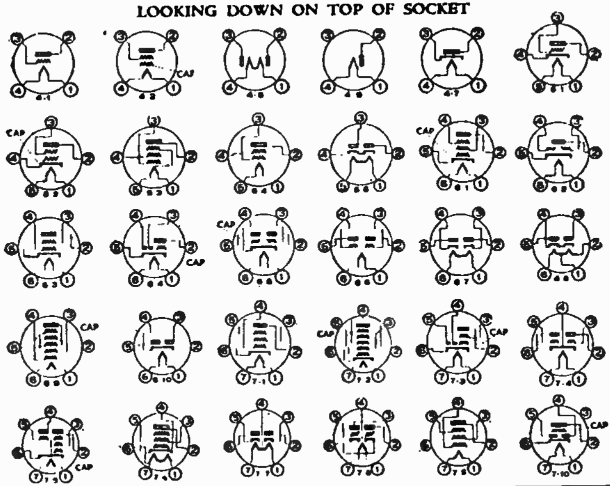
True total current in any lead is read in this way, since the inner jack of each pair functions as a closed circuit jack switch. When a pin tip is plugged into the inner of a pair of jacks, the main circuit is opened between the jacks. The total current,

TUBE BASE CHART

FOR USE WITH
THE WESTON METHOD OF SELECTIVE ANALYSIS

Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base
00A	4-1	27	5-1	47	5-3	71	4-1	98	5-5	12A5	7-6
01A	4-1	27HM	5-1	48	6-3	71A	4-1	X99	4-1	14Z3	4-7
01AA	4-1	29	6-2	49	5-4	71B	4-1	1A6	6-9	25Z3	4-7
1	4-7	30	4-1	50	4-1	75	6-4	2A3	4-1	25Z5	6-7
1V	4-7	31	4-1	51	5-2	76	5-1	2A3H	4-1	182B	4-1
G2	5-5	32	4-2	52	5-3	77	6-1	2A5	6-3	183	4-1
G4	5-5	33	5-3	53	7-4	78	6-1	2A6	6-4	213	4-5
KR1	4-7	34	4-2	55	6-4	79	6-5	2A7	7-2	216B	4-6
KR2	4-7	35	5-2	56	5-1	80	4-5	2B6	7-8	482A	4-1
KR5	5-3	36	5-2	57	6-1	80M	4-5	2B7	7-3	482B	4-1
10	4-1	36A	5-2	57AS	6-1	81	4-6	5Z3	4-5	483	4-1
12A	4-1	37	5-1	58	6-1	81M	4-6	6A4	5-3	484	5-1
WX12	4-1	37A	5-1	58AS	6-1	82	4-5	6A7	7-2	485	5-1
14	5-2	38	5-2	59	7-1	82V	4-5	6B7	7-3	585	4-1
15	5-2	38A	5-2	59B	7-9	83	4-5	6C6	6-1	586	4-1
17	5-1	39	5-2	61	5-2	83V	4-5	6C7	7-10	864	4-1
18	6-3	39A	5-2	61A	5-2	84	5-5	6D6	6-1	950	5-3
19	6-6	40	4-1	65	5-2	G84	4-6	6D7	7-2	951	4-2
20	4-1	41	6-3	65A	5-2	85	6-4	6E7	7-2	AD	4-7
22	4-2	42	6-3	67	5-1	89	6-1	6F7	7-5	AF	4-5
24	5-2	43	6-3	67A	5-1	90	6-2	6Y5	6-10	AG	4-5
24A	5-2	44	5-2	68	5-2	92	6-2	6Z3	4-7	LA	5-3
KR25	6-3	45	4-1	68A	5-2	95	6-3	6Z4	5-5	PZ	5-3
26	4-1	46	5-4	69	6-2	96	4-7	6Z5	6-8	PZH	6-3

LOOKING DOWN ON TOP OF SOCKET



therefore, must flow out through the measuring instrument and back into the other jack. Note that voltage measurements cannot be made in the inner jacks, since the circuit is opened when pin tips are placed in them.

Grid Current.—Grid and screen current measurements are made in the same manner as the plate current. All current ranges are available for this purpose. The push button marked "Press for D.C." must be held down for this test. These readings are obtained by placing one end of each of a pair of leads in the "M.A." pin jacks and the other ends in the two pin jacks opposite the terminal of the grid desired.

The plate current of the second plate of rectifier tubes is tested as above. It is advisable to consult the tube base chart for location of the terminals for the various elements.

Grid Tests.—Two grid tests are available, one with a low shift of 4.5 volts, the other a high shift of 13.5 volts for power tubes only. A separate set of pin jacks is provided on the panel for each shift.

A pair of short leads is plugged into the panel at the upper corner marked "Grid test" and the other ends plugged into the pin jacks opposite the control grid terminal desired on the selector unit. Be sure lead from "G" pin jack is inserted in the pin jack nearest the tube on selector unit.

Another pair of leads is plugged into the M.A. pin jacks on the panel, the other ends of these leads are placed in the two jacks opposite the plate terminal on the socket selector unit. The dial switch is turned to the desired M.A. range. This will give a plate current reading on the milliammeter. Pressing the "Grid Test" button (located in center of lower edge of panel) will give an increase in the plate current reading.

The grid test reading is an indication of the relative goodness of the tube, and is proportional to the mutual conductance. No values can be given for this reading because of the high plate circuit resistance in many radio sets.

Cathode Voltage.—Cathode voltage is measured with reference to the heater. In some sets the cathode is connected directly to the heater, in which case the cathode voltage reading will be zero.

In other sets the cathode is grounded through the grid bias resistor with heater connected to some positive potential, in which case the cathode will read negative with reference to the heater. In most alternating current radio sets the cathode is grounded through the grid bias resistor with the heater grounded, in which case the cathode will read positive with reference to the heater.

Output Test.—This test is made exactly like the measurement of *a.c.* voltage, except when *d.c.* is present in the output circuit, then the "Series Condenser" pin jack must be used. All voltage ranges are available for this test. It is necessary to hold down or lock in position the "Press for A.C." push button.

Weston Model 571 Output Meter.—The external view of this meter is shown in fig. 7 and its internal connection in fig. 8.

This instrument has a constant resistance of 4,000 ohms on each range, is usually used as a terminating impedance on sound line or receiver output circuits. It can be used, however, on bridging measurements on low impedance lines. It is also valuable as a multi-range *a.c.* volt-meter of wide adaptability.

The 5 voltage ranges are available at pin-jacks and are selected by means of a dial switch. It also has a self-contained condenser for blocking any *d.c.* components. This condenser is connected to a separate pin-jack.

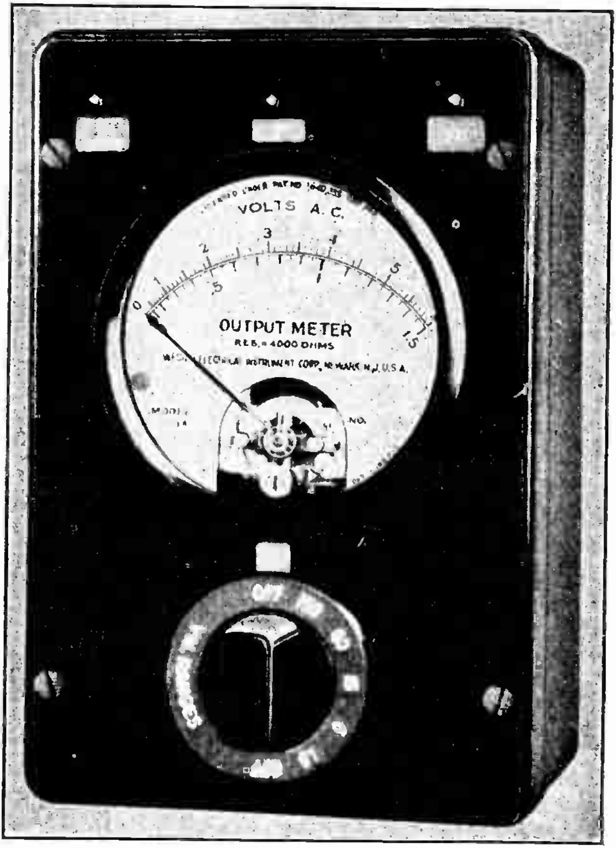


FIG. 7—Panel view of Weston Model 571 output meter.

The voltage ranges are: 0–1.5/6/15/60/150. Test leads and adapter for connection to the plate pin of any output vacuum tube are provided for the meter.

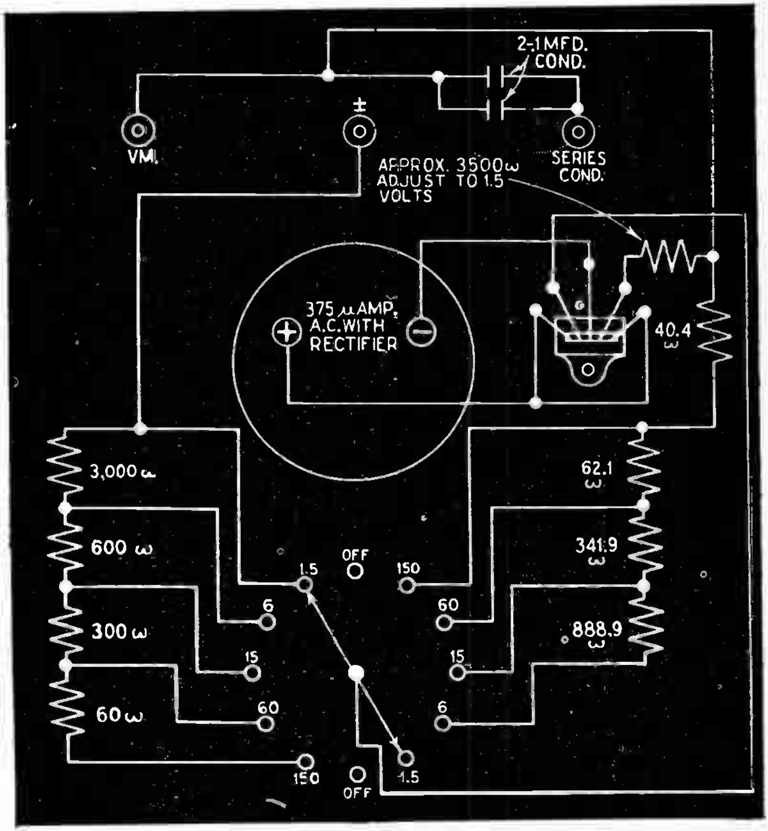


FIG. 8—Schematic wiring diagram of Weston Model 571 output meter.

Weston Model 763 Ohmmeter.—Front view and connection diagram of this instrument is shown in figs. 9 and 10 respectively.

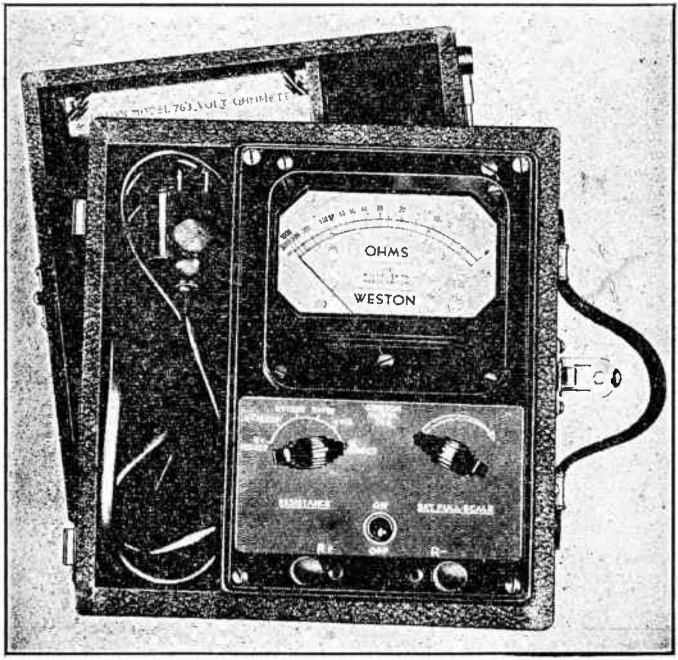


FIG. 9—Panel view of Weston Model 763 ohmmeter.

With this instrument resistance measurements of from 0.2 ohms to 300 megohms may be made with high accuracy on 6 ranges. It can also be used with good results on the top range as a modified megger in which 125 volts (maximum current 50 microamperes) is available for insulation tests.

The power consumption is small, as the instrument requires only 50 microamperes for full scale deflection.

Leakage on all types of condensers, even those having resistances of up to approximately 300 megohms can easily be measured. A filament type vacuum tube requiring a very short heating time is used as a rectifier, and the operating power is obtained from any 105-130 volts, 50-60 cycle *a.c.* source.

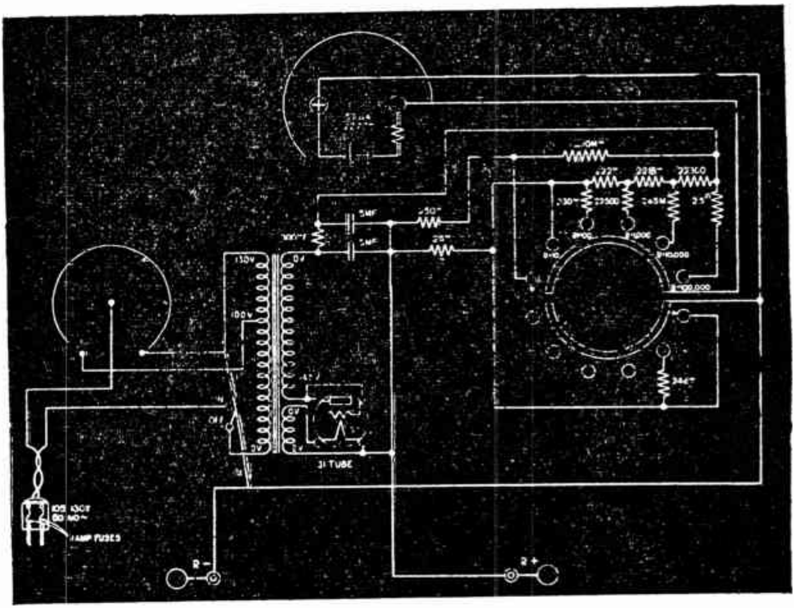


FIG. 10—Wiring diagram for internal connection of Weston Model 763 ohmmeter.

Weston Model 765 Analyzer.—A front view and internal connection diagram of this instrument is shown in figs. 11 and 12 respectively.

This instrument is claimed to be of very high sensitivity. For

FIG. 11—Front view of Weston Model 765 analyzer.

example the *d.c.* and *a.c.* sensitivity according to the manufacturer is 20,000 ohms per volt and 1,000 ohms per volt respectively. This minimum loading effect permits checking of sensitive relay circuits without interrupting operation and facilitates a great multiplicity of measurement which are practically impossible with instruments of lower sensitivity.

The over-all *a.c.* accuracy of the instrument is held within 3%, whereas for *d.c.* measurements the accuracy is within 2%.

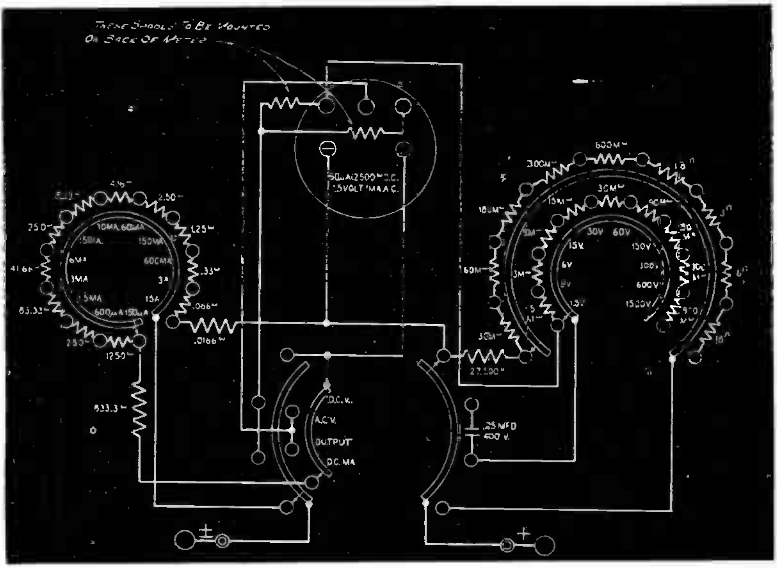


FIG. 12—Diagram showing internal connection of Weston Model 765 analyzer.

In addition a special rectifier circuit is incorporated designed for temperature compensation between 50 and 110 degrees F. limiting temperature errors to within 2%.

The ranges for *a.c.* and *d.c.* voltage measurements are as follows: 0–/1.5/3/6/15/30/60/150/300/600/1,500.

Ranges for *d.c.* current measurements are:
0–150 μ.*a.*/600 μ.*a.*/1.5/3/6/15/30/60/150/600 *m.a.*/3*a*/15*a*.

The decibel ranges provides measurements of power levels between—18 to +58 *db*.

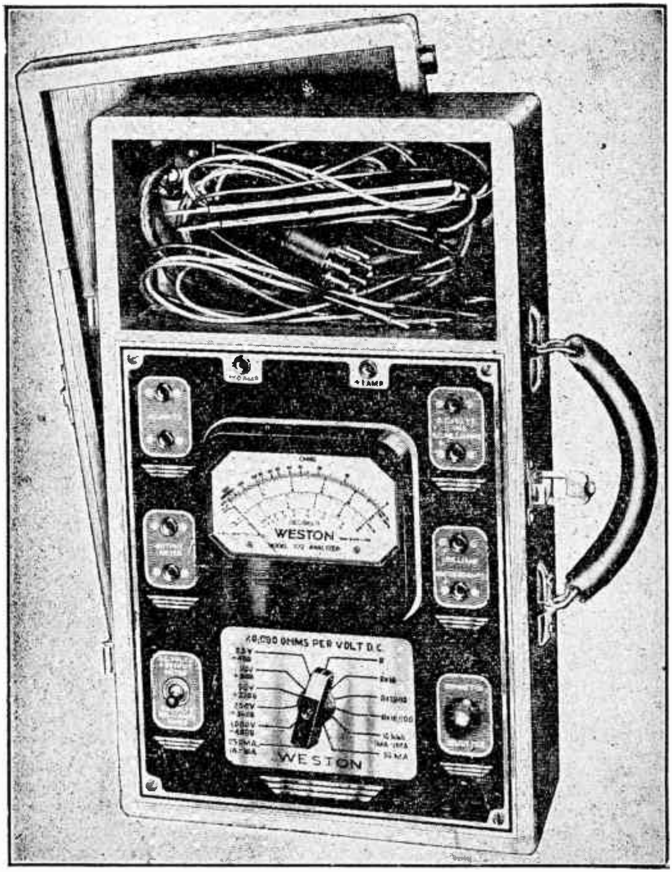


FIG. 13—Panel view of Weston Model 772 analyzer.

Weston Model 772 Analyzer.—This analyzer is designed to make the necessary tests on present day equipment such as commercial radio receivers, transmitters, television receivers,

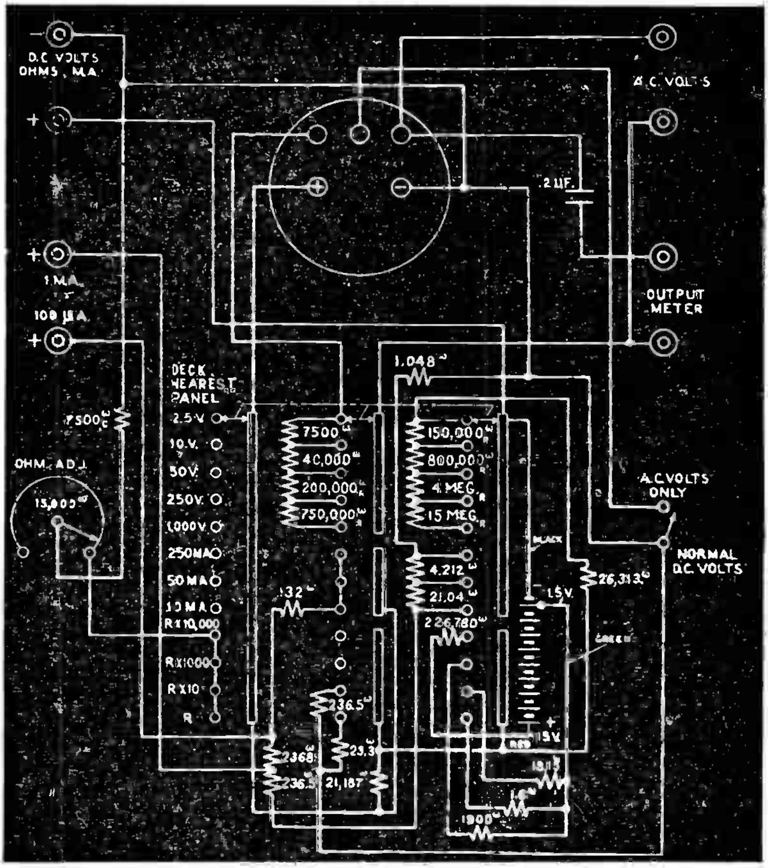


FIG. 14—Wiring diagram of Weston Model 772 analyzer.

public address systems, vacuum tube and cathode ray equipment, etc.

The instrument is illustrated in fig. 13 and its connection diagram in fig. 14.

It has a 20,000 ohms per volt sensitivity on five *d.c.* voltage ranges. *A.c.* readings are made on single arc scale.

The ranges for *d.c.* current measurements are 0–/0.1/10/50/-250 *m.a.*/1*a*/10*a*.

A.c. or *d.c.* voltage measurements have the following ranges: 0–2.5/10/50/250/1,000 *v.* Five decibel ranges provide power level measurement from—14 to +54 *db.*

Resistances are measured on the following scales 0–3,000/-30,000/3 Meg./30 Megohms.

The instrument is equipped with pin jacks for mounting model 666 socket selector unit.

Weston Model 773 Tube Checker.—This instrument is manufactured both for counter and movable service, as shown in figs. 15 and 17 with a common diagram of connections in fig. 16. It has eight sockets for the various types of tubes, a direct reading "Bad-Good" meter scale, two selector switches, voltage adjustment switch, in addition to position and test switches.

With this instrument a complete analysis of any tube may readily be obtained. Separate electrode switches for grid, plate, screen, suppressor, diode or cathode are provided for emission, short and leakage tests. This point to point testing feature will be recognized as extremely important whenever doubtful tubes are encountered.

A most frequent source of trouble in radio tubes are the defects in circuit continuity of the electrodes and although an over-all efficiency test may at times fail to disclose these defects, a point to point electrode check will nearly always disclose the trouble.

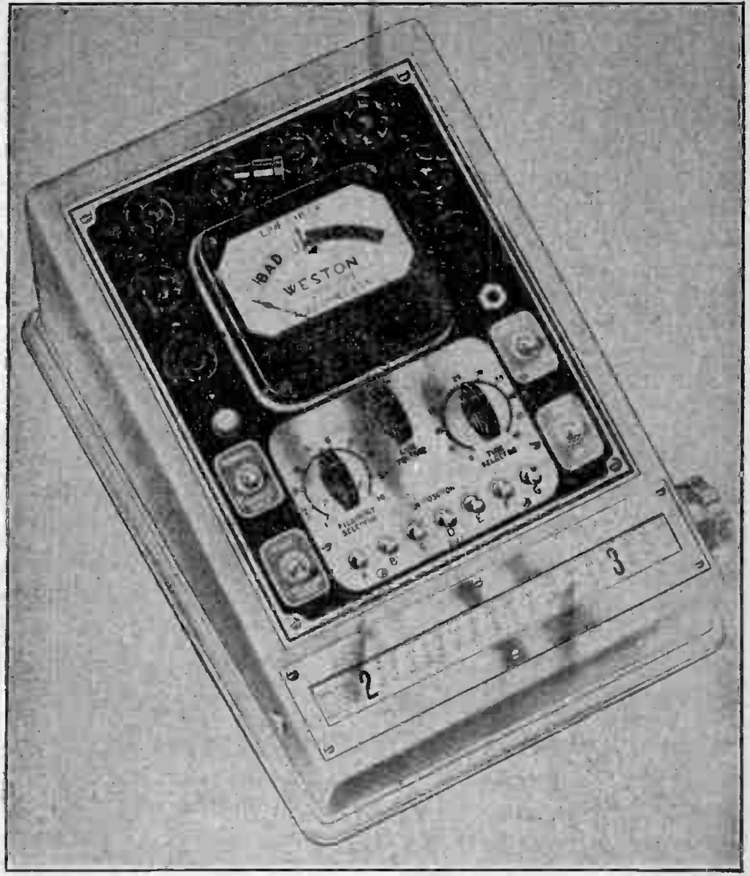


FIG. 15—Front view of counter type Weston Model 773 tube checker.

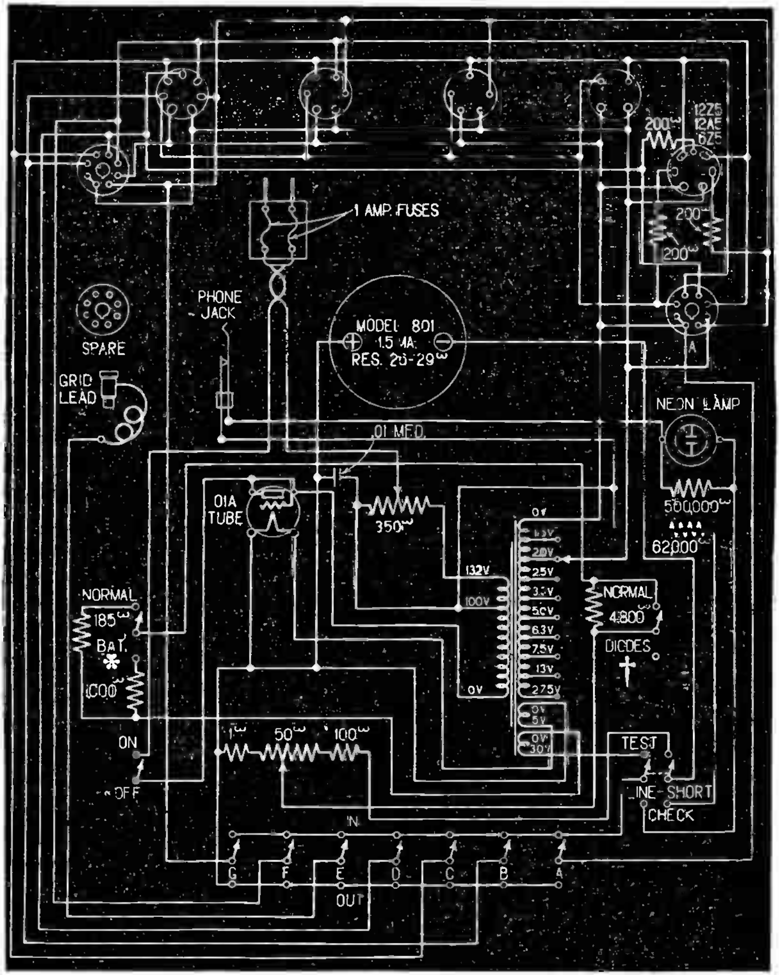


FIG. 16—Diagram of connection for Weston instruments Model 773.

FIG. 17—Panel view of Weston Model 773 movable type tube checker.

Weston Model 655-2 Selective Analyzer.—The internal connection of this instrument is shown in fig. 18.

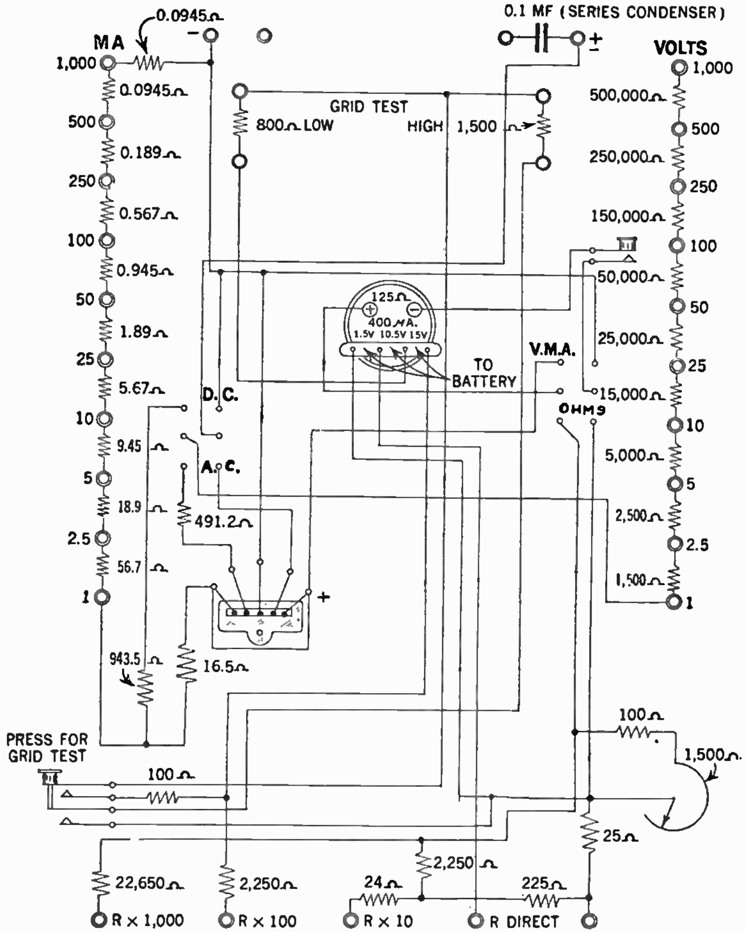


FIG. 18—Connection diagram of Weston Model 665-2 radio set analyzer.

The principal difference between this instrument and the 655 previously described is that the various scales are available by means of pin jacks instead of a rotary switch. The volt meter ranges *a.c.* or *d.c.* are: 0–1/2.5/5/10/25/50/100/250/500/1000 volts. The current ranges *d.c.* only are 0–1/2.5/5/10/25/50/100/250/500/1000 milliamperes.

Supreme Model 339 Analyzer.—The panel view and connection diagram of this instrument is shown in figs. 19 and 20 respectively.

It has five sockets for various types of tubes, a sensitive d'Arsonval fan shaped meter, and a rugged 4-gang, 5-position rotary switch for selectivity connecting the meter to any of the following measuring circuits:

(a) *d.c.* milliammeter—0/5/25/125/250/500 *m.a.*, and 0/1.25 ampere.

(b) *d.c.* voltmeter—0/2/25/125/250/500/1,250 volts.

(c) Ohmmeter—0/2,000/20,000/200,000 ohms and 0/2/20 megohms.

(d) *a.c.* voltmeter—0/5/25/125/250/500/1,250 volts.

(e) Capacity Meter—0/0.05/0.25/1.25/2.5/5.0/12.5 *mfds.* electro-static (paper) and electrolytic.

For current, potential and resistance measurement the meter is "built up" to a resistance value of 300 ohms by means of a multiplier resistor connected in series with the meter, and all shunt and multiplier resistance values are calculated on the basis of a full scale current sensitivity of 1.0 milliampere and a resistance value of 300 ohms for the meter.

The actual armature resistance of the meter is approximately 115 ohms. The operating procedure for the various measurements is as follows:

1. **Current Measurements.**—When it is desired to obtain current in terms of milliamperes the meter is shunted as shown

in fig. 20. The total shunt value of 75 ohms is determined by the lowest current-measuring range of 5 milliamperes. The meter, with its resistance built up to a value of 300 ohms, requires a potential of 0.3 volt (300 millivolts) to cause a full scale current of 1.0 milliampere to pass through the meter.

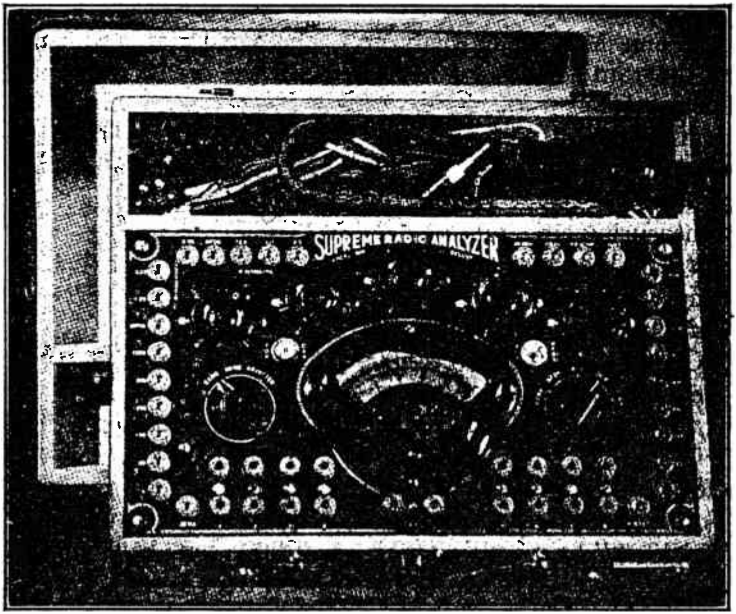


FIG. 19—Front view arrangement of Supreme Model 339 radio set analyzer.

The shunt resistor for the 5 milliampere range, being in parallel with the meter, will have the same 0.3 volt potential difference. Since 1.0 milliampere of the 5 milliampere range will pass through the meter, the shunt resistor will pass the other 4.0 milliamperes and its value is determined by dividing 4.0 milliamperes (0.004 ampere) into 300 millivolts (0.3 volts).

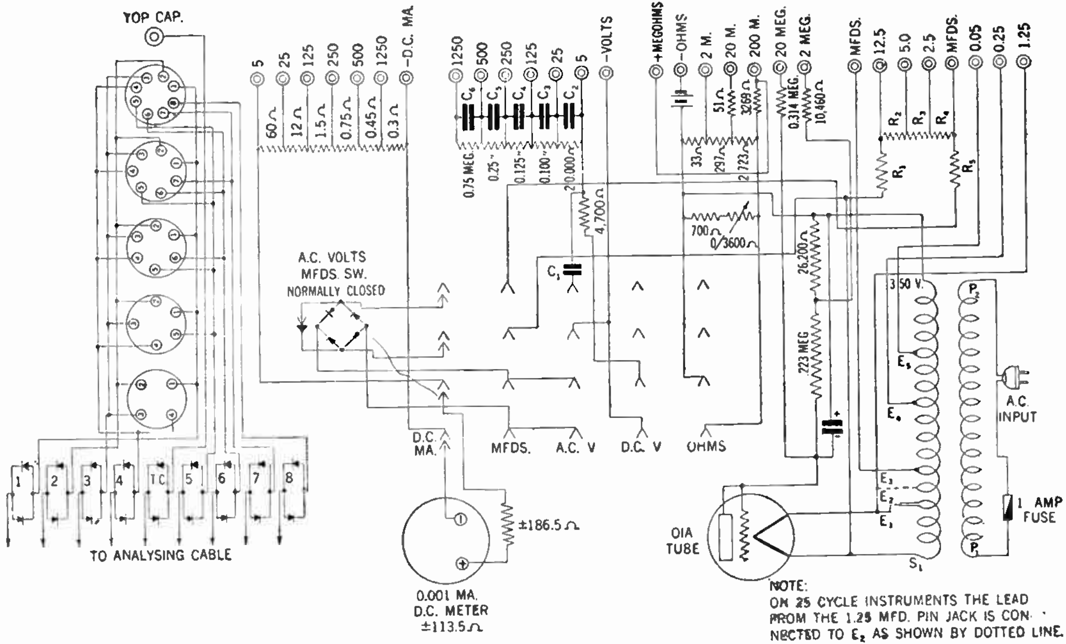


FIG. 20—Wiring arrangement and resistance values in Supreme Model 339 radio set analyzer.

For the current measuring ranges above the 5.0 milliampere range, the 75 ohm shunt resistor is divided into smaller values, thereby forming what is known as a "ring type" shunt, the total "ring" resistance value being 375 ohms.

The resistance values of the 75 ohm shunt resistors are determined by multiplying the total "ring" resistance by the full scale current of the meter, dividing the result by each range value, in turn, from the common terminal, and subtracting the sum of the preceding values from each newly-determined value.

When the "ring" value of 375 ohms is multiplied by the full scale sensitivity value of 0.001 ampere, 0.375 is the result, into which each range value is divided, in turn, for determining the required shunt values. For example, the shunt value for the 1.250 ampere range is determined by dividing 1.250 into 0.375, giving a value of 0.3 ohm for that range.

For the 500 milliampere range, 0.500 ampere is divided into 0.375, giving a value of 0.75 ohm for the 500 milliampere range; but since there already is a value 0.3 ohm for the preceding range, it is necessary to subtract 0.3 ohm from 0.75 ohm, leaving a value of 0.45 ohm for the second section of the shunt.

For the 250 milliampere range, 0.250 ampere is divided into 0.375, giving a value of 1.5 ohms for the 250 milliampere range; but since there already is a value of 0.75 ohm for the two preceding ranges, it is necessary to subtract 0.75 ohm from 1.5 ohms, leaving a value of 0.75 ohm for the third section of the shunt. The shunt sections for the other ranges are determined in a similar manner, and can be checked by Ohm's law.

For example, the shunt value of 0.3 ohm for the 1.250 ampere (1,250-milliampere) range is in parallel with the remaining 374.7 ohms of the "ring" circuit, which when multiplied by the meter current of 0.001 ampere, produces a potential drop of 0.3747 volt. With 0.001 ampere going through the meter, the remaining value of 1.249 amperes will be going through the 0.3 ohm shunt, producing potential drop of 0.3 times 1.249 or 0.3747 volt. Since the potential drop across both parallel paths is identical by Ohm's law, it is concluded that the calculations are correct. The other ranges may be similarly checked by Ohm's law.

2. **D.C. Potential Measurements.**—When the meter is being used for potential measurements, enough resistance must be connected with it to limit the current to within the full scale sensitivity value of the meter.

The value of the multiplier resistor for the 5-volt range is established by subtracting the meter resistance value of 300 ohms from the 1,000 ohms-per-volt value of 5,000 ohms leaving a multiplier resistance value of 5,000-300 or 4,700 ohms.

For the higher ranges the multiplier resistance values are calculated on this basis of 1,000 ohms per volt.

3. **Resistance Measurements.**—For resistance measurements, the meter is used primarily as a voltmeter, with the current passing through the meter calibrated on an "Ohms" scale instead of being calibrated on a "Volts" scale. In the multi-range ohmmeter circuits of this tester, however, shunts are used to enable the different sensitivities required for each range, and to this extent, the ohmmeter circuits resemble current measuring circuits in which shunts are usually required.

It will be observed from diagram fig. 20, that for the lowest or 2,000 ohm range, the 33 ohm resistor is a shunt resistor, while the 297 ohm and the 2,723 ohm resistors act as multipliers to the meter with its 700/4,300-ohm shunting resistor made up of a fixed 700 ohm resistor and a variable 3,600 ohm rheostat for accommodating battery potential variations.

For the 20,000 ohm range, the 33 ohm and the 297 ohm resistors, totaling 330 ohms, act as a shunting resistor, with the 51 ohm and 2,723 ohm resistors functioning as multipliers. For the 200,000 ohm range, the 33 ohm, 297 ohm and 2,723 ohm resistors act as a shunting resistor, and a 3,269 ohm resistor acts as a multiplier resistor.

4. **A.C. Potential Measurements.**—The *a.c.* potential measuring functions differ from the *d.c.* potential in that the meter is connected to the output terminals of a full-wave instrument rectifier and a capacitor is substituted for the 4,700 ohm multiplier resistor, the capacitor being connected in series with the rectifier input circuit. Each of the multiplier resistors above the 5-volt range is by-passed with a calibration capacitor. The elements involved in the *a.c.* potential measuring functions are indicated in wiring diagram.

5. **Capacity Measurements.**—When the meter is used for capacity measurements, the resistance value of the meter and of the shunt and multiplier resistors associated with the measuring circuit constitutes one leg of an impedance triangle. See fig. 21. The reactance of a capacitor of unknown value, which may be connected into the measuring circuits for the purpose of determining its value, constitutes another leg of the same impedance triangle.

It is obvious that the resistance value of the meter and of its associated shunt and multiplier resistors is a constant value for any particular capacity-measuring range, regardless of the capacitive value of any capacitor which may be connected to that range, and that the capacitive reactance, in every case, is determined by the capacitive value of the capacitor which may be subjected to the measurement; therefore, the capacitive leg of the triangle is the variable element.

It is further obvious that the meter current is related directly to the hypotenuse of the impedance triangle and will not, therefore, have a linear relationship to capacitive values. For example, assume an impedance triangle in which a full-scale meter current corresponds to a certain hypotenuse length, and in which the reactance leg corresponds to a capacitive value of

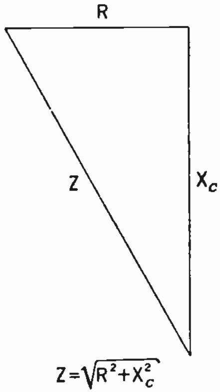


FIG. 21—Arrangement of impedance triangle in capacity measurements.

5.0 microfarads; if we remove the 5.0 mfd. capacitor and put in its place a 2.5 mfd. capacitor, the length of the reactive leg of the triangle will be doubled, but the length of the hypotenuse will not be doubled, and, therefore, the meter current will not be reduced to one-half of its former full scale value. In other words, a linear or evenly-divided scale cannot be used on the basis of fixed resistance values for the meter and its associated shunt and multiplier resistors.

From what has just been explained, it is natural to ask a question as to how capacitive measurements are enabled on an evenly divided scale in this tester. The answer lies in the fact that, although the meter, shunt and multiplier resistance values constitute a fixed resistive value for each capacity measuring range, a variable resistive value is introduced by the full wave instrument rectifier employed, and shunts and multipliers are employed of such values as will enable the variable element of the rectifier resistance to approximately counterbalance the variable reactive element introduced by the different capacitive values which may be encountered for measurement.

In other words, the divisions of a meter scale would be crowded on the upper end of the scale for capacitive measurements if the rectifier were linear in its characteristics, and the non-linear characteristics of the rectifier would cause the divisions of the meter scale to be crowded on the lower end of the scale, if no capacitive variable elements are introduced into the circuit; but when both variable elements are introduced into the circuit in approximately equal and opposite proportions, the meter scale divisions can be equally separated across the whole scale, or, what amounts to the same thing, the regular evenly-divided scales can be utilized for capacitive measurements.

For the measurement of electrostatic (paper) capacitive values, comparatively high *a.c.* potentials are used, but it is necessary to use comparatively low *a.c.* potential values for the measurement of electrolytic capacitive values, so as not to puncture the electrolytic film around the electrodes. Actually the *a.c.* potential applied to electrolytic capacitors in the 0/1.25/2.5/12.5 mfd. ranges is about 9 volts. The capacity-measuring circuits are shown in the wiring diagram.

Supreme Model 585 Diagnometer.—This instrument shown in fig. 22 with the connection diagrams of the tube testing circuit in fig. 23 has the following service facilities. It actually consists of 14 instruments in one compact assembly, for complete circuit and tube checking on all radios, P.A. amplifiers and television sets.

The instrument is a complete point to point set tester, or the "Free Reference" system of analysis direct from tube sockets may be chosen.

The meters provide for the following ranges:

1. Six *d.c.* potential ranges of 0–7/35/140/350/700/1,400 volts.

2. Six *a.c.* potential measuring ranges of 0–7/35/140/350/700/1,400 volts.

3. Seven *d.c.* current measuring ranges of 0–1/7/35/140/350/700/1,400 *m.a.*

A *d.c.* scale 0–14 amp. is provided for checking drain of auto radios and 6 volt mobile sound systems. There are six output meter ranges, ohms 0–200/2,000/20,000/200,000. The first division on the 200 ohm scale is 0.25 ohm. Can be read to 0.05 ohm. Megohmeter 0–2/20.

The 20 megohm range operating at 450 volts is an excellent electrostatic and main filter electrolytic condenser breakdown tester.

Decibels—10 to +6/0 to +16/+10 to +26/+20 to +36/+30 to +46 direct reading on the 500 ohm line; zero level 0.006 watts Electrostatic capacity meter 0–.07/0.35/1.4/3.5/7.0/14.0 Mfd.

Electrolytic capacity meter 0–3.5/7.0/14.0 Mfd. Direct meter leakage test for main filter electrolytics on colored "Good-Bad" scale.

Also a sensitive full size neon test for electrolytic condensers.

All meter services and ranges are selected by indicating rotary switches. New "Free Reference" tube for all old and new radio, P.A. and television tubes, except thyratrons and kinescopes.

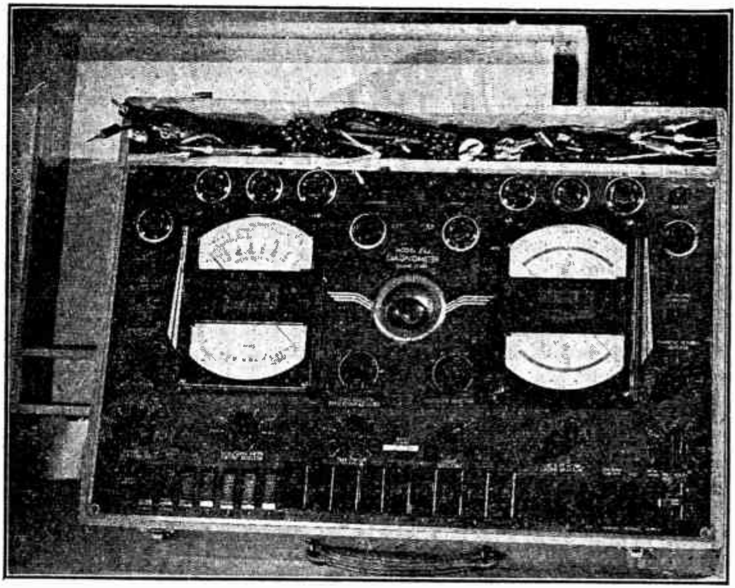


FIG. 22—Front view showing arrangement of instruments and switching devices in Supreme Model 585 diagnometer.

With this diagnometer it is possible to test all multi-purpose tubes section by section, as well as for overall performance, there are 48 possible basic combinations of load and voltage to insure proper and accurate tests of every conceivable type of tube.

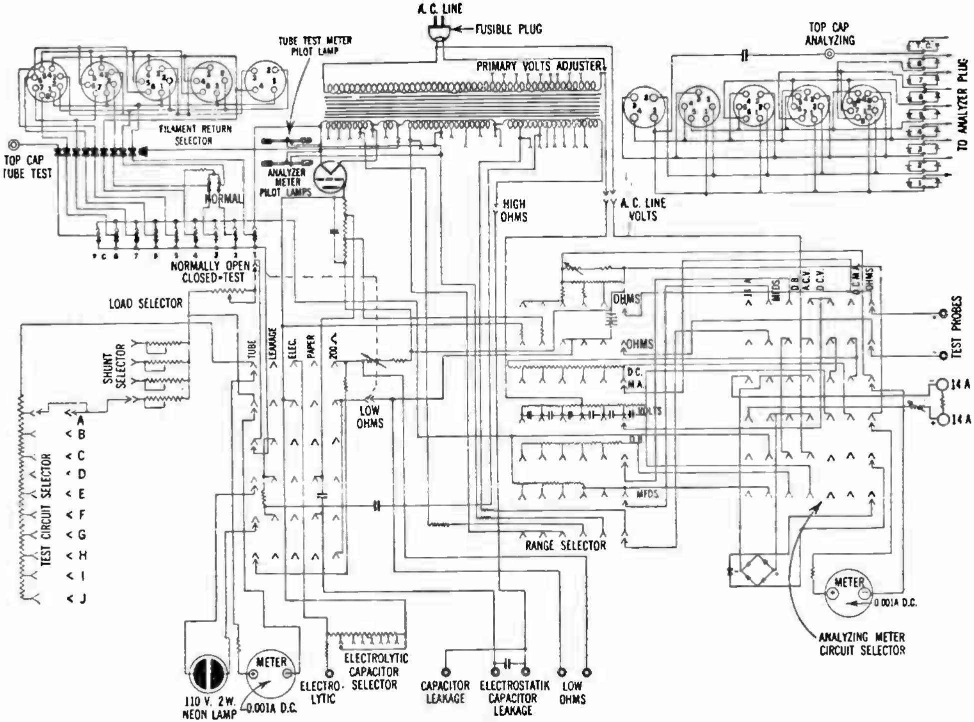


FIG. 23—Internal connection of Supreme Model 585 diagnometer.

Supreme Model 501 Tube Tester.—The panel view of this tester is shown in fig. 24 and illustrates the various controls. The connection diagram is shown in fig. 25. This new improved circuit tests all old and new tubes for radio, public address systems, and television, except thyratrons and kinescopes. It tests all multi-purpose tubes section by section, as well as for overall performance.

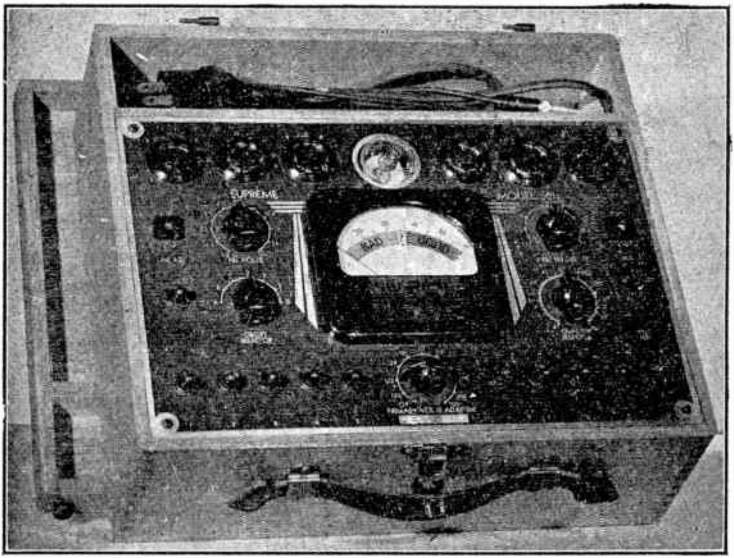


FIG. 24—Front view of Supreme Model 501 tube tester.

All quality tests are made at full rated load for highest accuracy. Six sockets test all types and combinations of tubes, as both ends of the filament or heater are free, through switches, for instant connection to any pair of tube terminals including the top cap.

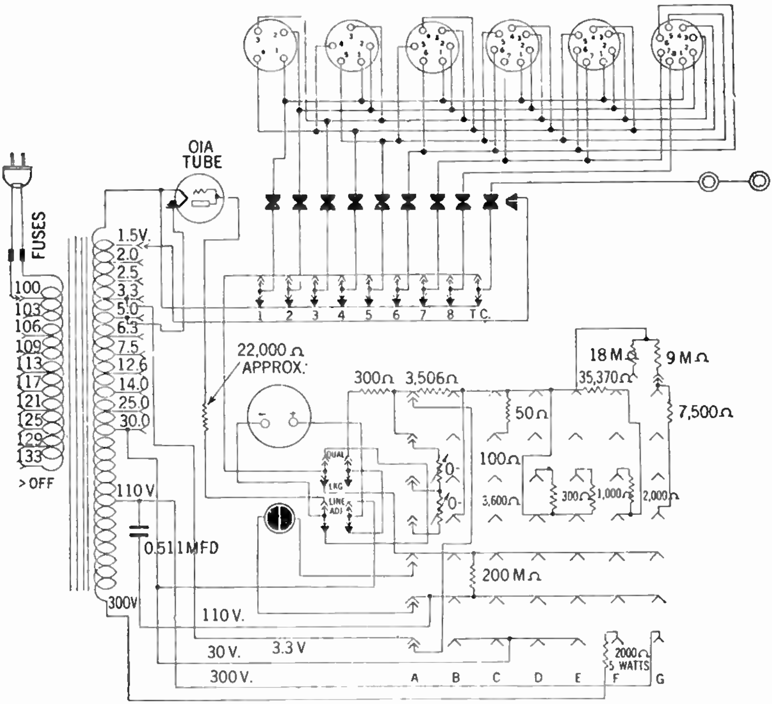


FIG. 25—Schematic wiring diagram of internal connection in Supreme Model 501 tube tester.

Supreme Model 551 Analyzer.—The panel view and connection diagram of this instrument are shown in figs. 23 and 24 respectively.

This set analyzer will handle all service and circuit problems of all types of radios, P.A. amplifiers and television sets. It is also as useful in servicing industrial vacuum tubes and photocell devices.

It has five sockets for the various types of tubes, and a sensitive 4 in. square meter, with easily readable scale. The various ranges and services are quickly available by means of an indexed rotary switch connecting the meter to any of the following measuring circuits:

a. *D.c.* volts 0–7/140/350/1,400
b. *A.c.* volts 0–7/140/350/1,400
c. *D.c.* milliamperes 0–1/7/35/140
d. Ohms 0–200/2,000/20,000

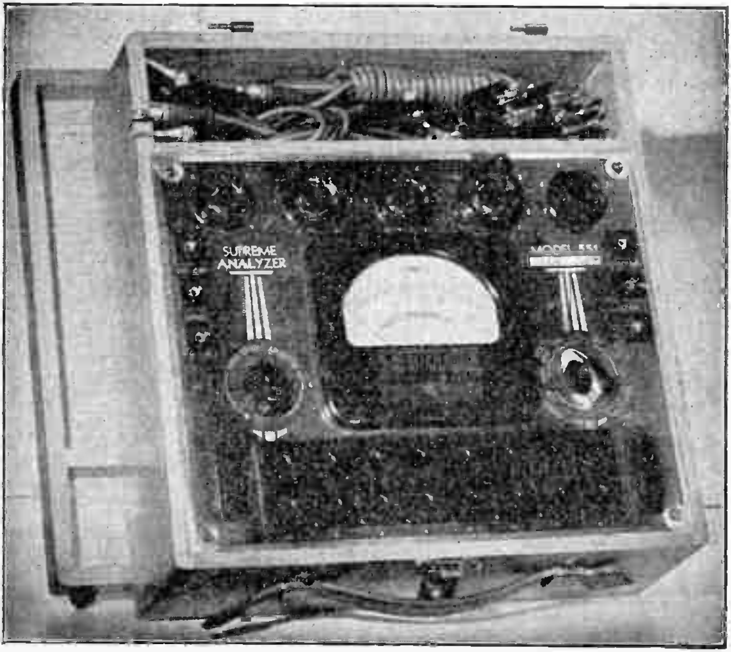
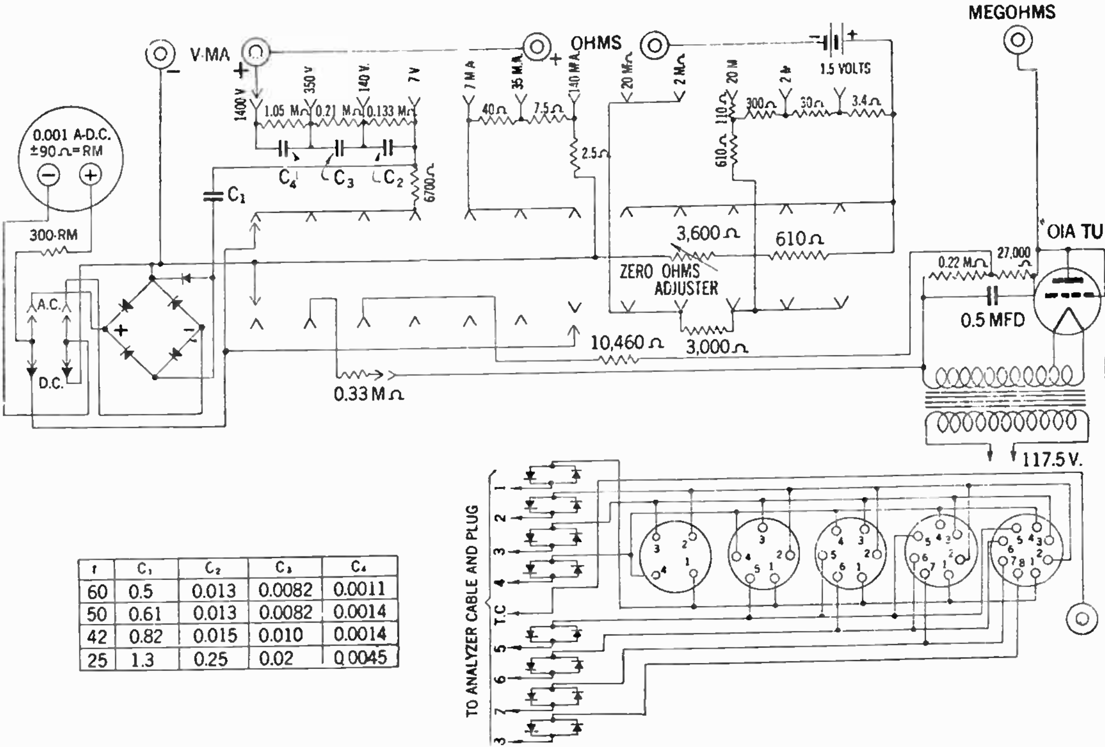


FIG. 26—Exterior view of Supreme Model 551 analyzer.



f	C_1	C_2	C_3	C_4
60	0.5	0.013	0.0082	0.0011
50	0.61	0.013	0.0082	0.0014
42	0.82	0.015	0.010	0.0014
25	1.3	0.25	0.02	0.0045

FIG. 27—Wiring diagram of Supreme Model 551 analyzer.

The first scale division of the 0–200 ohm range is 0.1 ohm, and at center scale the resistance reading is 3.5 ohms. This extreme open scale which can easily be read as close as 0.02 ohms is especially valuable when checking the resistance of shorted voice coils, filament windings on transformers, rosin joints, shorted turns in converter armatures, etc.

The megohmeter has two ranges 0–2/20 megs, which is operated from a self-contained power supply for high resistance and cable leakage testing.

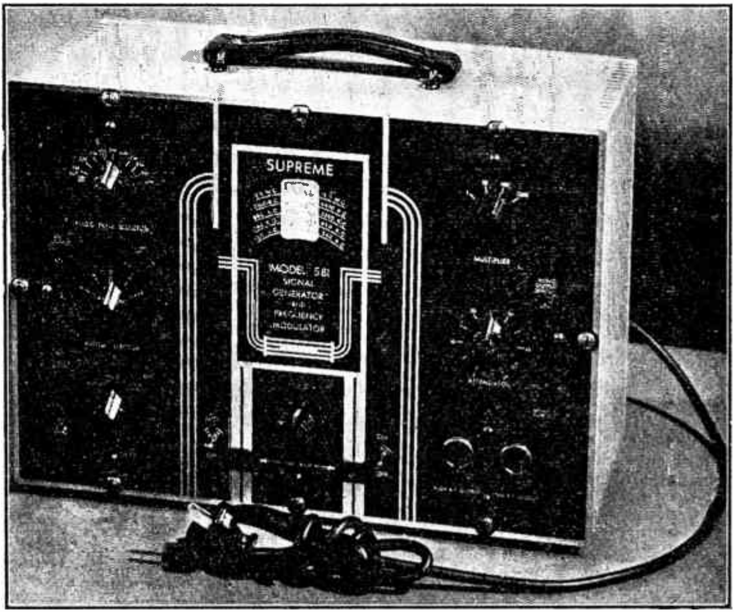


FIG. 28—Panel view of Supreme Model 581 signal generator.

Supreme Model 581 Signal Generator.—This all wave *r.f.* oscillator has a range of 130 *k.c.* to 60 *m.c.* on 5 fundamental bands and 3 harmonically related bands.

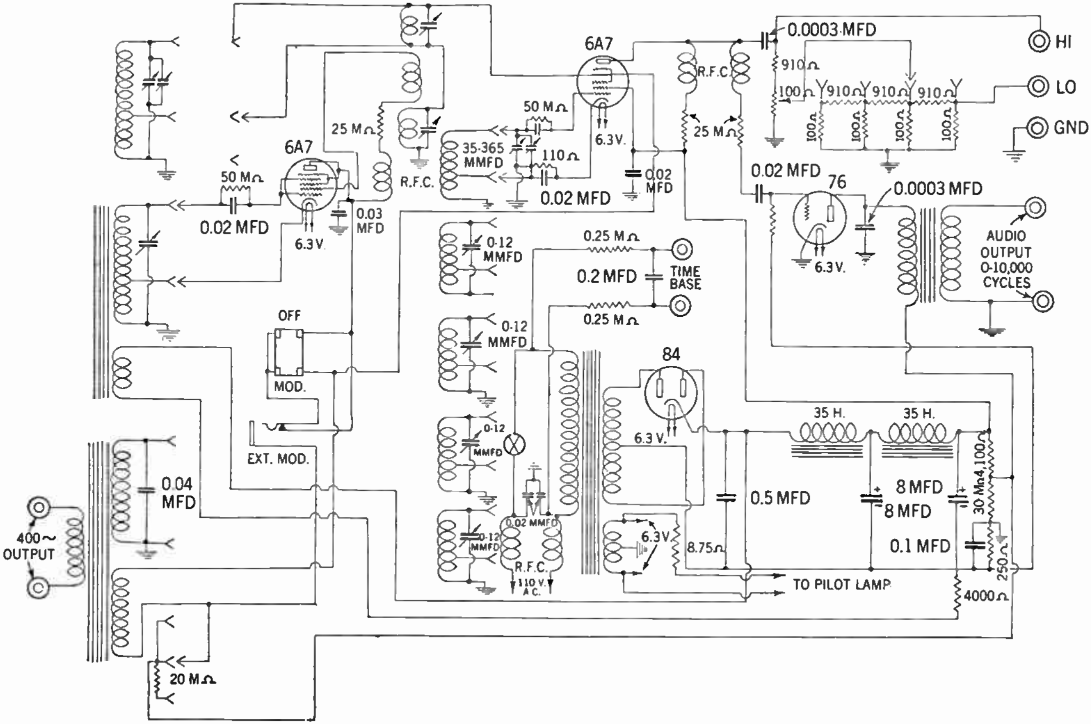


FIG. 29—Circuit diagram of Supreme Model 581 Signal generator.

Other noteworthy features includes a 400 cycle modulating oscillator which modulates the *r.f.* carrier the standard 30%; a beat frequency audio frequency oscillator having a 60/10,000 cycle range with less than 5% harmonic distortion; and an electronic frequency modulator or "Wobbulator."

This model is useful for alignment testing by the output meter (amplitude modulated *r.f.* signal) method or the visual cathode ray tube (frequency modulated *r.f.* signal) method; demodulation and detector testing; checking fidelity and overall response, and gain of audio and P.A. amplifier systems, band pass width; selectivity curves of *i.f.* amplifiers, etc.

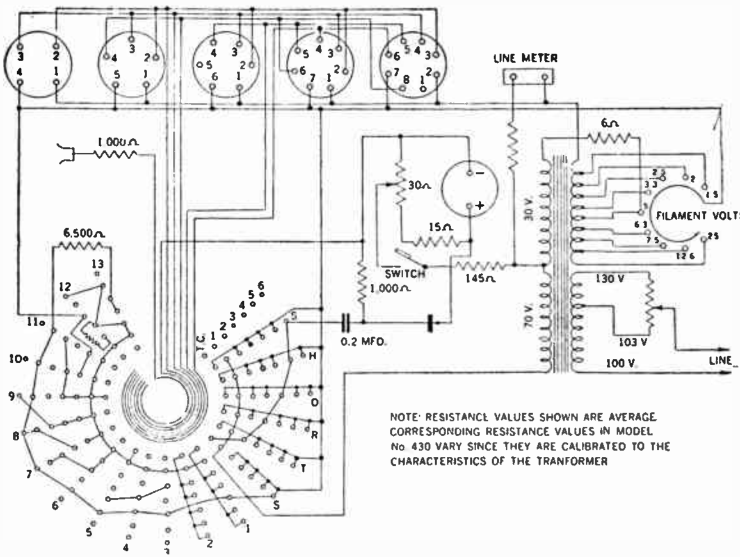


FIG. 30—Internal connection diagram of Readrite Model 430 tube tester.

The whole circuit is very stable, using a modified electron coupled system, which will not drift due to changes in line voltages, ambient temperature or attenuator control operation.

The circuit shown in fig. 29 has incorporated in it two 6A7, one 84 and one 76 tube.

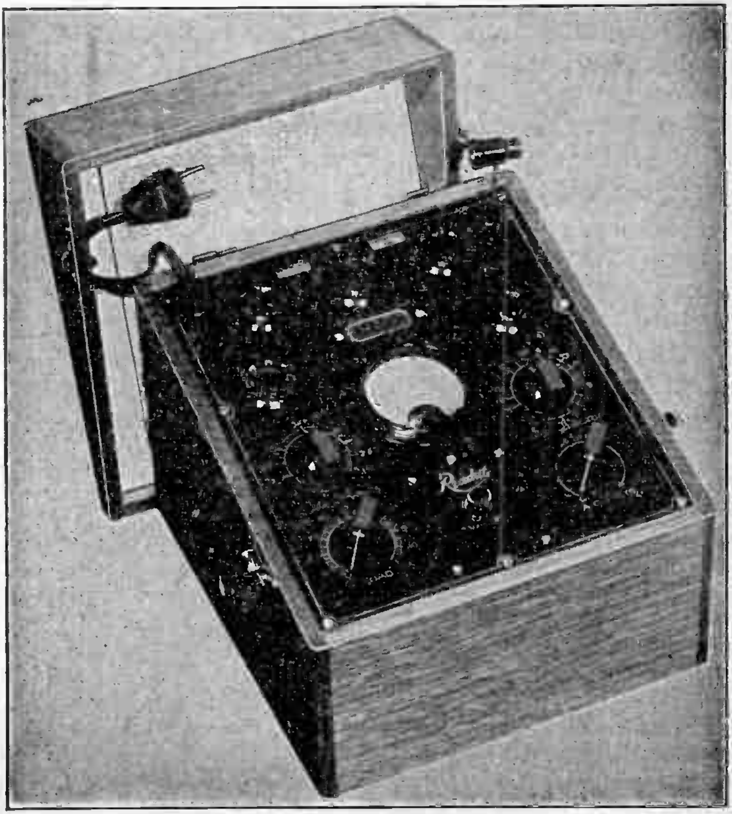


FIG. 31—Front view arrangement of devices in Readrite Model 430 tube tester.

Readrite Model 430 Tube Tester.—The wiring diagram and panel view of this type of instrument is shown in figs. 30 and 31 respectively.

This instrument is designed to test both metal and glass types of tubes.

The panel has five sockets and a direct reading "GOOD-BAD" meter scale, two selector switches, one load control knob, one *a.c.* voltage adjustment knob and one push button switch to indicate the condition of the tube under test.

The circuit is designed on the "emission" principle in that the meter indication depends on an emission test of the tube.

Cathode-leakage and short-circuit tests can also be made with this instrument.

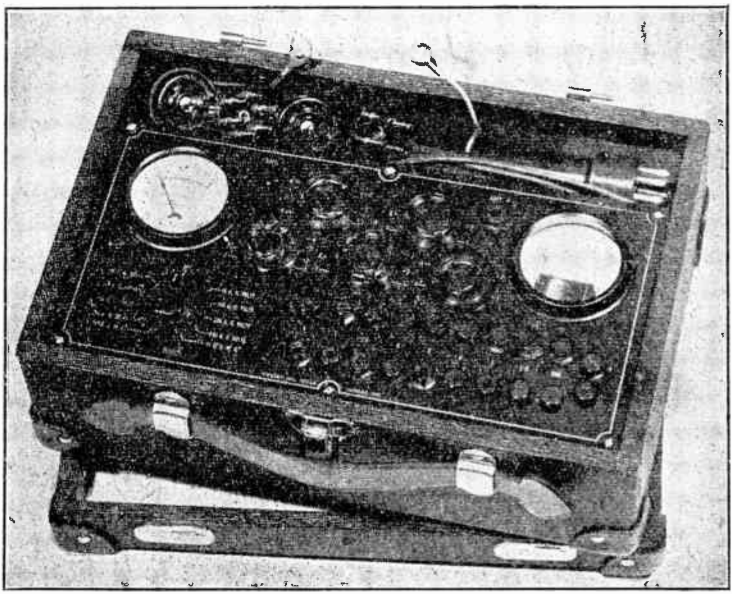
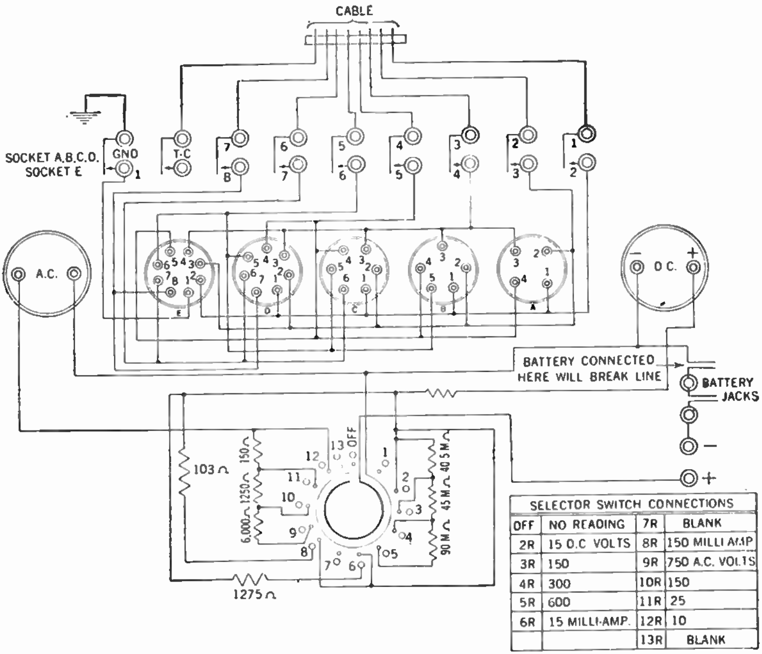


FIG. 32—Panel view of Readrite Model 720-A point to point panel.

Readrite Model 720-A Point-to-Point Tester.—This tester is equipped to handle both the glass and the glass-metal tubes. It may be used to measure resistance capacity and continuity, as well for voltage checking of any tube circuit.

The point-to-point tests are made through an eight conductor cable, which is plugged into the receiving set socket. Tester socket terminals are arranged according to R.M.A. standards, thereby making it unnecessary to remove chassis from cabinet when localizing faults. Arrangement of the different tube elements does not affect tests.



SELECTOR SWITCH CONNECTIONS			
OFF	NO READING	7R	BLANK
2R	15 D.C VOLTS	8R	150 MILLI AMP
3R	150	9R	750 A.C. VOLTS
4R	300	10R	150
5R	600	11R	25
6R	15 MILLI-AMP.	12R	10
		13R	BLANK

FIG. 33—Connection diagram of Readrite Model 720-A point to point tester.

The tester is equipped with two meters; a *d.c.* meter having scale for reading 15-150-300-600 volts, 15-150 milliamperes and an *a.c.* meter for reading 10-25-150 and 750 volts.

Separate meter ranges made available by connecting a single pair of jacks and using the selector switch. For diagram of connection and panel view, see figs. 33 and 32.

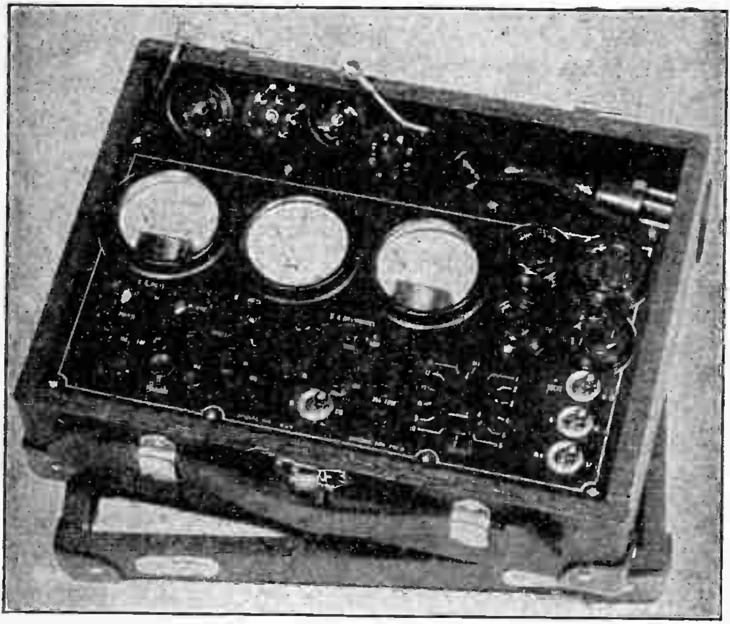
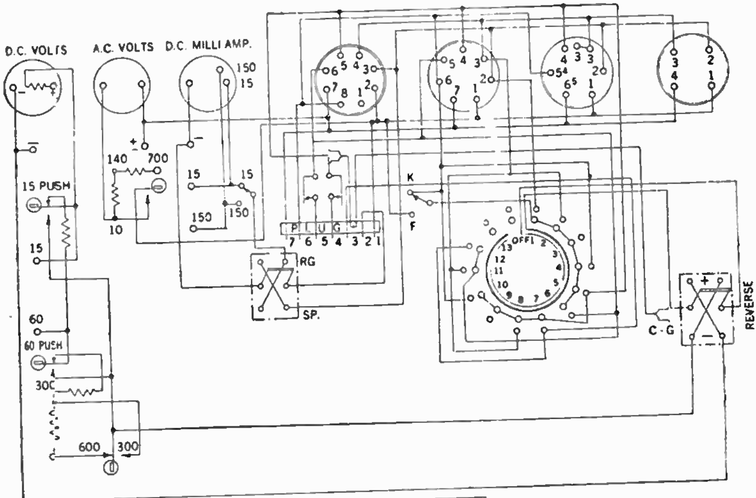


FIG. 34—Front view arrangement of Readrite Model 710-A tester.

Readrite Model 710-A Tester.—This instrument is used to test all parts of the tube circuits by plugging directly into the receiving set socket.

It will handle sets equipped with either glass or glass-metal tubes.

There are three meters, a *d.c.* volt-meter which reads 0–20/60/300/600 volts, and has 1,000 ohms resistance per volt, a *d.c.* milli-ammeter scale 0–15/150 and an *a.c.* voltmeter. scale 0–10/140/700.



SELECTOR SWITCH	CONTACTS 7-PRONG SOCKET	SELECTOR SWITCH	CONTACTS 7-PRONG SOCKET
1	2 – 6	7	4 – 2
2	3 – 6	8	4 – 3
3	C-G – 6	9	4 – 5
4	1 – 6	10	4 – 6
5	6 – 4	11	5 – 3
6	6 – 5	12	5 – 4

FIG. 35—Schematic diagram of connections in Readrite Model 710-A tester.

A special positive contact selector switch connects all *d.c.* circuits to the *d.c.* volt meter. Panel jacks are provided to make individual range connections for the three meters.

The panel view and connection diagram are shown in figs. 34 and 35.

Philco Model 025 Signal Generator and Radio Tester.—This instrument consists principally of a volt-ohm-milliammeter for both *a.c.* and *d.c.* service.

The *a.c.* and *d.c.* voltage scales are 0–10/30/100/300/1,000. Current up to 10 amperes may be read directly on the milliammeter by using a special shunt.

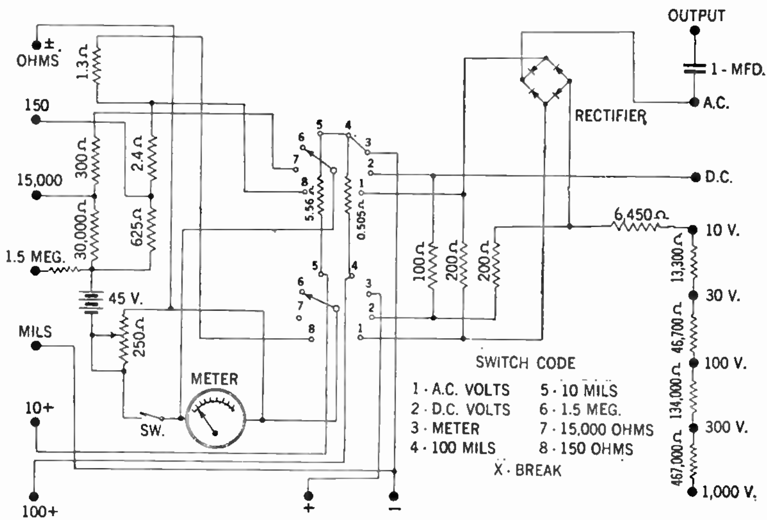


FIG. 36—Wiring diagram of Philco Model 025 radio tester.

The circuit is designed for capacity and resistance measurements which values are recorded on special scales, although in reading capacity (Mfd.) a special calibration chart should be consulted.

For internal connection and exterior views of instrument, see figs. 36 and 37.

Readrite Model 557 Signal Generator.—This signal generator is equipped with coil combinations to obtain frequency band as follows:

Coil "A" covers the band from	110 to	295	K.C.
Coil "B" covers the band from	275 to	840	"
Coil "C" covers the band from	820 to	2,800	"
Coil "D" covers the band from	2,500 to	8,500	"
Coil "E" covers the band from	8,000 to	20,500	"

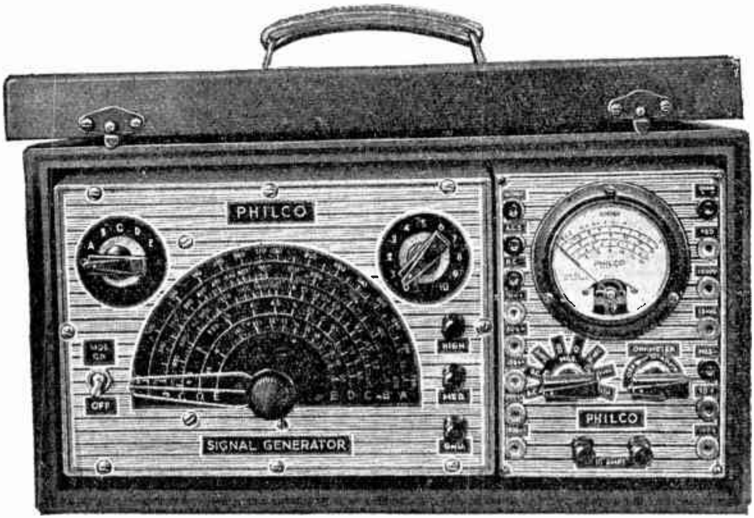


FIG. 37—Panel view of Philco Model 025 Signal generator and radio tester.

The operation of the oscillator is as follows: After determination of the frequency to be covered, select proper plug in the coil as shown under heading "Plug-in Coils"; place coil in 6-hole socket in shield can which is accessible by removing the nickle cap near the toggle switch marked "**On-Off**". Connect oscillator and set the attenuator to approximately 75 on the dial, after which the toggle switch marked "MOD-UNMOD" is set to position desired.

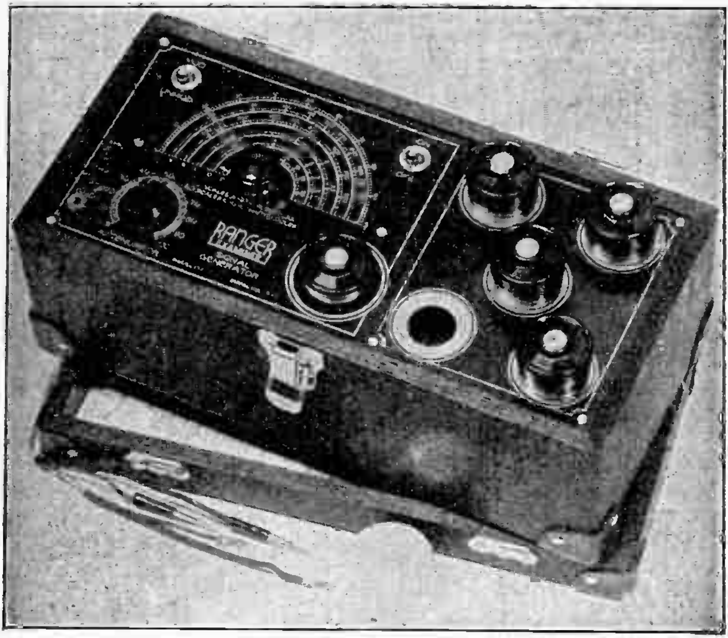


FIG. 38—Panel arrangement of Readrite Model 557 signal generator.

Generally speaking, all oscillator alignments are made with a modulated signal. Consult graph chart for the coil selected. Note dial setting for the frequency desired. Set dial pointer of frequency selector dial to the position as shown on graph. Turn oscillator power on by throwing the OFF-ON switch to the ON position and attenuate the signal to desired level by rotating the attenuator control so that a minimum signal is reached. If further reduction in signal strength is wanted, use jacks marked Minimum and Ground.

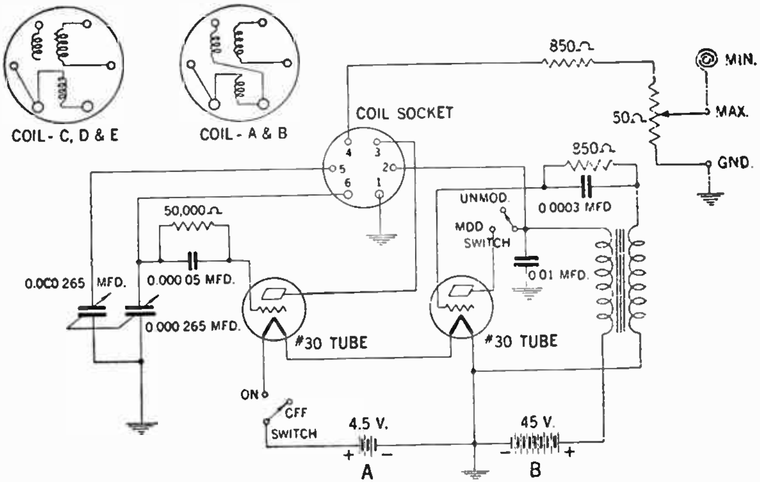


FIG. 39—Wiring diagram and coil arrangement in Readrite Model 557 signal generator.

Output Meter.—An output meter should always be connected to the radio output when using a signal generator. In order to avoid serious energy loss the output meter should be connected between the plate of output tube and chassis. If the output meter does not have a condenser there should be a condenser inserted in the output plate lead. This will prevent a burnout of meter. A .5 mfd. 400 volt condenser is suitable.

Vacuum Tube Voltmeters (General).—The vacuum tube voltmeter is an instrument used in service work for direct measurement across high impedance circuits, such as in the measurements of radio-frequency and audio-frequency voltages where the use of power consuming instruments would be unsatisfactory on account of the small current in the circuit.

For example, the impedance of an *r.f.* circuit such as is used in the first and second stage of a receiver may be as high as 2 or 3 megohms when adjusted to resonance with an incoming signal.

To make any measurement of potential across such a circuit it is obvious that a meter having a resistance of 3 to 4 megohms would be required, as a meter having a lower resistance might change the potential condition in the circuit it is desired to measure, too much, and hence make the measurement unsatisfactory.

It has been found that the only connection that could profitably be made across such a circuit without upsetting the circuit potentials would be that of another vacuum tube, the connection being made across the grid and cathode of said tube.

Essentially, the vacuum tube volt meter as the name implies, is nothing more than a vacuum tube connected through a meter in its plate circuit to a suitable power supply.

The grid and the cathode of the tube are connected across the circuit to be measured, the potential of said circuit causing a change in grid voltage on the tube and thus, a resultant change in plate current is indicated on the instrument.

As the vacuum tube is also a rectifier, potentials of any frequency placed across the grid and cathode of the vacuum tube voltmeter will result in a direct current deflection on the instrument in the plate circuit.

It is for this reason that the vacuum tube voltmeter can be used for measuring audio as well as radio frequency potentials provided the circuit is worked out correctly to cover this broad range of frequency.

Weston Model 669 Vacuum Tube Voltmeter.—Front view and internal connection of the instrument is shown in figs. 40 and 41 respectively. The principal characteristics of this type of instrument is as follows:

1. It has 6 self-contained ranges controlled by a rotary switch in the lower left hand corner, the full scale readings being 0–/1.2/3/6/8/12/16 volts. This meter is different from other multiple range vacuum tube voltmeters in that on all of these ranges only the grid to cathode impedance of the vacuum tube appears across the circuit to be measured.

2. The device operates directly from a 120 volt 60 cycle *a.c.* line, a self-contained transformer and power supply providing the necessary direct current potentials. A neon regulator bulb is used to hold the *d.c.* grid and plate voltages fixed irrespective of variations in line voltage. Up to the present time the problem of eliminating variations in vacuum tube meter readings with line voltage fluctuations has been a serious problem. The use of this regulator bulb has therefore put measurements of this type on a different plane as readings in the vicinity of .2 to 1 volt were practically impossible without having some sort of regulation of supply voltages.

3. Tubes used in the instrument are a type 78 and a type 1V, the former being the measuring tube and the latter the rectifier for the power supply. The 78 tube is mounted with the top projecting through the panel so that direct connection can be made to the grid cap using short leads. In the same way the grid is kept approximately 1 in. from any other metal surface and in this way input capacity is kept at a minimum.

4. A six range scale is provided, all *a.c.* readings being made directly without reference to curves or charts of any kind. The circuit has been worked out so that readings can be taken on 60 cycle lines without visible error, the frequency coverage of the device being from approximately 40 cycles up through receiver

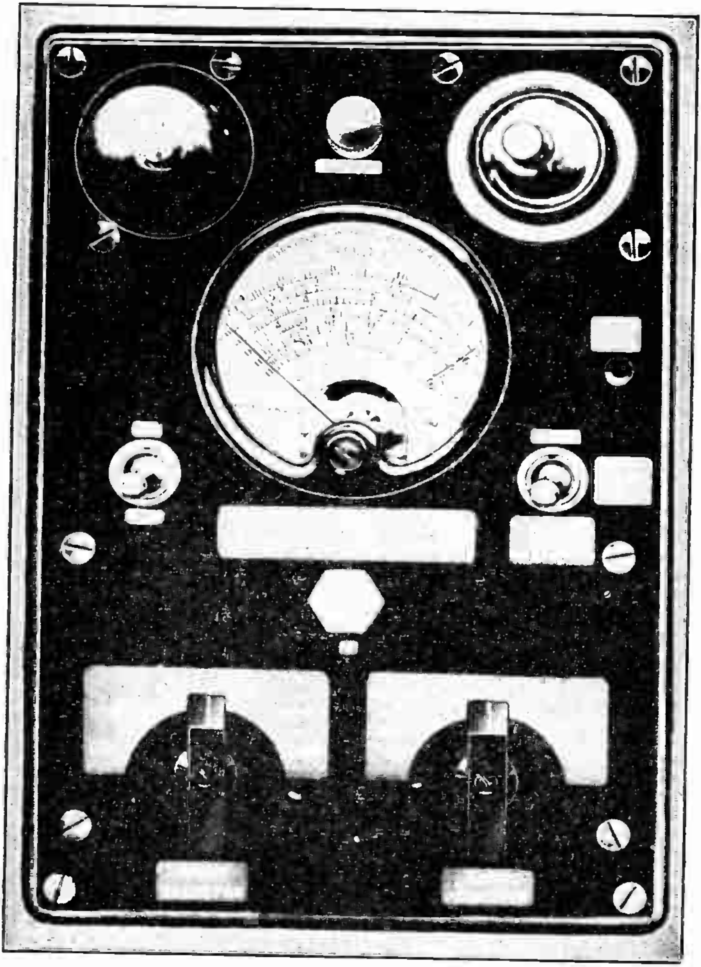


FIG. 40—Panel view of Weston Model 669 vacuum tube voltmeter.

short wave ranges. On very high frequencies such as from 10 to 20 megacycles slight errors will occur due to tube capacity even though this has been kept at a very low value. Such errors, however, are not very great being of approximately the same order as attained on other instruments used in this frequency range.

Among the measurements which can be made on this instrument is analysis of oscillator performance on super-heterodyne receivers, measurements of gain per stage in all types of receivers, checking of resonance, automatic volume control measurements, etc.

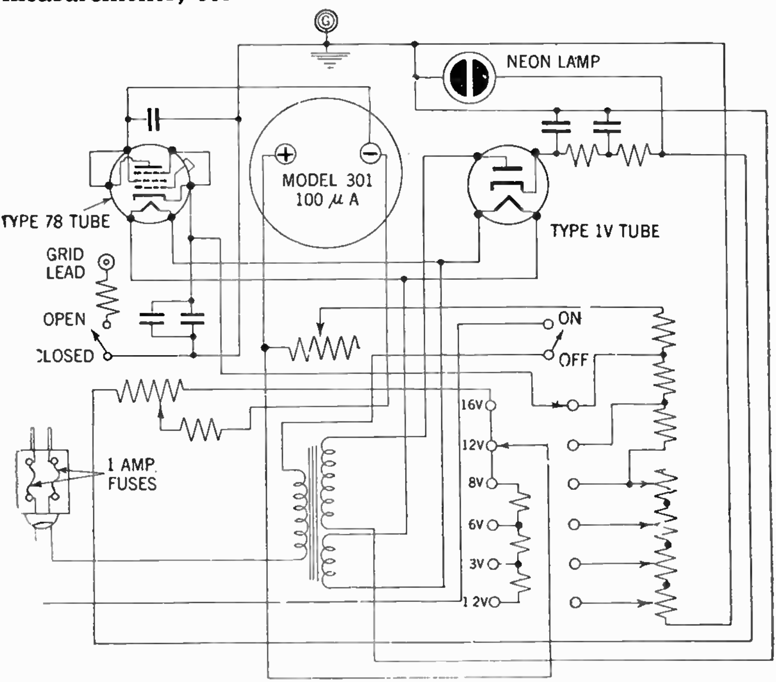


FIG. 41—Schematic wiring diagram of Weston Model 669 vacuum tube voltmeter.

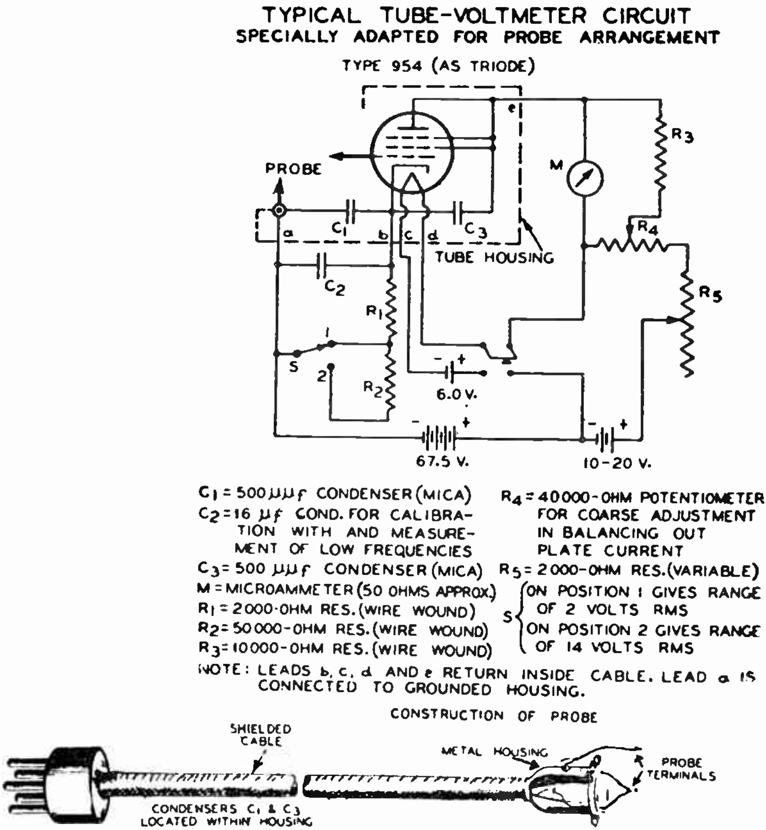


FIG. 42—Vacuum tube voltmeter arrangement in which 954 (on account of its small size) is placed at the point of measurement. In this way long leads and high input capacitances are avoided with the desirable result that measurements can be made at radio frequencies with a minimum effect on the constants of the circuit under measurement. (Courtesy Radio Corp. of America).

CHAPTER 31

The Cathode Ray Oscillograph

The cathode ray oscillograph is at present one of the most useful of radio testing devices. Although as yet relatively expensive, its applications are so numerous that it will readily replace a number of measuring instruments of more or less satisfactory characteristics.

A few of the more important applications of the instrument are the study of wave shapes and transients, measurements of modulation and peak voltages, adjustment of radio receivers, comparison of frequencies, the indication of balance in bridge circuits, tracing of vacuum tube characteristics, etc.

One of its chief advantages over other types of instruments is its freedom from inertia, allowing the observation of very rapid changes of current and voltage without appreciable distortion.

The Cathode Ray Tube.—Since the cathode ray oscillograph is built around the cathode ray tube, it is necessary to understand the principles of the latter before a study of the instrument itself.

A cathode ray tube, shown schematically in fig. 1 consists fundamentally of the following elements:

1. A glass envelope (*F*) whose purpose it is to maintain a vacuum in the tube.

2. A cathode (*L*) for the production of free electrons.

3. An electrode (*I*) whose purpose it is to accelerate the free electrons.

4. A focusing electrode (*G*) identified as **anode No. 1,** whose purpose it is to concentrate the liberated electrons into a cathode ray or beam.

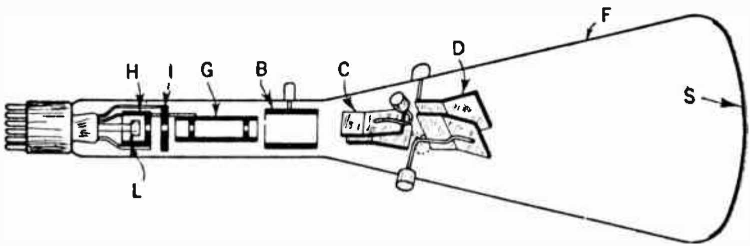


FIG. 1—Principal elements and electrode arrangement in a cathode ray tube of the electro-static deflection type.

5. A high voltage anode (*B*) known as **anode No. 2** for further accelerating the electrons.

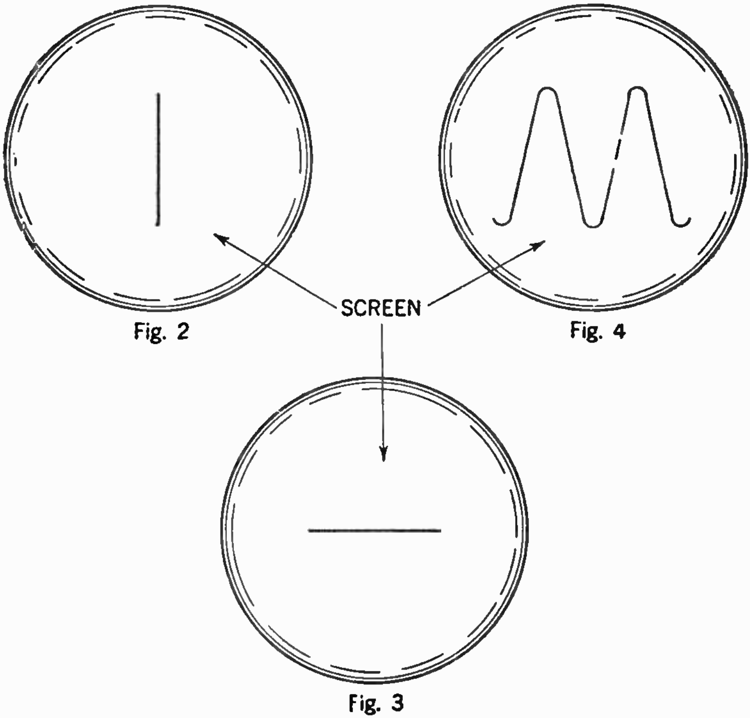
6. A control electrode (*H*) referred to as **grid No. 1** whose purpose it is to control the beam current.

7. Two sets of electrostatic deflection plates (*C*) and (*D*) for deflection of the electron beam.

8. The screen (*S*) which is coated on the inner surface of the enlarged end of the bulb with a material which shows a fluorescent glow at the impact point of the electron beam.

The collective action of electrodes (*L*), (*H*), (*I*), (*G*), and (*B*) are called an "**Electron Gun**" inasmuch as their function is to generate a beam of electrons and direct it toward the viewing screen (*S*).

As the electron beam consists of rapidly moving electrons, it constitutes a current having both electromagnetic and electrostatic properties. Because no material conductor is required to carry the electrons, the beam has negligible mass and inertia.



FIGS. 2, 3 and 4—Illustrates various fluorescent patterns which the electronic beam traces on the screens of the cathode and ray tube, under various conditions.

It is due to this inertialess characteristic that the electron beam can be deflected easily and rapidly by either electromagnetic or electrostatic fields. In the cathode-ray tube shown in fig. 1 the deflecting force produced by the phenomenon under investigation takes the form of an electrostatic field produced by a potential applied across the deflecting plates *C*. If this be an alternating voltage, the field produced causes the fluorescent spot viewed from the front of screen (*S*) to move up and down.

This movement of the spot traces a vertical line, as in fig. 2. A "time sweep" voltage of suitable wave form is applied across the deflecting plates *D*, causing the beam to move back and forth horizontally, as in fig. 3. The combined deflecting forces of the two fields may be caused to produce a pattern such as that in fig. 4. The fluorescent pattern which the electron beam traces on the screen can be distinguished, measured and photographed.

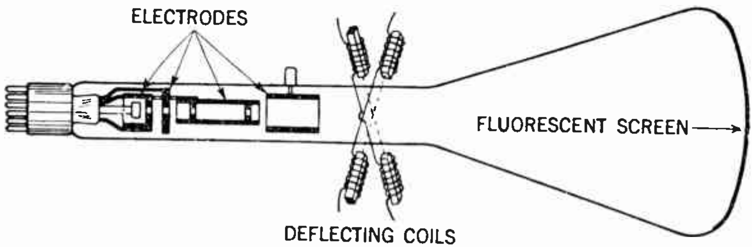


FIG. 5—Principal elements of a cathode ray tube of the electro-magnetic deflection type.

A type of cathode ray tube in which the deflection of the beam both horizontally and vertically is accomplished by means of two electromagnetic fields produced by two deflecting coils schematically depicted in fig. 5. In this case no electrostatic plates are used, otherwise this type of tube functions principally the same as the electrostatic deflection type.

Parts of R.C.A. Type T.M.V.-122 B Cathode Ray Oscillograph.—The fundamental parts of this cathode ray oscillograph, shown in figs. 6, 7 and 8 are as follows:

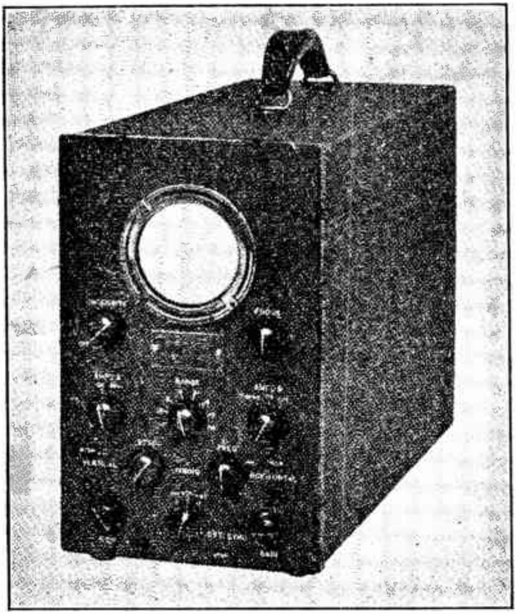


FIG. 6—Panel view of cathode ray oscillograph. (Courtesy R.C.A. Inc.)

(1) The cathode ray tube.
(2) Signal amplifier for vertical deflection.
(3) Signal amplifier for horizontal deflection.
(4) A saw-tooth timing axis oscillator.
(5) A low voltage full-wave rectifier for amplifier tube supplies.
(6) A high voltage half-wave rectifier to supply approximately 1,200 volts to the cathode ray tube.

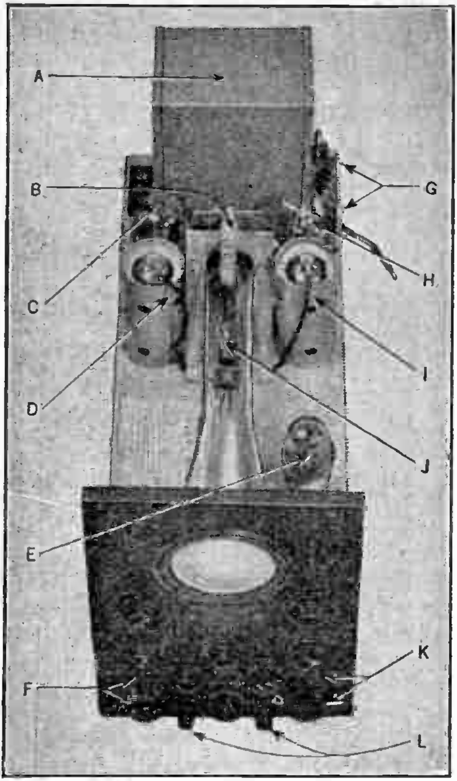


FIG. 7—View of RCA oscillograph with cover removed. The parts are as follows: *A*, power transformer, supplies power for all tubes and rectifier circuits—oversize to prevent stray magnetic fields; *B*, spring mounted cathode ray tube socket; *C*, low voltage full wave rectifier—supplies amplifier tube; *D*, vertical amplifier, high gain, wide frequency range; *E*, gas triode, "saw-tooth" timing axis oscillator; *F*, input binding post; *G*, vertical and horizontal beam centering adjustment—provide a simple means of centering beam on screen; *H*, high voltage half wave rectifier—supplies 1,200 volts to cathode ray tube; *I*, horizontal amplifier—high gain, wide frequency range; *J*, cathode ray tube—3 in. screen; *K*, binding posts for external horizontal deflecting voltage; *L*, binding posts for external synchronizing voltage.

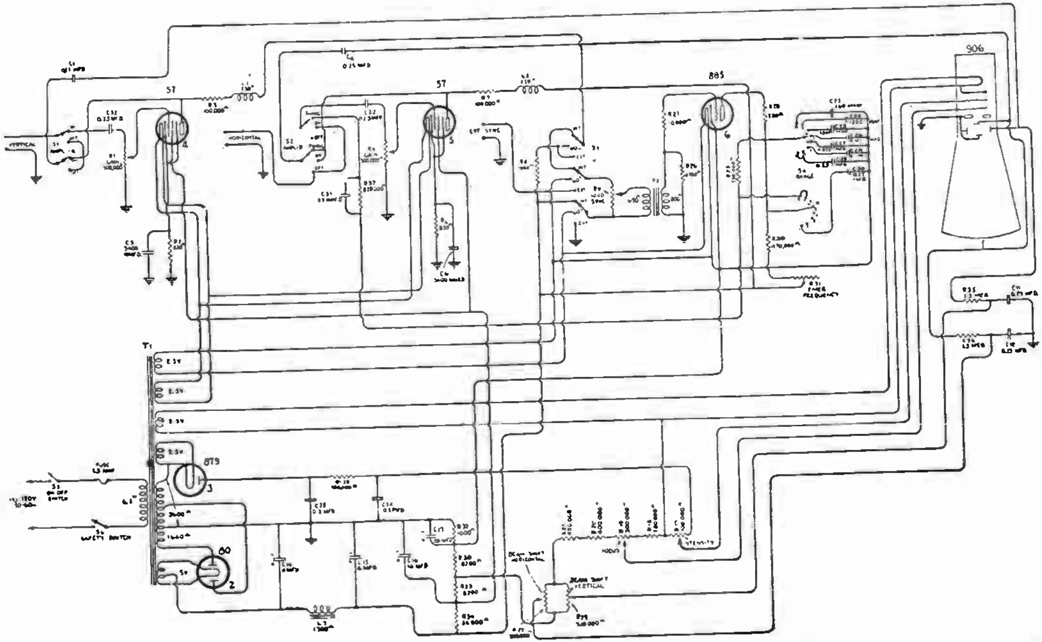


FIG. 8—Schematic connection diagram of R.C.A. type TMV-122B cathode ray oscillograph.

Various designs may vary slightly, although principally the number of elements employed are the same.

In commercial types of cathode ray oscillographs, the deflection of the cathode ray beam is caused by an electrostatic field produced by an impressed alternating current applied across either of two plates (*C*) or (*D*), fig. 1.

Two types of cathode ray tubes commonly employed for radio servicing are 906 or 908. The construction of the two are similar, the only difference being in the screen coating employed.

The use of No. 906 in a typical oscillograph circuit is shown in fig. 9. In this circuit the electrode voltages are obtained from the bleeder circuit connected across the high voltage supply.

Regulation of *spot size* and *intensity* can be accomplished by the variation of No. 2 anode current and voltage. The current to anode No. 2 may be increased by reducing the bias voltage applied to the control electrode (grid No. 1). An increase in the No. 2 anode current increases the size and intensity of the spot. An increase in the voltage applied to anode No. 2 increases the speed of the electrons, which increases spot intensity and decreases spot size.

In applications involving extremely accurate measurements, the No. 2 anode current should be reduced to the minimum value consistent with the desired brilliance of pattern. Where high brightness is an important consideration, the No. 2 anode voltage may be increased to the maximum rated value. This procedure, however, is not always desirable since the greater electron speed causes reduced deflection sensitivity.

The maximum input power to the fluorescent screen should not exceed 10 mw. per sq. cm. except for short-interval operation. The use of screen-input power in excess of this value will adversely affect the fluorescent coating, depending on the magnitude and the duration of the power input. The resultant injury to the screen may be a temporary loss of sensitivity, or a permanent destruction of the active screen material.

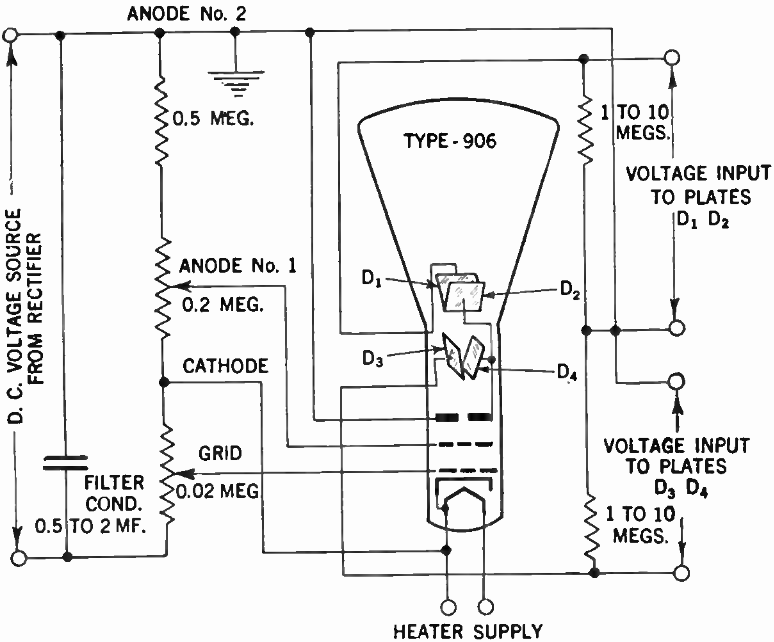


FIG. 9—Schematic diagram of cathode ray tube connection in an oscillograph.

A high intensity spot should be kept in motion by applying voltage to the deflecting system, in order not to exceed the maximum fluorescent screen input rating. Until this voltage is applied, the fluorescent screen input power should be kept low, either by applying a high negative control-electrode bias or removing the voltage from anode No. 2.

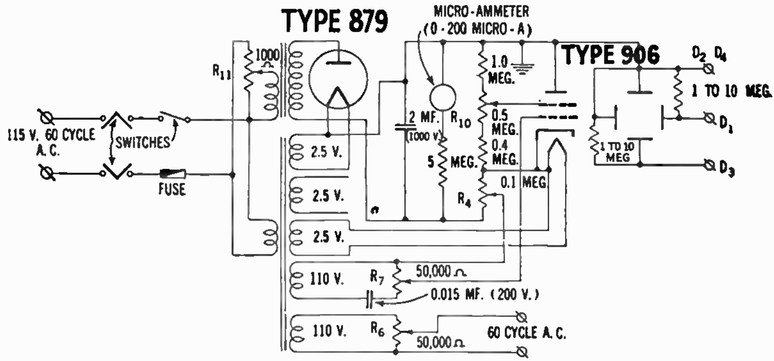


FIG. 10—Typical circuit for cathode ray oscillograph.

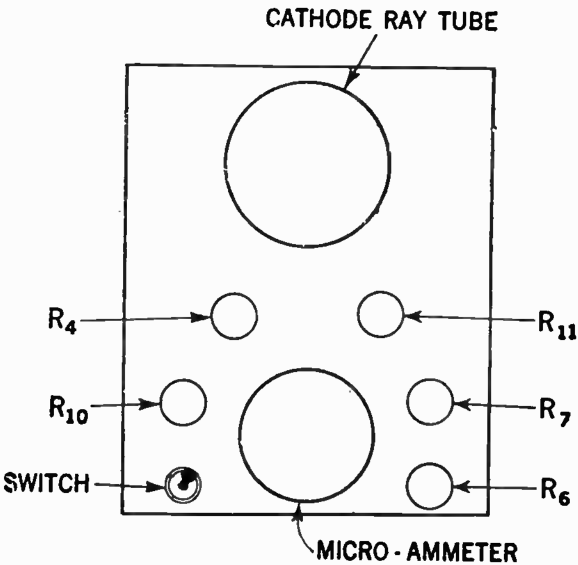


FIG. 11—Front view arrangement of oscillograph whose circuit is shown in fig. 10.

Time sweep circuits are of various types. The choice of circuit depends upon the type of phenomena under observation as well as upon the type of cathode-ray tube used. For recurrent phenomena, a periodic sweep with a repetition frequency adjustable to a simple multiple relation with the frequency of the phenomena is generally employed. For transient phenomena, a single sweep of the electron beam across the screen is ordinarily desirable; the starting of this sweep essentially coincident with the starting of the transient can be controlled manually, or automatically by electrical circuits, depending upon the application.

Supreme Model 546 Cathode Ray Oscillograph.—The front view and connection diagram are shown in figs. 12 and 13 respectively.

All the controls are located on the front panel for instant and convenient use. It has an intensity and focus control, also vertical and horizontal spot centering control. The vertical and horizontal amplifiers are built in, each using a 6C6 tube with graduated gain control.

The input impedance is 500,000 ohms at less than 20 micro-micro-farads input capacitance. Both amplifiers are flat from 15 to 90,000 cycles. The linear saw tooth time base or sweep voltage is developed by an 885 gas triode oscillator which covers a range of from 15 to 30,000 cycles in seven over-lapping steps, which make it possible to observe frequencies of up to approximately 300,000 cycles. A vernier control allows accurate setting of any frequency desired.

Another important feature is the high speed return trace eliminator which takes out the return sweep at high time base frequencies and eliminates distortion when observing high frequency patterns on the cathode ray screen.

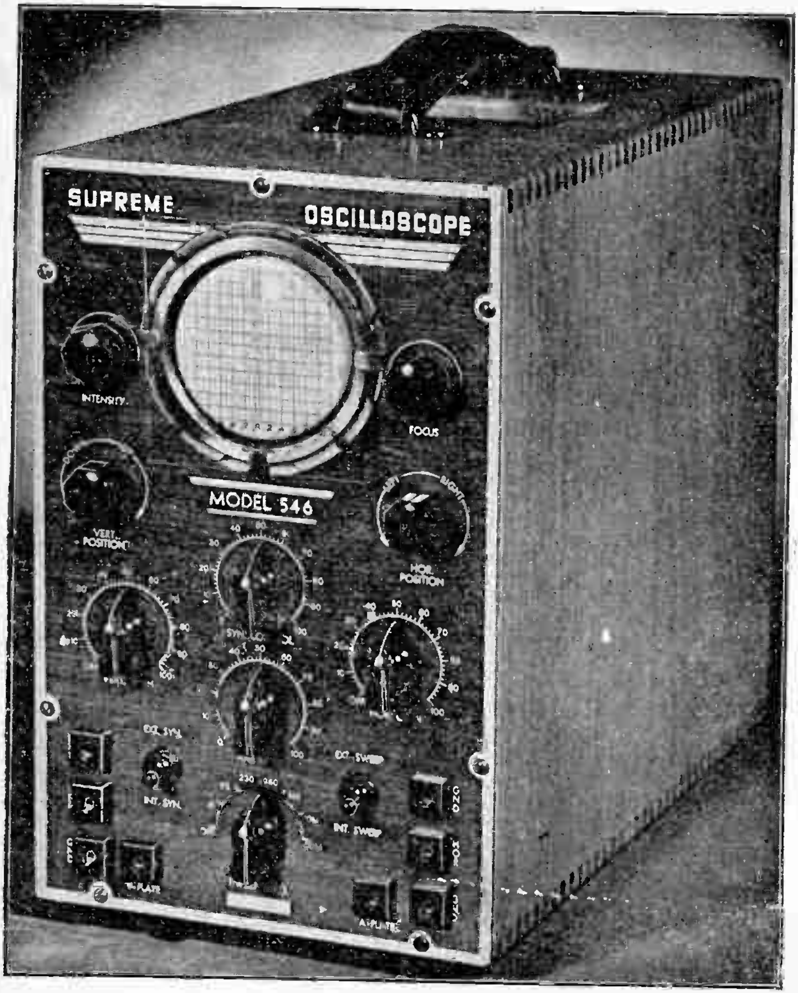


FIG. 12—Panel view of Supreme Model 546 cathode ray oscilloscope.

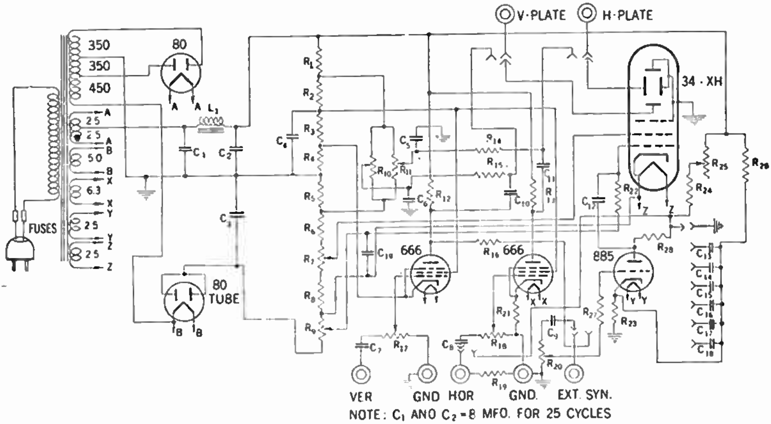


TABLE OF SYMBOLS AND RESISTANCE VALUES

R	OHMS	R	OHMS	R	OHMS	C	MFDS.	C	MFDS.
R - 1	25 M	R - 11	4.0 MEG.	R - 21	1000	C - 1	4.0	C - 11	0.05
R - 2	10 M	R - 12	0.13 "	R - 22	0.5 MEG.	C - 2	4.0	C - 12	50 MMFD.
R - 3	10 M	R - 13	0.10 "	R - 23	1000	C - 3	0.5	C - 13	0.2
R - 4	220	R - 14	1.0 "	R - 24	1.0 MEG.	C - 4	8.0	C - 14	0.04
R - 5	0.25 MEG.	R - 15	0.5 "	R - 25	4.0 MEG.	C - 5	0.05	C - 15	0.01
R - 6	0.75 "	R - 16	1.0 "	R - 26	0.1 MEG	C - 6	0.05	C - 16	0.0025
R - 7	0.50 "	R - 17	1.0 "	R - 27	0.1 MEG.	C - 7	0.1	C - 17	600 MMFD.
R - 8	0.10 "	R - 18	4.0 "	R - 28	500 ⏜	C - 8	0.1	C - 18	200 MMFD.
R - 9	0.20 "	R - 19	1.0 "			C - 9	0.05	C - 19	0.5 MFD.
R - 10	4.0 "	R - 20	15 M			C - 10	0.05		

FIG. 13—Schematic wiring diagram of Supreme Model 546 cathode ray oscilloscope.

The operator has a choice of internal or external synchronization, and of either the internal linear sweep or any external sweep.

The rectifier uses two type 80 tubes in a special series circuit. The first one operates a full wave rectifier to supply operating voltages to the two amplifiers and the linear sweep oscillator.

In series with the full wave rectifier is another 80 tube operating as a half-wave rectifier to build up the operating potential to 1,200 volts for the cathode ray tube.

This modern rectifier circuit minimizes the reaction of the amplifiers and 885 gas triode, as adjustments are made about the cathode ray tube and greatly stabilizes their operation.

Operating Notes on Cathode Ray Tubes.—The size of cathode ray tubes for oscillograph work may vary for different applications, although the average length will be approximately 12 inches with a screen diameter of between 4 and 5 inches.

The base pins are generally designed to fit standard receiving tube sockets of the five- six- and seven contact type, which may be installed to operate the contacts.

On account of high potential encountered, the socket should be made of good insulating material and should be designed with adequate spacing between the contact springs to prevent voltage breakdown.

A socket designed with insulating baffles between contacts provides an additional factor of safety.

Some types of cathode ray tubes have all leads brought out to their base pins, while in others some of the electrode leads are brought out to caps on the bulb.

When iron or steel material is employed in the case, to minimize the effect of extraneous fields on tube operation, care should be taken that the metal is completely demagnetized.

The heater is usually designed to operate at 2.5 volts. The transformer winding supplying the heater power should be constructed to operate the heater at the rated voltage under average line conditions.

In most circuits where the design is such as to cause a high potential difference between the heater winding and ground, the heater winding should be adequately insulated to withstand the maximum high voltage that will be applied.

It is very important to note that the high voltage at which the cathode ray tubes are used are dangerous, and hence great care should be observed in the design of the equipment, to guard the operator against coming in contact with these voltages. Some of these precautions are: 1. Enclosure of high potential terminals. 2. The employment of interlock switches to break the primary circuit of the high voltage power supply when access to the apparatus is required.

In most cases it is recommended that the positive high voltage terminals be grounded rather than the cathode terminal, because this method places the cathode and heater at a high negative voltage with respect to the ground, and hence the dangerous voltages can more easily be made inaccessible.

Also in the use of cathode ray tubes, it always should be remembered that high voltages may appear at normally low voltage points in the circuit, due to condenser faults or incorrect circuit connections.

Therefore, before any part of the cathode ray or its associated circuit be touched, the power supply switch should be turned off, and both terminals of any charged condenser should be grounded.

Additional Applications.—In addition to the utilizing of the cathode ray tube in the oscillograph, the tube has found a large variety of applications in various fields, a few of which are:

In the power field. (*a*) For voltage and current measurement; (*b*) study of wave forms; (*e*) measurement of power; (*d*) measurements of hysterises curves.

In the industrial field. (*a*) Study of wave form of spark plug discharge; (*b*) pressure measurements; (*c*) gas engine detonation characteristics; (*d*) gas engine vibration study; (*e*) high speed transient phenomena; (*f*) torsisal vibration of axles.

In the medical field. (*a*) The electrocardiograph; (*b*) study of impulses from the brain.

In the electronic television field. As a scanning device in television transmitters and receivers.

Questions and answers on terms commonly employed in cathode ray tube operation.

Is there a difference between apparent line width and the apparent spot size on the luminous screen of a cathode ray tube?

Yes, the apparent line width can be different from the apparent spot size of the stationary spot because the screen luminescence is dependent upon the duration of excitation.

What must be noted in the observation of apparent spot size, and apparent spot diameter?

When the spot size is measured visually or from a photographic record, the resultant spot size is not necessarily the true spot size; therefore, the terms "apparent spot size" and "apparent spot diameter" should be used in such cases.

What is meant by "Beam current"?

The current in the electron beam at the screen, usually measured in microamperes.

Define "Beam voltage".

The instantaneous voltage of the electron beam at any point; usually referred to as the voltage of the beam at the point of deflection, where the beam voltage is substantially the same as the second anode voltage.

What is the candlepower distribution characteristics of a cathode ray tube?

The relation which when plotted is invariably represented by a polar curve illustrating the luminous intensity of a cathode-ray tube in a plane of the tube axis and with the screen at the origin. This characteristic shows how the candlepower of a luminescent screen varies when the screen is viewed at different angles.

What is meant by the electrostatic, deflection sensitivity of a cathode ray tube?

The ratio of the distance which the electron beam moves across the screen to the change in potential difference between the deflection plates; this is usually expressed in millimeters* per volt. The sensitivity varies inversely with the beam voltage at the point of deflection.

What is meant by the term "Defocus"?

A term used to describe a spot which is not optimum with respect to shape and size.

What is meant by the following efficiency terms used in cathode ray tube operation:—(a) Gun current efficiency; (b) Screen actinic efficiency; (c) Screen luminous efficiency; (d) Screen radiant efficiency.

(*a*) The ratio of the beam current to the current which leaves the cathode. This ratio, multiplied by 100, gives the gun-current efficiency in per cent.

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*One millimeter = 0.03937 inch.

(*b*) The measure of the ability of a viewing screen to convert the electrical energy of the electron beam to radiation which affects a certain photographic surface. This term should be expressed in microwatts *per* watt, but is often expressed for ease of measurement in terms of actinic power per watt relative to a screen of well-known characteristics.

(*c*) The measure of the ability of a viewing screen to produce visible radiation from the electrical energy of the electron beam. The efficiency should be measured in lumens per watt. For convenience of measurement, however, it is usually expressed in candlepower per watt, because candlepower is a measure of the luminous flux per unit solid angle in a given direction and can be converted to lumens where the candlepower-distribution characteristic of the screen is known. It is usual practice to measure candlepower in the direction normal to the screen.

(*d*) The measure of the ability of a viewing screen to produce luminescence from the electrical energy of the electron beam. The efficiency should be expressed in microwatts per watt, but due to the difficulty of making absolute measurements, is more often expressed in radiant energy per watt relative to some screen of well-known characteristics.

What is meant by Fluorescence of the screen in a cathode ray tube?

The luminescence emitted by a phosphor during excitation. As applied to a cathode ray tube, this term refers to the radiation emitted by the viewing screen during the period of beam excitation.

What is meant by the true line width as distinguished from that of the apparent line width of a cathode ray tube?

The true line width is the width of the moving spot measured at right angles to its direction of motion.

What is meant by luminescence of the screen in a cathode ray tube?

The term describing all forms of visible and near-visible radiation which depart widely from the black-body radiation law. It can be divided according to the means of excitation into many classes, such as:

Cando-luminescence—luminescence of incandescent solids

Photo-luminescence—luminescence created by exposure to radiation

Chemi-luminescence—luminescence created by chemical reactions

Electro-luminescence—luminescence given off by ionized gas

Bio-luminescence—luminescence emitted by living organisms

Tribo-luminescence—luminescence created by the disruption of crystals

Crystallo-luminescence—luminescence excited by emissions from radio-active materials

Galvano-luminescence—luminescence phenomena observed at electrodes during some electrolyses

Cathodo-luminescence—luminescence produced by the impact of electrons

etc.

In cathode ray tubes, cathode-luminescence is principally involved: therefore, the luminescence of the screen is that radiation which is produced by the impact of the electron beam.

What is generally understood by the term luminescent spot on the screen of a cathode ray tube?

The spot formed on the screen of a cathode ray tube at the impact point of the focused electron beam.

What is understood by "pattern distortion" on the screen of a cathode ray tube?

When the electron beam is moved by changing fields, a pattern is formed on the screen; the wave form of the spot movement will be identical with the resultant wave forms of the electrical phenomena producing these fields unless there be pattern distortion present. This distortion takes many forms, such as: amplitude, frequency, phase, brightness, persistence, spot size, etc.

What is meant by the following characteristics as applied to the cathode ray tube? (*a*) Persistence; (*b*) spectral; (*c*) actinic spectral; (*d*) visual spectral.

(*a*) The relation showing the brilliance of light emitted by a cathode ray tube screen as a function of time after excitation. This characteristic is generally shown in a curve where relative brilliance as the ordinate is plotted on a logarithmic scale against time on a linear scale. *Relative brilliance* is used to denote luminous intensity per unit area evaluated in arbitrary units;

(*b*) The relation between the radiant energy per element of wave-length and each wave-length of the spectrum. It is generally shown in a curve plotted with relative radiant energy against wave-length in angstroms,* microns, or millicrons. *Relative radiant energy* is expressed in arbitrary units of radiant energy.

(*c*) The relation between the energy per element of wave length which affects a certain photographic surface, and each wave length of the spectrum. This is generally shown in a curve

*One Angstrom unit is equal to one ten millionth of a millimeter (0.0000001 m.m.) = 10^{-10} meters.

plotted with relative actinic energy against wave length in angstroms, microns, or millimicrons. *Relative actinic* energy is obtained by multiplying the relative radiant energy values (taken from the screen's spectral characteristic) for each wave length by the relative sensitivity of a given photographic surface at that wave length.

(*d*) The relation between the luminous energy per element of wave length and each wave length of the spectrum. It is generally shown in a curve plotted with relative microns. *Relative luminous energy* is obtained by multiplying the relative radiant energy values (taken from the screen's spectral characteristic) for each wave length by the relative response of the eye at that wave length.

What is the purpose in the use of phosphor on the screen of a tube?

It is used on account of its ability to produce luminescence when actuated by an electron beam.

What is meant by phosphorescence in a cathode ray tube?

The luminescence emitted after excitation. As applied to a cathode ray tube, this term refers to the radiation which persists after the electron-beam excitation has ceased.

What is meant by the following terms: (*a*) *Spot diameter;* (*b*) *Spot distortion;* (*c*) *Spot size?*

(*a*) The term used to express the true size of a round spot;

(*b*) The condition of a spot which is not optimum with regard to shape.

(*c*) The true dimension or dimensions of the spot. Spot size may be measured under various conditions, and is commonly designated by such names as *spot diameter* or *line width*. When the spot is stationary, its size can be measured in any direction, but is usually determined by its dimensions along the longest and shortest axes.

CHAPTER 32

Radio Trouble Pointers and Interference Suppression

(Questions and Answers)

It is now generally recognized that successful radio receiver trouble-shooting or radio servicing requires an intimate knowledge of thousands of component parts constituting the receiver.

Years ago, when the best receiver consisted of a condenser, a coil and the catwhisker thrown together in haphazard manner, anybody in possession of a buzzer, a pliers and a screw-driver. could find and eliminate the trouble in short order.

However, since then, radio receivers have gone through an epoch of revolutionary changes—a glance underneath the chassis of a modern receiver for example will illustrate how every fraction of an inch is literally crammed with radio components —which themselves contract in size as time goes on.

There is a bewildering array of colors stamped into the radio parts, and an equal splash of dazzling colors on the connecting wires. In addition, variable condensers, potentiometers, and other moving parts are built in such a manner that it takes special tools and expert handling to adjust or remove them.

Finally, after a look at the dial—the dial mechanism and the various remote control features, it is still more evident that a very fundamental knowledge as well as a thorough understanding is required for servicing the modern radio receiver.

It is self-evident, therefore, that with the increasing refinement and complexity of the receiver, the more susceptible it becomes to various kinds of *interference* and *troubles*, and the more specialized knowledge will be required to eliminate it.

Where does radio interference originate?

There are four broad classifications into which interference normally falls, namely: 1, *that caused by electrical devices;* 2, *by various radio stations or the neighbor's receiver;* 3, *originating in the receiver itself;* 4, *natural static.*

The *first classification* is of interest, particularly to city dwellers where elestrical devices are very numerous and their usage condensed. The average city apartment house is a veritable generator of all kinds of so-called man-made radiation interference. The various offending sources to give a few examples are: electric bells and buzzers; elevator motors and contactors; sign flashers; X-ray machines and ultra-violet ray units used by physicians; third rail contacts on elevated structures; overhead wires on trolley lines, etc.

The *second classification* also is more of a problem to city populations than to others. Here, on apartment house roofs for example, several dozens of aerials usually are mounted very close together, with very little thought or method, hence there is bound to be a certain amount of inter-play between the aerials and the set they serve. In addition if some sets are capable of regeneration or circuit oscillation without blocking means, the result will be a constant squeal, sometimes affecting receivers located several blocks distant.

The *third classification* is a problem for the receiver designer, and the serviceman, to be on constant guard against causes of noise. Very often a faulty condenser for example may give rise to an appalling amount of noise. This usually will be blamed on everything, from static to the neighbor's receiver, until found and corrected.

The *fourth classification* deals with natural static, and there is very little anybody can do. It is self-evident that there is no control, or nothing that can be done to prevent it. Although the amount of actual disturbance in this case is less noticeable in locations of strong transmitters and where the serviceable areas are well proportioned, at present at least, there is no remedy for noise for example emanating during a heavy thunderstorm.

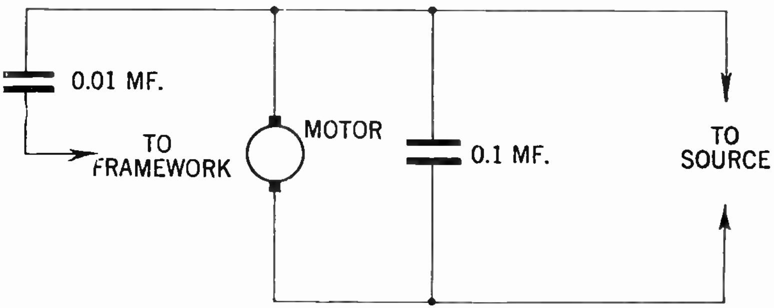


FIG. 1—Schematic diagram showing connection of interference suppressors to a vacuum cleaner.

How may radiation interference caused by an a.c. vacuum cleaner be eliminated and what are the proper condenser capacity values to be employed?

Condensers of the values commonly used for interference suppression purposes on fixed electrical machinery are not necessarily suitable for ungrounded appliances such as vacuum cleaners. A break-down in insulation between the electrical circuits and the metal frame-work of the cleaner might cause an unpleasant (or even dangerous) shock to the operator if the condenser capacity be too high.

Fig. 1 illustrates schematically the connections and values of condenser suppressors generally used on vacuum cleaners or similar portable appliances. It is necessary to observe that the capacity values recommended should not be exceeded, also the voltage rating of the condensers should be the same as that of the voltage employed in operating the appliance in question.

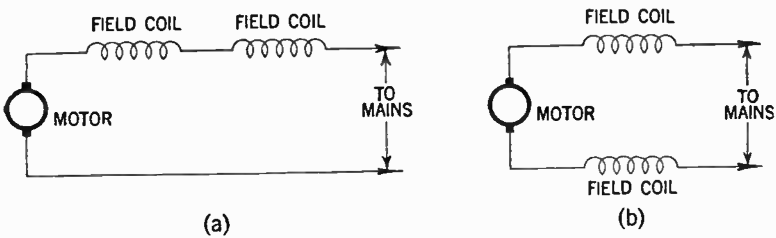


FIG. 2—Diagram indicating how internal connections of a motor may be altered to cause less radiation interference.

How may field coils, of a small d.c. motor employed to drive a lathe, be rearranged so as to cause less radiation interference?

Assuming that the motor is series-wound (i.e. the field coils are in series with the armature), it is probable that a simple alteration will reduce the radiation of interference.

Normally the field coils are connected as shown in fig. 2 (a). By rearranging them as shown in (b) with one coil on each side of the brushes, the bad effects on commutator sparking are reduced due to the fact that the coils now act as radio frequency chokes and prevent interfering impulses generated by the sparks from passing out to the wiring. Rearrangement of the coils in the manner described should have no adverse effect on the operation of the motor.

Is there a possibility that interference of reception can be caused by a Diesel engine located in the proximity of the receiver?

Interference from ordinary internal combustion engines originates in the electrical ignition system, which is absent in the Diesel engine, and accordingly a compression ignition engine of this type is totally incapable of causing electrical interference.

How should interference suppressors (condensers) be connected in order to mitigate leakage in a wiring system?

From a consideration of fig. 3 (a) it is fairly clear that as one of the main cables is grounded at the power station, full main potential is applied between the condenser and ground. Although the leakage current is largely wattless, it is a source of embarrassment to power station operators and so should be avoided. One of several ways of avoiding appreciable leakage is to use condensers much smaller than the standard value of 2 mfd.

A capacity of 0.01 mfd. is generally recommended and in most cases proves to be effective. Another method of reducing leakage to negligible proportions is to connect the conventional type of suppressor in the manner illustrated in fig. 3 (b). This arrangement is recommended by certain supply companies.

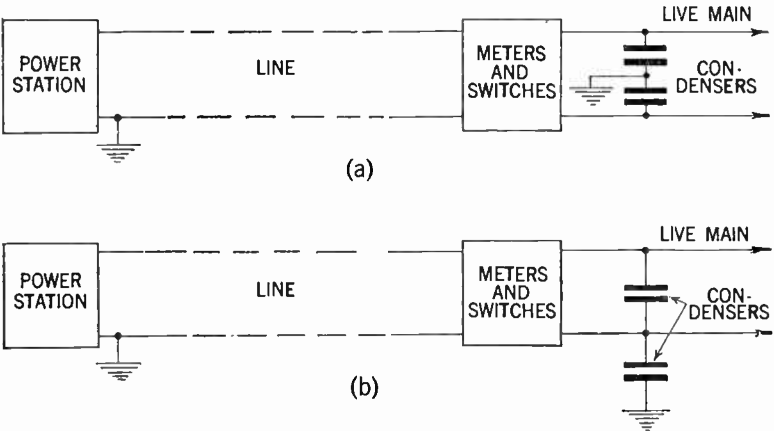


FIG. 3—Outline of connections of interference suppressors, to prevent leakage in an *a.c.* wiring system.

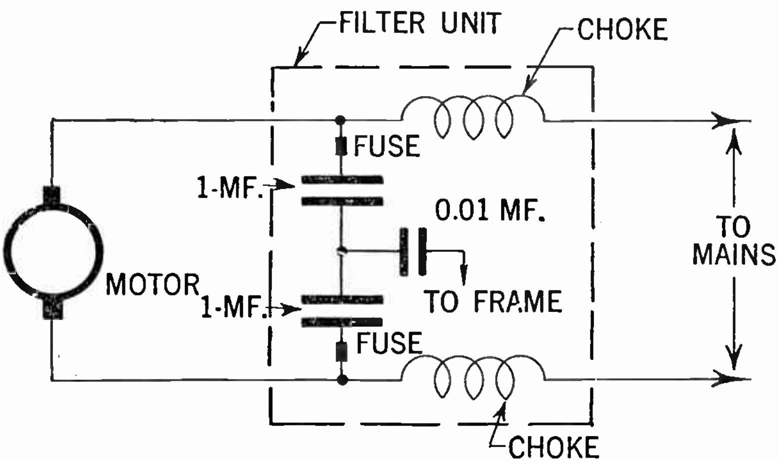


FIG. 4—Arrangement and connection of radiation interference suppressor unit to washing machine.

It is desired to eliminate the radiation interference caused by a washing machine. How may this be accomplished and what are the component values?

This trouble will be eliminated by connecting a filter unit as shown in fig. 4. Necessary precautions should be observed that the values of the filter unit does not exceed the values given, also that the voltage and frequency of the source is similar to that of the manufacturers marking on the filter parts.

How is it possible to locate or to track down suspected sources of man-made static?

This is usually done by a device known as interference locator, usually a portable receiver with a highly directional antenna or radio frequency pick-up system.

How may radiation interference emanating from a motor generator set be eliminated?

Interference of this sort is generally suppressed in the same manner as that of previously described electrical equipment. Referring to fig. 5 employing the same number of condensers as there are incoming and outgoing wires in the system to be filtered. The condensers should not exceed the values given.

How does radiation interference originate in a switch and how may it be eliminated?

Radiation interference of this sort is generally due to defective contacts in the switch, causing a spark which may be of short duration and occur only at switching, in which case a short click will be noticed in the receiver. At other times the

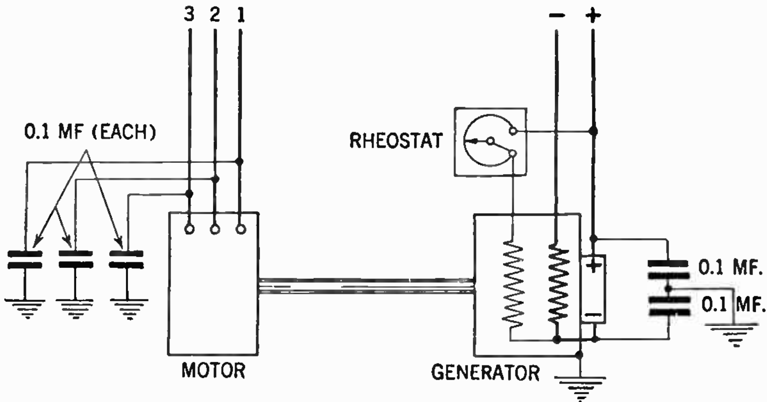


FIG. 5—Interference suppressor arrangement and connection for motor-generator set.

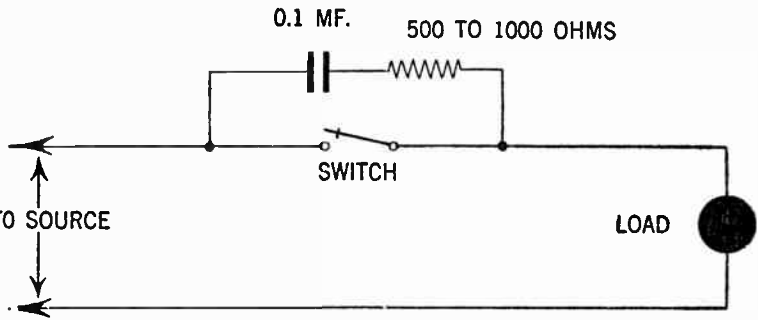


FIG. 6—Method of filter connections across switch.

spark will be observed intermittently causing prolonged scraping or howling. The remedy depends on the extent of damage in the switch. If the switch is relatively inexpensive, a replacement will most likely solve the problem.

However, if the switch be only slightly worn, a thorough cleaning and smoothing of the contact surface will prove to be helpful. A resistance capacity filter shown in fig. 6 is commonly used as a switch interference eliminator. This filter is connected in parallel with the switch. The proper sizes of resistor and condenser depend on the current drawn by the circuit. In most instances a 500 to 1,000 ohms resistor and a condenser of 0.1 microfarad will be found satisfactory.

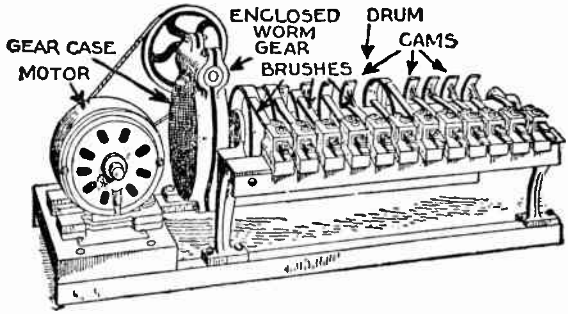
What can be done to eliminate the interference caused by a Neon sign?

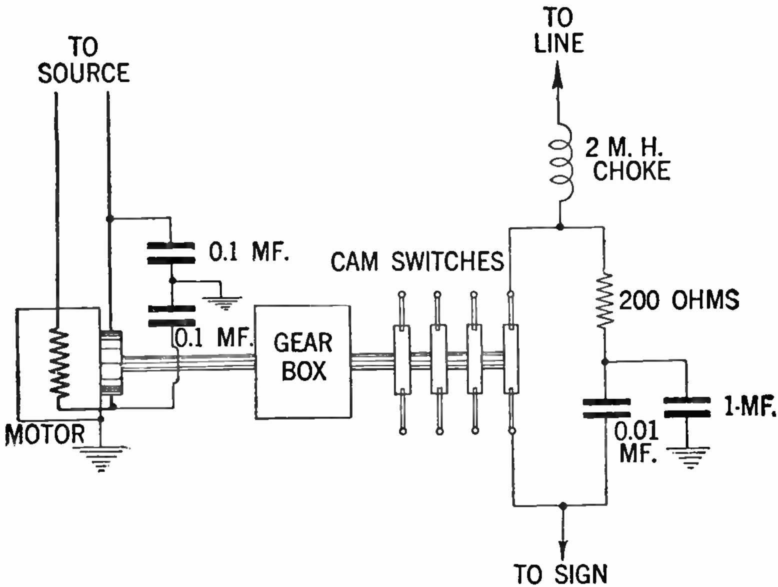
It is a well known fact that Neon signs are notorious offenders in the matter of radio reception disturbance. The flasher device is nothing but a set of switches and hence will be treated similarly to that employed to silence switch disturbances.

Another source of disturbance is arching between connections particularly in the electrode housing, or between cable ends. Again interference may be caused by flickering tubing, overloaded transformers, faulty insulation, corona discharges between tubing and ground, loose connections, ungrounded transformer case, etc.

When reception interference has been found to be caused by the sign, each one of the aforementioned trouble sources should be investigated. As a general rule, however, it has been found that the employment of filters across switch contacts, and also across the primary winding of the transformer, will mitigate the trouble.

It has also been found effective to include a choke properly insulated in between the letters of the sign. Diagrams of connections to effect the above improvements are shown in figs. 8 and 9. When filters are installed, it should be remembered that the designs of components employed must be able to withstand the potentials and the current (in the case of radio frequency chokes) which must flow through them.





FIGS. 7 and 8—Layout of switch controls and schematic diagram of electrical connections for lightning type sign flasher.

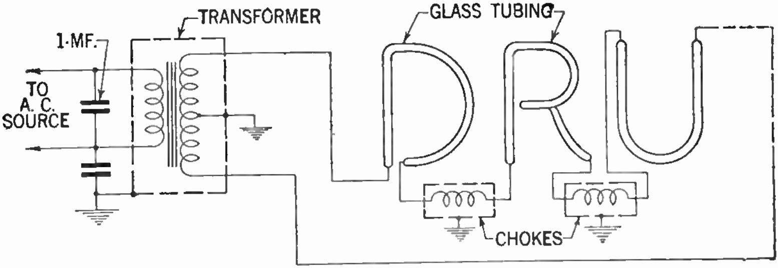


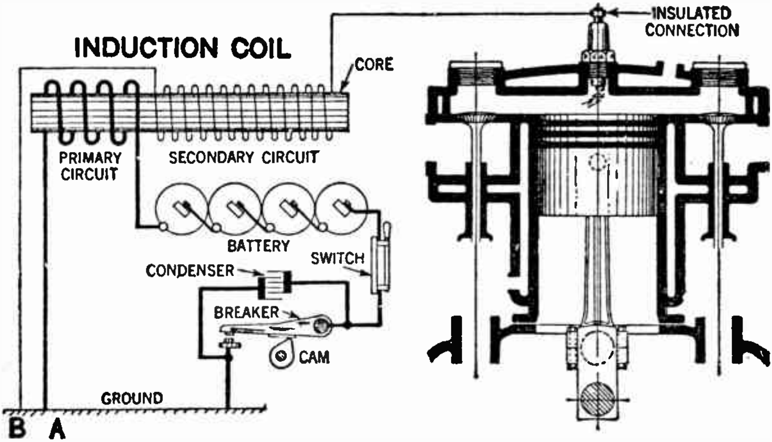
FIG. 9—Typical connection diagram showing interference suppressor arrangement as applied to Neon signs. Chokes, if used, should be of sufficient size to carry the required current without undue heating.

Where does radiation interference affecting an automobile radio receiver usually originate?

In the electrical system, and particularly so in the ignition system of which a schematic diagram is shown in fig. 10. The interference originating in the ignition system is usually referred to as *ignition noise interference* and emanates from the electric sparks in various parts of the system, such as in the spark plugs, distributing head, loose contacts in the wiring system, etc.

What can be done to eliminate radio noise emanating in the electrical system of the automobile?

There are a number of precautions to be observed in order to be able to successfully cope with this problem and the author believes that the method of *suppression of ignition and generattor noise* as described in a bulletin furnished by the General Electric Co. in relation to installation of their popular automobile radio Model N-60, gives a good set of instructions. They are as follows:



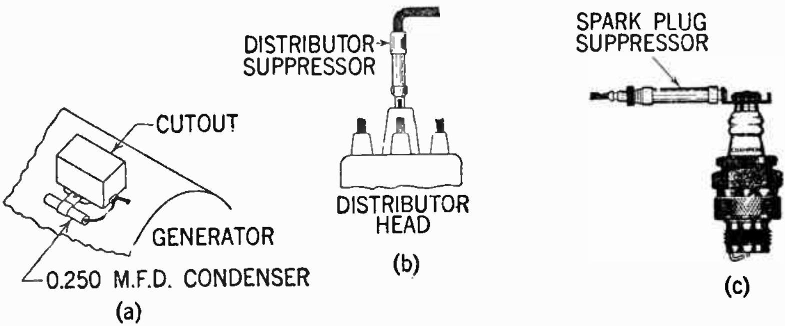


FIG. 10—Fundamental schematic diagram of ignition system of an automobile.

FIG. 11—Method of installing radio interference suppressors in the electrical system of an automobile.

Distributor Suppressor.—Remove the high tension lead to the distributor. Insert a distributor suppressor and connect the wire to the other end of the suppressor (see fig. 11b). If this be not practical, cut the high tension lead close to the distributor and use a wood screw end type distributor in this line.

Generator Condenser.—The generator condenser is installed at the cut-out as shown in fig. 11 (a). The lead from the condenser goes to the terminal on the cut-out. In some of the new cars the cut-out relay is on the front of the dash or in some other location. It will be most convenient to mount this generator condenser at the relay.

Withdraw Antenna Cable Plug.—Turn on the receiver and start the engine. If motor noise be heard, proceed as follows:

Shielding High Tension Lead.—In some cars when the coil is mounted on the dash, the high tension lead from the coil to within about 4 ins. of the distributor must be covered with braided shielding and the shield grounded to the motor block or frame.

By-Pass Condenser.—Try a .25 or .5 mfd. condenser from the ammeter to ground. Try a condenser from the car fuse to ground, switch to ground, windshield wiper connections and various other 6 volt connections to ground, noting what effect these condensers have on the noise pick-up. Try a .25 or .5 mfd. condenser from the *hot* side of the coil primary to ground. In some cases this condenser may not help. It can be tried out, however, experimentally.

Spark Plug Suppressors.—If motor noise persists, spark plug suppressors should be installed. One suppressor is put on each plug as shown in fig. 11 (c). The majority of cars however will not require spark plug suppressors. Care should be taken that a good mechanical and electrical connection be made between the spark plugs, suppressors and plug wires.

Then re-insert antenna cable plug. If motor noise is heard when the antenna cable is reconnected, proceed as follows until the noise is satisfactorily reduced:

Dome Light Lead.—To determine the amount of noise due to the dome light lead, disconnect this lead at the ammeter, block, or where it is connected, coil it up, and tuck it as far as possible up in the column at which it comes down. Then, with the engine running, ground the end of this wire. If this be found to reduce the noise noticeably, interference is being radiated by the dome light lead.

Reconnect the dome light lead and try a .25 or .5 mfd. condenser from the connecting point of the lead to ground. If this does not cure the noise, disconnect the lead and encase it in braided copper shield from the point where it leaves the column post to the point of connection. Keep the lead as far away as possible from car ignition wires and ground the shield.

If the noise due to the dome light lead still persists, disconnect this lead and remove it from the front corner post, at which point it is generally run down. Run the lead down one of the side posts in back of the door and direct to the storage battery. If done in this manner this lead should be fused.

Bonding Cables.—Try grounding to the dash all cables and tubing which pass through it, such as oil lines, gas lines, etc. By means of a file, contact can be established between any of the lines and the dash, in order to determine whether such a ground will reduce the noise.

To bond the cables to the dash, clean the point of contact, wrap a length of braided shielding around the cable and solder the connection. Then solder the end of the shielding to the dash or ground it under a screw head if one is convenient.

Sufficient play should be left in the bonding shielding so that movement of the cables or tubing will not loosen this shielding from the dash.

High and Low Tension Leads.—In some cases, the high and low tension leads between the coil and distributor are run close together. In some cars they are in the same conduit. If this be the case, remove the low tension lead from this conduit. In any event, keep the high and low tension leads as far apart from each other as possible. Shield and ground the shield of the low tension lead, if separating the two leads is not sufficient.

Steering Column, etc.—It is possible for the steering column, foot pedals and brake lever to carry interference to the back of the dash at which point it may affect the radio receiver. See if each of these items are well grounded to the frame of the car. By means of a file or a braided shielding jumper, contact can be established between any of these items and the frame in order to determine whether such a ground will reduce the noise. A piece of 1 in. braided shielding should be used if such a ground be necessary and this shielding may be grounded under a screw head, nut or may be soldered in position.

Grounding Engine and Other Parts.—The engine must, in every case, be well grounded to the frame of the car. If it be not, use a very heavy braided lead for this purpose, similar to a storage battery ground lead. In like manner it may be necessary to check the grounding of the metal dash, instrument panel, radiator and hood to the frame of the automobile.

Weak Pick-up.—Noise, on occasion, may be due to weak pick-up caused by the automobile being in a shielded location or by a faulty antenna system. The action of the automatic volume control, due to the low pick-up, causes the set to operate at its maximum sensitivity, thereby increasing noisy reception, due both to external pick-up and internal conditions.

Loose Parts in Car—Noisy operation is also caused in some instances by loose parts in the car body or frame. These loose parts rubbing together affect the grounding and cause noises, due to the rubbing or wiping action. Tightening up the frame and body at all points and in some cases, the use of a copper jumper will eliminate noise of this nature.

Where does static interference in an automobile receiver originate, and what is usually done to eliminate it?

This kind of interference is most common in old or worn-out cars and usually originates in wheels and tires, and is identified as *wheel or tire static*. Another source of static interference is badly adjusted break linings, in which case the remedy is obvious. To eliminate wheel and tire static, it is well to have a clear understanding about the cause, as well as how to identify this particular form of interference.

The sounds developed in a receiver from wheel or tire static may be heard as an intermittent rasping or clicking, with the time intervals varying with the speed of the car, or maybe a steady hissing developed after the car reaches a given speed and will change only on the condition to be described.

Wheel and tire static occur only with the car in motion along the road and will occur whether the ignition is turned on or off. It will be most pronounced on asphalt or cement pavement but may be noticed in some cases on brick pavement or on a dry gravel road. To drive off the pavement, should stop the noise.

From the above it is clear that it is the *friction* between the dry pavement and the rubber tires of the car that generates static electricity which collects on isolated substances in the tires or on the metal wheels which may be electrically isolated from the body of the car by grease and oil. This electricity then discharges to the car body or road bed depending upon the potential developed and the distance to either. Generally the distinguishing symptoms between wheel or tire static is that if on application of the brakes the noise disappears, the noise is attributed to wheel static; if not, to tire static.

When the static interference has been identified as *wheel static*, the most commonly used method of elimination is to make a metallic contact between the movable wheel and the stationary axle end.

This is accomplished by inserting a large coiled spring inside the hub cap so that one end makes good contact against the end of the shaft and the other against the cap.

In case of *tire static* a large percentage of causes has been found due to the use of metallic (zinc oxide) balances used in the bottom of the casing as a valve stem balance. Where this occurs, it may be corrected by removing the casings and buffing out the inside with a wire brush and then wiping the casing thoroughly with benzine and cloth. Vulcanized spots or patches with a metallic glue base will also cause tire static. Sometimes tire static may be reduced to a neligible amount by changing the tires about from wheel to wheel.

How may a power transformer with a primary rating of 220 volt, 60 cycles and connected as shown in fig 12 (a) be reconnected for temporary use on a 110 volt, 60 cycles supply? An examination shows that the primary winding consists of two bobbins with an accessible junction.

The transformer should work quite satisfactorily with the primary section connected in parallel as shown in fig. 12 (b).

The secondary winding of the transformer should remain unchanged.

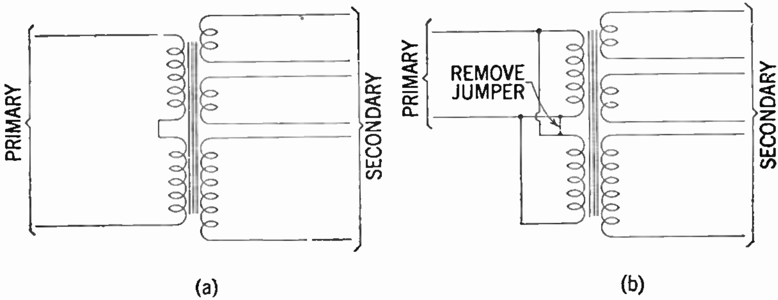


FIG. 12—Before connection to 110 volt source *remove* connection shown with dotted line and connect primary in parallel as shown in (b).

After design of an a.c. receiver, it is desired to check the various anode voltages. Maximum voltage is in the order of 400 volts, and the only measuring instrument obtainable is a multi-range ammeter of which the highest scale reading is 5 milliampere.

Bearing in mind that a voltmeter after all is nothing but a milli-ammeter fitted with a suitable value of series resistance, and then calibrated in volts, voltage readings accurate enough for practical purposes will be obtained by using the milli-ammeter (on the lowest range) in series with a suitable resistance. Ignoring the internal resistance of the instrument, a value of 100,000 ohms will do well and the meter will then measure voltages up to 500. By multiplying the readings in milliamps by 100 the dial indications may be readily converted into voltages; 2 milliamperes will correspond to 200 volts, 3 milliamperes to 300 volts, etc. Of course in this case as always voltage readings will be reasonably accurate only when the value of the external resistance is low compared with that of the meter resistance.

It is desired to us a standard 60 cycle a.c. receiver on and a.c. system of 25 cycles. Will this be possible and what changes or precautions if any should be taken?

This problem may be briefly summed up by the fact that almost any *a.c.* set may be made to work satisfactorily on a network of 25 cycles. Of course a specially designed power transformer must be used. This transformer will be somewhat larger than the one used on 60 cycle supply, and hence a slight modification of the original layout may become necessary.

It may also be necessary to change the relative positions of the power transformer and the *a.f.* transformer in order to minimize hum. There is also the question of smoothing. Theoretically, a considerable more generous smoothing system will be required, but in practice the ordinary smoothing circuit may be quite effective; this is because both the loud speaker and the human ear are less sensitive to the lower hum frequency of the 25 cycle supply. It is therefore recommended that additional smoothing condensers and possibly an extra choke should not be added until they are found necessary.

When operating a receiver of a well-known make, the power transformer becomes exceedingly hot, causing smoking and running of the pitch in fluid form, what may be the cause and how may this trouble be eliminated?

To correct the trouble a replacement of the power transformer will be necessary. The transformer to be installed should be similar to that originally installed by the manufacturers. However, before connecting it up, a thorough check up of resistance values is recommended.

It is desired to utilize a scratch filter, suitable for coupling a crystal phonograph pick-up to a high fidelity amplifier. How should the filter be connected, and what are the component values to be employed?

With reference to fig. 13 giving the schematic arrangement, it should be noted that with the components shown, the resonant period is approximately 4,000 cycles, the amount of attenuation being controlled by the 0.1 megohm variable resistor. If it be desired to shift this period to some other frequency, this will easily be accomplished by changing the value of either the 0.01 *m.f.* condenser or the 0.2 henry choke.

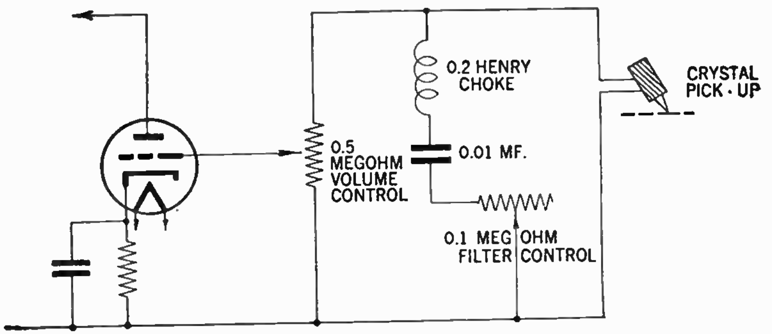


FIG. 13—Method of connection for phonograph pick-up.

In connection with the instalment of loud-speakers in a public address system, when should the speaker voice coils be connected in series and when should they be connected in parallel?

From the point of convenience it is preferable to connect the speaker voice coils in parallel. With reference to fig. 14 (a) it may readily be noted that the wiring will be considerably simplified when several speakers are employed, for example in the parallel system the use of a 3-wire cable in which one side of the voice coil and one side of the field are common may be used. In the series system shown in fig. 14 (b) however, a 4-wire cable is necessary for complete service to every speaker. Again from the point of efficiency the parallel system is superior; a loose connection for instance in any part of the series system will put the combined number of speakers out of service, whereas in the parallel system generally only one speaker will be effected.

What may cause a receiver to give normal reception for a short period of perhaps five to ten minutes, then suddenly go all "muzzy"?

There are several possible causes for such trouble—a defective tube; a break in the windings of an audio-frequency inter-stage or output transformer; a faulty power transformer. It is when the receiver reaches a certain temperature while warming up that they become manifest.

After giving satisfactory performance for some time, a super-heterodyne receiver fails to operate on the medium band of wave-lengths higher than about 400 meters. As the tubes in use are those originally supplied, is it likely that the trouble is due to failing emission?

It is reasonable to suppose that in the circumstances described, the defect is due to incipient failure of the frequency changer tube. The best course to follow would probably be to replace this tube, but its life may be prolonged a little by increasing the voltage applied to the oscillator anode or by tightening the reaction coupling.

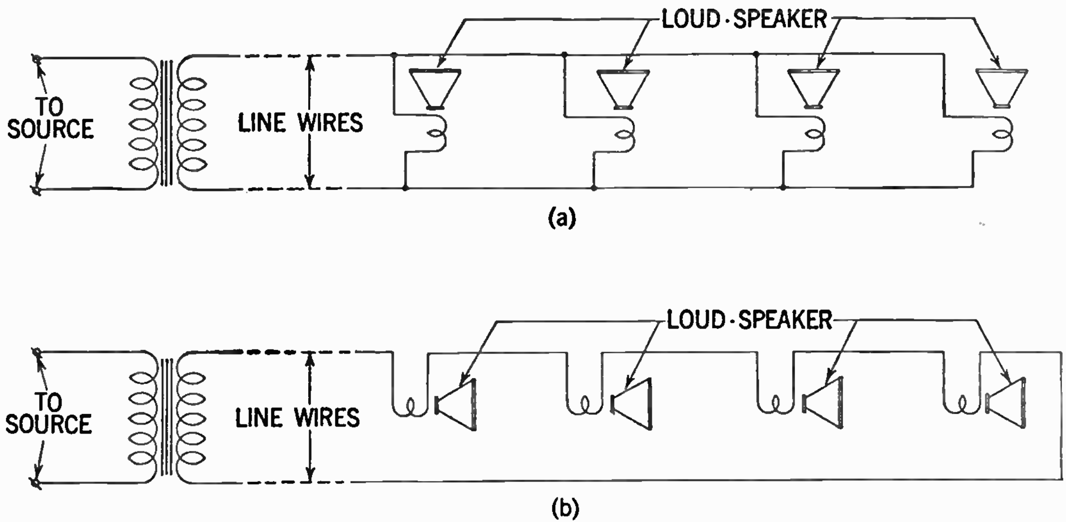


FIG. 14—Schematic diagram of series and parallel connected loudspeakers in a public address system.

How may modulation hum which is "given a ride" through the r.f. and i.f. circuits of a receiver on the back of any signal that may be passing through them be detected and cured?

A receiver which emanates hum only when it is tuned to a carrier wave gives the best example of trouble of this kind. This trouble is sometimes due to allowing main leads to run in close proximity to radio and intermediate frequency circuits, in which case the remedy is obvious.

More often, however, the interference enters by way of the main transformer, and nowadays a metal screen between primary and secondary is generally interposed as a barrier. In the absence of such a screen, the simple expedient of connecting a condenser of 0.001 mfd. between one of the main leads and ground is usually effective. The condenser should be rated for working at full supply voltage, and a connection to each main lead should be tried.

What may cause "distortion of sound"?

A defect in the loud-speaker—the voice coil may have loosened, or is off center. Lowering the tone volume may show difference in sound; and this localizes the trouble. The power tube or stage may be defective. Tuned circuits may not be properly aligned; in other cases the detector circuit may be overloaded, i.e. the signals are too powerful.

This may be determined by shortening the outside antenna, then noting the results; or the signal input may be lowered by reducing the volume by means of the control if the receiver is so wired that the volume control acts on the radio frequency tubes and not expressly on the audio tubes and stages.

What may cause "Fading" in a radio receiver?

Trouble of this sort is most likely to be caused by the following: Leakage within tubes; defective volume control; defective condenser resistor or other parts which changes in value with usage, or by extraneous conditions. The source of trouble is usually best found by an evaluation of circuit components; by means of the usual set analyzer or tube tester. In case replacement is required, care must be observed that correct components are used—otherwise, instead of eliminating the trouble it is likely to be exaggerated.

How may extensive squeals and pitch interference which changes with tuning, be eliminated in a receiver?

A type of interference referred to is often encountered in inexpensive receivers and usually appears as an annoying whistle on desired stations that changes in pitch as the receiver is tuned. This is known as image frequency interference and is due to lack of selectivity in the first detector circuit. (Constant pitch whistles are another matter and will be experienced even in high priced receivers.)

Using a shorter antenna will often help matters as it reduces pick up. This in itself has nothing to do with the interference ratio, as it also cuts down the strength of the desired signal. However, to compensate this loss in signal strength the volume control is turned up and this often sharpens the tuning of the first detector circuit.

That other type of interference—the pitch of which varies with tuning, is that of dot and dash code signals. This is due to code stations working close to the intermediate frequency of the receiver. A great many sets have a trap to reduce this type of interference, the adjustment for which appears as a small screw extending from the rear of the chassis. This screw should be adjusted until the interference is at a minimum. The adjustment can be made without much trouble.

However, in case of attack on the wrong screw, the original position of the slot should be noted, and the screw turned back to its original position, if no improvement is noted.

Will the all around performance of a receiver used for a year or more be improved by tightening grounds and other connections on the chassis base?

Yes, the operation of many receivers over one year old can be improved by this simple expedient—which is generally very simple to perform. In every receiver, dozens of by-pass condensers and resistors are grounded to the chassis by means of lugs and nut and bolt connections.

While the leads are soldered to the lugs, the connection between the lug and the chassis becomes oxidized in time, increasing the resistance of the connection to a considerable degree. In effect this places resistors in the receiving circuit where they do not belong with naturally detrimental results.

While the effect of such an added resistor in series with a resistor would ordinarily be negligible, it is another matter in the case of a condenser and the accumulative effect of many such resistors in series with a similar number of condensers may result in lowered sensitivity, instability, alignment shift, etc.

This effect can usually be eliminated by tightening all screws from the top of the chassis. Even when screws are already tight, the slight movement will be sufficient to erase oxidation. Most of the connections are made to the bolts that fasten the socket to the chassis, and it will generally be necessary to remove the tube shields to get at them.

How may noisy reception originating in the automatic motor driven tuning unit be eliminated?

The great multiplicity of parts necessarily associated with the tuning device is located immediately within the electric field surrounding the receiver; and as the mechanical connections loosen with usage, microphonic contacts are formed which cause noise.

A loud signal may be sufficient to induce a rasping accompaniment, as well as from any slight movement of the receiver, as might be caused by steps across the floor. In aggravated cases, a hissing scratch, akin to static, will be present at all times.

This difficulty can be removed by *bonding*—making a good electrical connection between the chassis of the receiver and the *floating* parts. Fasten a short length of flexible wire securely under some convenient nut or bolt on the chassis, and touch the free end to various portions of the framework supporting the timing mechanism, at the same time endeavoring to produce the sound by tapping the receiver.

If the rectifier tube of a receiver has become defective and trouble still exists after changing the tube, what may be the cause?

A defective electrolytic condenser. The heat, especially in midget type receivers where space is limited and ventilation poor, causes a drying up of the condensers and thereby a lowering of capacity. Voltage measurement of the output of the rectifier tube may show a decreased output, and hence point to condenser trouble.

If tubes do not light in a series wired receiver, what may be the cause?

A burned out tube or a loose connection. In a series circuit an open circuit will affect all tubes. In either case the remedy is obvious.

What important precautions should be observed when replacing parts in a radio receiver?

It is of extreme importance that they be of the identical types or of the same characteristics throughout, as the parts removed. If components of different values be inserted, they may upset the values of the circuits or cause trouble in other ways. A list of replacement parts for various receivers is usually furnished by the manufacturers of the various sets, and it is these parts that should be used for replacement, to prevent continuation and even exaggeration of the trouble.

What are the two general classes of resistors used in radio receivers, and where are they used?

The two types are classified as the wire-wound and the carbon type. Wire wound resistors generally are used where a comparatively large current is required to flow, such as in voltage dividers, and as power tube grid biasing resistors, etc. whereas the carbon resistor is utilized for small currents, i.e. the carbon resistor as a rule has a high resistance, and will usually handle power requirements up to 1 watt. The resistance value of a carbon resistor may be identified by means of special color code markings (see page 182) and the resistance of wire wound resistors are usually plainly marked or tagged on it.

Is it well to change or remove part of the wiring to eliminate trouble in a radio receiver?

Only where substitution of wires is absolutely necessary, but the circuit should not be changed. It is evident that if the circuit was incorrect the receiver would never have functioned in the first place. It may generally be assumed that before a receiver leaves the manufacturers test room, the circuit as well as its components are correct. Hence, servicemen should not change circuits on the assumption that they are wrong after the set has been operating properly for some time, but should seek to find the trouble that has occurred and rectify it.

How many short wave coils be assembled so as to cover a range of short waves as well as medium waves?

In order to be able to successfully cope with a problem of this sort, the following precaution should be taken: The several coil sections must be reasonably separated from each other, a minimum spacing of one-half in. is recommended. Opinion is divided as to whether to short out the unused sections or to use a change over, but actually neither method is satisfactory by itself. The main difficulty arises from absorption of any particular waveband from the coil serving the band immediately above it.

Thus in fig. 15 (a) consider the circuit switched from the reception on coils *C* and *D* in series, while coils *A* and *B* are shorted out. Absorption will be found however, at the wavelength corresponding to coil *B*, tuned with its own self capacity since it is actually not short-circuited.

As a rule when it happens to fall within the band covered by coil *C* a dead spot will result. In (b) is shown an arrangement with a change over switch and it will be clear that this trouble is still present—in fact in an aggravated form. The remedies are to arrange the sections of the coil so that they do not couple to one another, which is not always convenient, or else to arrange to short out the section immediately next to the coil in use, in conjunction with a normal shorting or change over scheme.

Figs. (c) and (d), illustrated the methods likely to be most suitable when critical reaction is being employed.

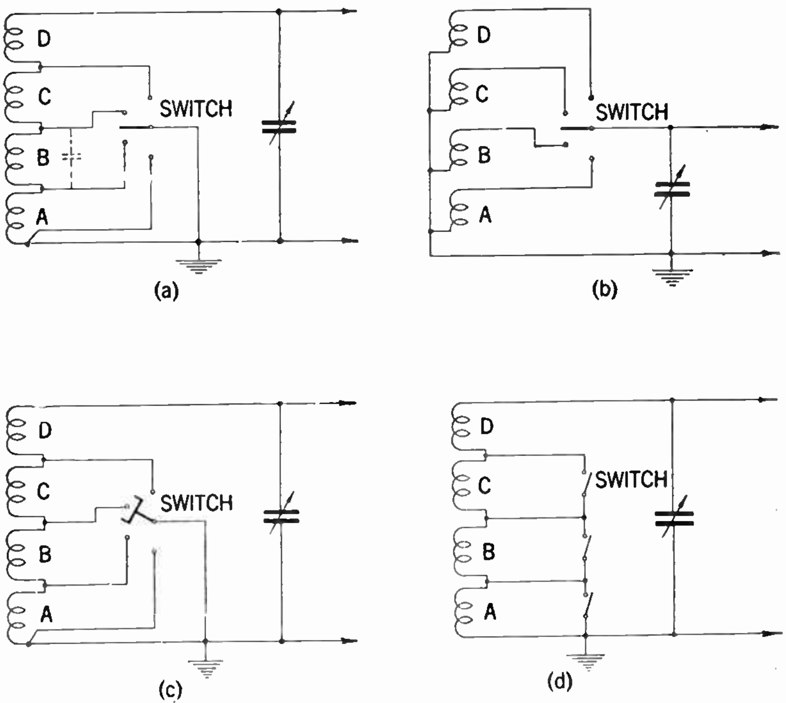


FIG. 15—Various coil switching arrangements for response on short and medium waves.

What is the simplest way to provide d.c. current necessary for testing of d.c. receivers—i.e. how may a.c. current be rectified to d.c.?

This problem may best be solved by building a power supply unit as shown in fig. 16. The circuit is largely self-explanatory and with an *a.c.* supply voltage of 110 volts the voltage on the *d.c.* side will be 110 volts as well, provided that the components as shown are used.

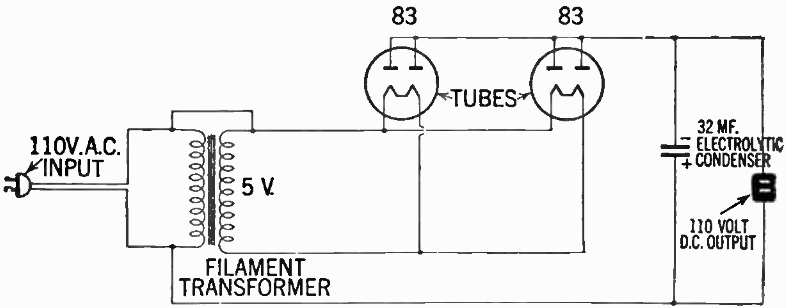


FIG. 16—A simple 110 volt-*a.c.*/110 volt-*d.c.* rectifier unit.

What is generally understood by the term high-fidelity as applied to radio amplifiers?

A set of tentative standards has been set up by the Engineering Department of the Federal Communications Commission for high fidelity transmitting stations. These standards may be applied to audio amplifiers with slight revisions. For example, the total audio distortion shall not exceed 10% at maximum output or 5% at rated output throughout the range of audio frequencies of from 50 to 7,500 cycles. The audio frequency characteristics of the amplifying system measured from the microphone terminals to the speaker voice coil terminal shall be flat within two decibels between 50 and 7,500 cycles.

Hum and other extraneous noises to be at least 60 decibels below peak-power output between 150 and 5,000 cycles, and at least 40 decibels below outside that range.

What can be done to compensate for voltage fluctuations which at times may amount to 10% or more?

A simple remedy may be afforded by the addition of a booster transformer shown in fig. 18. This transformer is con-

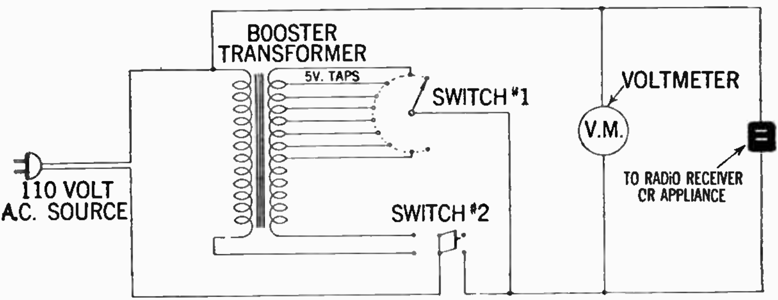


FIG. 17—Schematic diagram of voltage compensating equipment.

nected directly to the line circuit, feeding the individual appliance and thus stepping up the voltage, compensating for the drop. The transformer should have a rating in watts equal to or higher than that of the appliance which it feeds.

The transformer connection scheme is largely self explanatory. For example, switch No. 2 is the "on-off" control for the booster; when it is turned to the left it cuts in the booster and when turned to the right it removes the booster from the line.

As a precautionary measure the volt-meter should always be connected in the circuit when the booster is being used, to indicate excessive voltage. Switch No. 1 finally controls the amount of booster voltage added to the primary of the transformer.

It is suspected that a faulty winding in an audio-transformer is the source of a considerable amount of noisy and scratchy reception. What is the simplest way of locating this trouble?

A means of detecting this trouble may be had by the aid of a simple 4.5 volt dry battery connected to one side of the transformer and a pair of head-phones across the other side as shown in fig. 19.

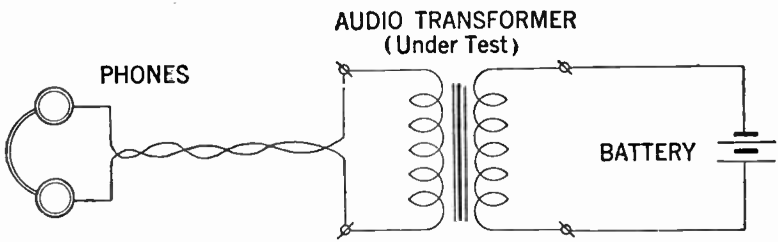


FIG. 18—Method of detecting trouble in audio transformer.

In the case of a defective winding in the transformer, a loud scratch will be heard in a few minutes. For a test of the other winding simply reverse the connections, i.e. connect the battery to the side where the 'phones previously were connected and the 'phones in place of the battery.

TELEVISION SECTION

CHAPTER 33

Television Antennas and Transmission Lines

General.—All present day television receivers, irrespective of their location with reference to the transmitting station, require an antenna for their proper functioning.

Television antennas may be classified according to their location as:

1. Built-in antennas.
2. Indoor antennas.
3. Window antennas.
4. Attic antennas.
5. Outdoor antennas.

*Built-in antennas**, as the name implies, are those which are a component part of the television receiver, and are designed by the set manufacturer to function without the aid of an exterior antenna.

Indoor type antennas on the other hand are designed for placement in the immediate vicinity of the receiver, and where the dipoles are usually adjustable both as to length and to V-angle.

*Most television receivers are equipped with built-in antennas connected to antenna terminal screws at the rear of the cabinet. In many locations, however, it will be found that an outdoor antenna will provide better reception. In case an outdoor antenna be used, the built-in antenna has to be disconnected from its terminal screws and the outdoor antenna leads connected in its place.

Window antennas are designed for mounting on the window sill and its vicinity, and takes various forms depending upon requirements.

Attic antennas are designed for mounting in the attic of small dwellings, from which point they are connected to the receiver in the conventional manner.

Outdoor antennas are generally designed for installation on roofs of dwellings and are usually supported by a suitable piece of galvanized iron piping or masts whose dimension depends upon the height of the antenna array.

Television antennas may also be classified with respect to their geometrical structure and number of elements involved, as:

1. Dipole antennas (straight or folded).
2. Conical antennas (double or single).
3. Yagi antennas, etc.

Antennas for television reception are manufactured in a great variety of types as shown in figs. 34 to 46, although for average reception in localities fairly close to the transmitter the half-wave matched dipole type with reflector is most generally employed.

The quality of the picture that is reproduced on the screen of a modern television receiver is dependent upon many factors, some of which are beyond the control of the receiver. The information presented here is intended mainly to assist the service man in determining the factor the antenna plays in the normal reception of television.

The strength of the transmitted picture signal that reaches the receiver is a vitally important factor in determining the quality of the picture that is reproduced on the screen. A very weak signal will produce an unsatisfactory picture. In locations where the signal is exceedingly weak the picture will display a milky appearance which is usually accompanied by a "speckled" or "snow" effect.

Television Transmission.—The very high frequency waves used for the transmission of television picture signals acts quite similar to rays of light, in that they do not bend around corners and are reflected by obstacles in their path.

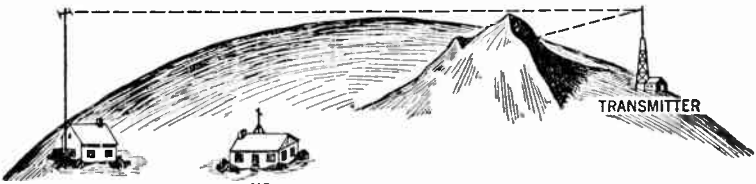


FIG. 1—Illustrating line of sight transmission. Due to the line of sight behavior of television signals, receivers located in obstructed areas will generally not receive television programs unless precautions be taken in the form of special antennas.

It should therefore be appreciated that television waves do not follow the curvature of the earth and reliable reception should only be anticipated in the region determined by the "line of sight*" to the horizon in all directions from the antenna tower of the transmitting station.

This region is generally designated as the "service area" of the station and includes an area having a radius of 50 miles

*The line of sight distance as denoted in television literature is the maximum distance which high frequency radio waves will reach without being impeded by the curvature of the earth. It is illustrated in Fig. 1 and is governed by the relationship

$$d = 1.41\,(\sqrt{h_t} + \sqrt{h_r})$$

Where d is the distance between antennas in miles
h_t is the transmitting antenna height in feet
h_r is the receiving antenna height in feet.

or more, depending upon the relative height of the transmitting and receiving antennas, and the terrain between them.

Since signal strength decreases rapidly when the "line of sight" distance is exceeded, it is not possible to reliably predict conditions which might prevail at greater distances away from the transmitter. The technician who installs the television receiver must always carefully check to determine if signals at a particular location are of satisfactory strength.

The characteristic of high frequency television signals which permit them to be reflected from the walls of nearby buildings or other objects, may under certain conditions, create "multiple transmission paths." This would permit the reflected signal to arrive at the antenna a short interval of time later than the signal travelling in a direct path from the transmitter and the effect produced on the picture of the television receiver consists of a multiple image. These multiple images, known as "echos" or "ghosts" may generally be prevented by careful installation and orientation of the antenna.

Transcontinental Television Transmission Systems.—Since television transmission is limited to "the line of sight," an efficient relay system is necessary to link the country into television networks. There are two principal systems presently used for this purpose. They are:

1. The underground coaxial cable system.
2. The micro-wave radio relay system.

The coaxial cable system consists principally of a special type of telephone cable capable of passing a wide range of frequencies without the usual prohibitive losses and distortion. For a successful television transmission over longer distances however,

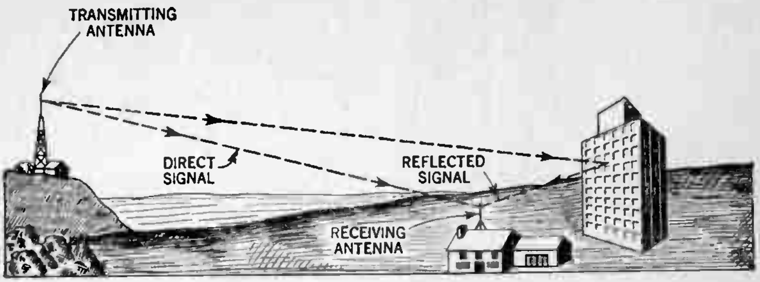


FIG. 2—Showing reflected signal path, causing multiple image or ghost on television receiver screen.

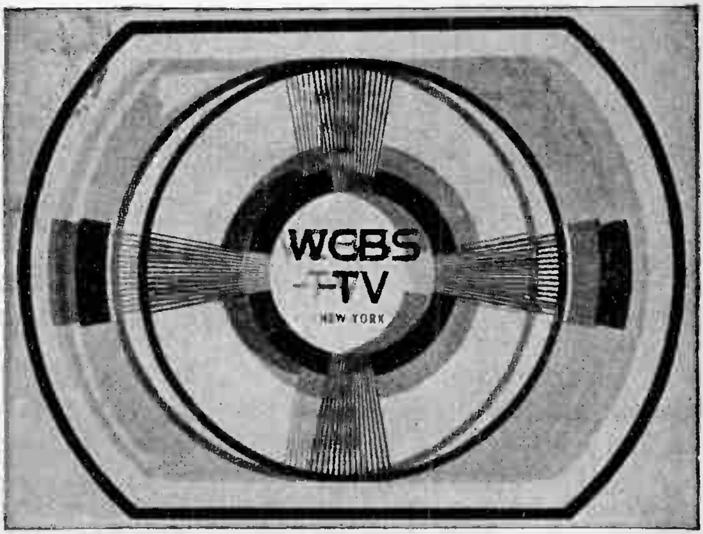


FIG. 3—Typical test pattern showing "ghost signals" due to reflected waves from intervening structures.

in addition to the coaxial cable, special repeater amplifiers (relay stations) are required spaced at an equal distance from one another.

The micro-wave radio relay system of increasing the range of television coverage, on the other hand, consists of a chain of towers located 10 to 25 miles apart. Each tower contains a receiver to pick up the signal from the preceding tower and a transmitter to rebroadcast it to the following tower.

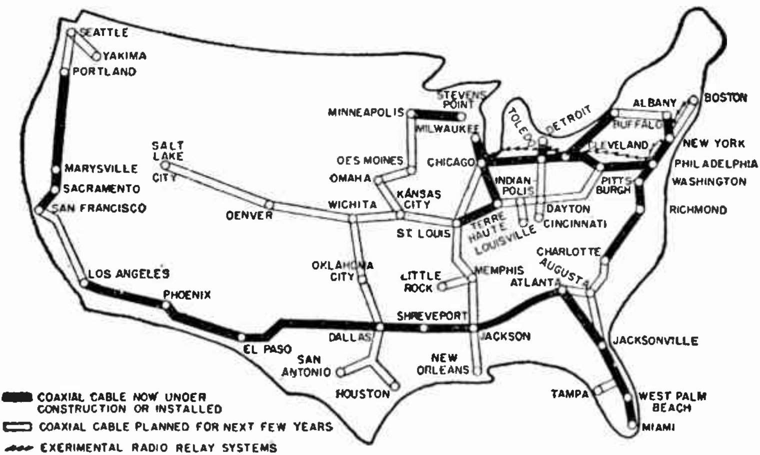


FIG. 4—Showing present status of transcontinental coaxial cable and radio relay system.

Receiving Antenna Principles.—For best reception each antenna should be selected with reference to distance and other factors covering the particular installation.

Fundamentally the three elements present in any television antenna installation are:

1. Antenna.

2. Transmission line.
3. Receiver.

The function of the antenna is to pick up the signal transmitted from the station and to transmit the signal to the receiver through the connecting transmission line.

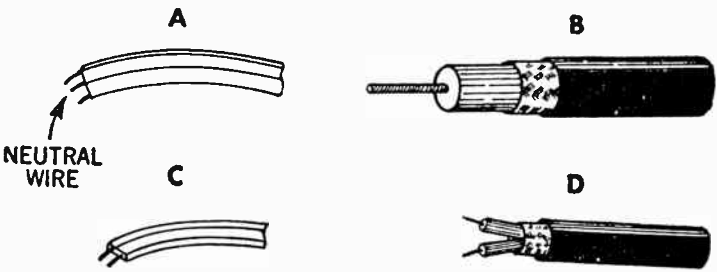
Transmission Lines.—There are four general types of transmission lines acting as a transmission link between the antenna and the receiver. They are:

1. The two-wire parallel-conductor type.
2. The coaxial cable type.
3. The twisted pair type.
4. The shielded pair type.

There are several constructional variations in the basic types of transmission lines. Prior to the introduction of the polyethylene dielectric two-wire transmission line, a parallel conductor line in which the two wires (ordinarily No. 12 or No. 14) were supported a fixed distance apart by means of insulating rods called "spacers". The dielectric between the conductors consisted of air.

The modern two-wire transmission line is a parallel conductor line with stranded conductors imbedded in a low-loss insulating material (polyethylene). It has the advantages of low weight, compactness and neat appearance, together with close and uniform spacing. Losses, however, are higher in the solid dielectric than in air, and dirt or moisture on the line tends to change the characteristic impedance. Two-wire transmission lines of this type are available in impedances of 75, 150, and 300 ohms.

The most common type of coaxial transmission line consists of either a solid or stranded wire inner conductor surrounded by polyethylene dielectric. Copper braid is woven over the dielectric to form the outer conductor, and a waterproof vinyl covering is placed on top of the braid. This cable is made in a number of different diameters. It is moderately flexible, and so is easy to install. Coaxial cable is available in characteristic impedances of 52, 72, or 150 ohms.



FIGS. 5 to 8—Various types of transmission lines. In the illustration A, represents a 300 ohm molded wire line with a third or neutral wire separating the parallel pair. B, coaxial cable with full length polyethylene dielectric. C, typical 300 ohm two wire transmission line. D, shielded parallel twin lead 300 ohm transmission line.

The air insulated coaxial cable transmission lines have lower losses than the solid dielectric type, but are less used because they are expensive and difficult to install as compared with the flexible type. The common type of air insulated coaxial cable uses a solid wire conductor inside a copper tube, with the wire held in the center of the tube by means of special insulating "beads" spaced at regular intervals.

Most television receiver manufacturers have made provision on the 300 ohm input to allow for the direct connection of 72 ohm cable. This is usually accomplished by the employment of a tap connected to unbalance the input circuit when the 72 ohm cable is attached.

Practical Antenna Calculation.—For proper antenna design it is necessary to know the length of the electromagnetic waves involved. In order to determine wave lengths, however, it is necessary to know the speed at which electromagnetic waves travel through free space, and the frequency. In speaking of the frequency of electromagnetic waves we merely mean the number of waves passing a given point in one second, expressed in megacycles (millions of cycles).

Since electromagnetic waves of all lengths move at the same speed, the number of waves passing a given point in one second will be small if the waves are long, and large if the waves are short. Thus, 500,000 waves 600 meters in length will pass a given point in one second at a frequency of 500,000 cycles. Similarly, if the waves were only one meter in length 300,000,000 would pass each second, which is a frequency of 300 *mc*.

The actual velocity of electromagnetic waves is for all practical purposes 300,000,000 meters or 984,300,000 feet per second.

Now, if the speed at which the waves travel is equal to 3×10^8 meters per second, the distance it will cover in one cycle will be equal to this velocity divided by the frequency in cycles per second, or

$$\lambda = \frac{3 \times 10^8}{f}$$

where "f" represents frequency, and the Greek letter *lambda* stands for wave length in meters. Since feet and inches are the measurement used for practical television antennas we obtain:

$$\lambda = \frac{984}{f(mc)} \text{ ft. (approx.)}$$

and

$$\lambda = \frac{11{,}808}{f(mc)} \text{ ins.}$$

Because the length of each quarter dipole element in inches, is the dimension most frequently required, we obtain:

$$\lambda/4 = \frac{2{,}952}{f(mc)} \text{ ins.}$$

Due to certain electrical characteristics of the antenna material it has been found that in practice the antenna elements should be somewhat shorter (about 5 per cent) than that given in the foregoing formula. The formula then becomes:

$$\lambda/4 = \frac{2{,}952 \times 0.95}{f(mc)} = \frac{2{,}804}{f(mc)} \text{ inches}$$

From this latter formula it is comparatively simple to obtain the antenna dimension for each frequency, by substituting the proper value in megacycles (mc).

Dipole antennas that are to be used in outside installations consist usually, of two quarter wavelength sections of 3/8 in. aluminum tubing or rods.

The following example shows the general procedure when it is desired to calculate the exact length in inches, of each element (quarter wavelength) of a simple half-wave dipole antenna.

Example.—*It is desired to determine the length of a quarter wave dipole rod suitable for use on channel four, where the frequency according to the table page* 755 *has an average value of* 69 *mc. What is the dipole rod length?*

Solution.—By employing the foregoing formula a substitution of values gives the quarter wave length in inches as

$$\lambda/4 = \frac{2{,}804}{69} = 40 \text{ Approx.}$$

By using a similar procedure, it is a comparatively simple matter to calculate antenna dimension for any desired channel or frequency.

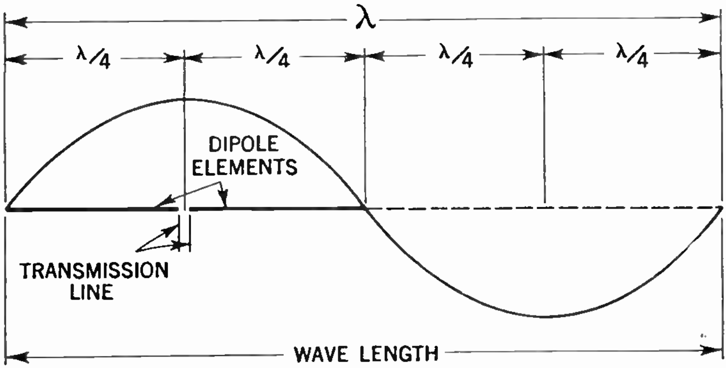


FIG. 9—Showing relations between wavelengths and length of dipole elements used in television antenna construction.

Dipole Antennas.—The fundamental form of a dipole antenna consists of two single wires, rods or tubings, whose combined lengths are approximately equal to half the transmitting wavelength. It is from this basic unit various forms of television antennas are constructed. It is also variously known as a half wave dipole, half wave doublet or Hertz antenna.

The complete television receiving antenna normally consists of two half wave dipoles (receiver and reflector) mounted in the form of an H on a substantial supporting mast or pole, strapped at its lower end to the building or roof housing the receiver.

The dipole elements are made of steel, aluminum or copper-alloy tubing and surface treated against corrosion. The receiver dipole is equipped with terminals at its adjacent ends for

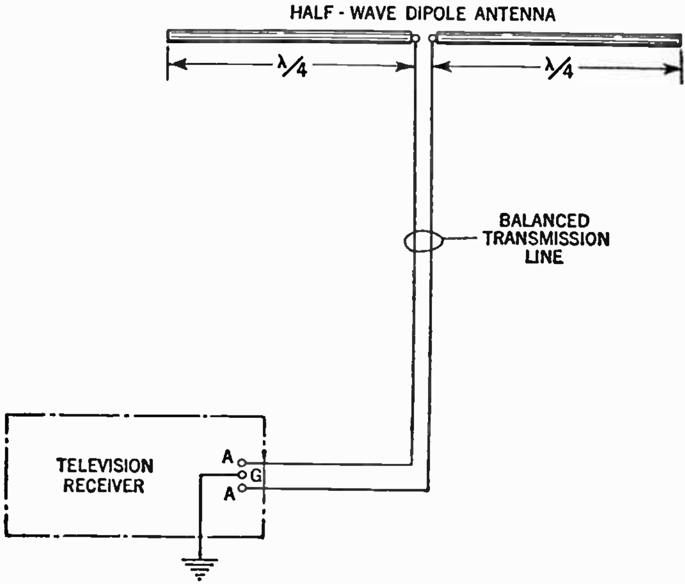


FIG. 10—Showing transmission line connection between a half-wave dipole antenna and television receiver.

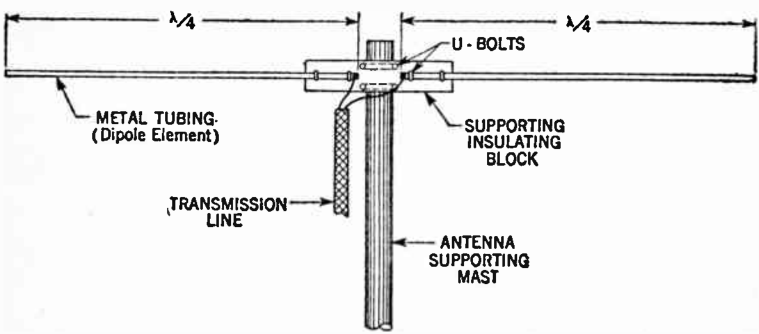


FIG. 11—Illustrating mounting arrangement and connection of half-wave dipole antennas to transmission line.

transmission line connections and must be properly insulated from the mast or supporting structure. The reflector on the other hand, may be joined directly to the antenna cross member, as shown in fig. 12.

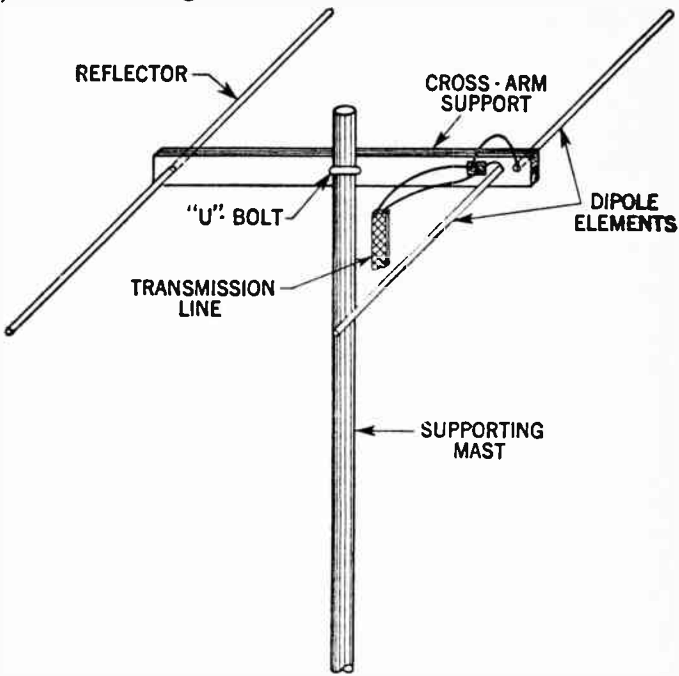


FIG. 12—Typical mounting arrangement of dipole antenna elements with reflector.

Folded Dipoles.—The necessity for separating, insulating and fitting the receiver dipole at its center, however, tends to weaken and complicate the antenna assembly. Because of this, a considerable simplification may be obtained by employing an unbroken member bent and clamped to the supporting member as shown in fig. 14. A television antenna of this type is known as the *folded dipole type* and is widely used.

The spacing between the folded dipole elements should vary inversely with the frequency, that is, the higher the frequency

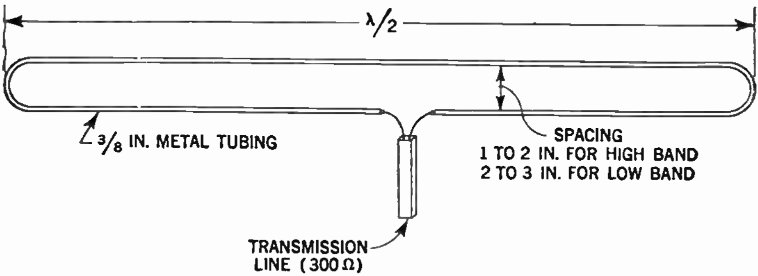


FIG. 13—Dimensional requirements of folded dipole antenna.

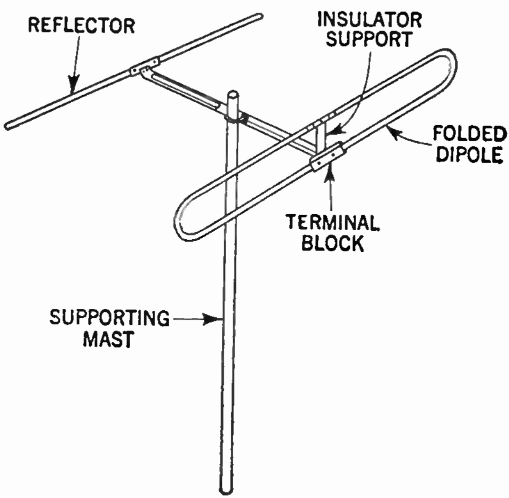
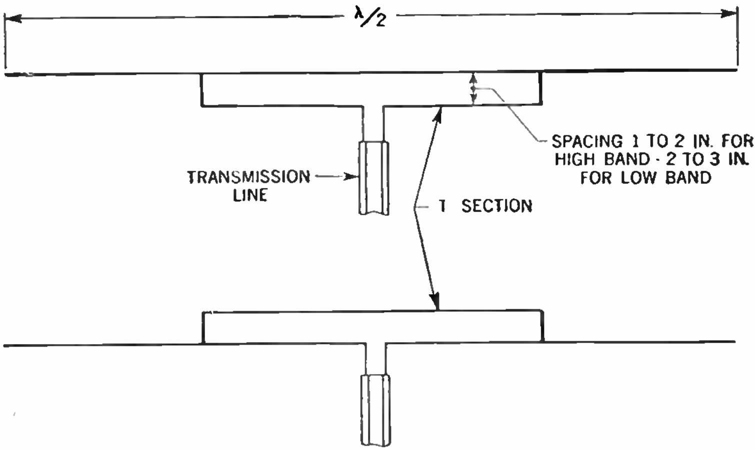


FIG. 14—Showing mounting arrangement of folded dipole antenna with reflector.

the smaller the spacing. The element spacing for the center frequency on the low band is usually 2 to 3 inches, and 1 to 2 inches for the high band.

T-Matched Dipoles.—A further combination of the common half-wave dipole and the folded dipole has become known as the T-matched dipole type. With reference to figs. 15 and 16



FIGS. 15 and 16—Showing T-matched dipole antennas. In the illustration both antenna arrangements have identical electrical characteristics.

the assembly is obtained by cutting the ends of a folded dipole and fitting the remaining stub ends to the bottom element, the T-section having a length of two-thirds the length of the dipole.

There are three principal factors to be considered in the design of a dipole antenna for television reception purposes. These are:

1. The length of the dipole shall be suitable for the particular wavelength in use.

2. The polarization of the transmitted waves shall be that for which the dipole is intended.

3. The directional properties of the dipole shall be such as to receive the desired waves effectively, while being unfavorable towards local interference.

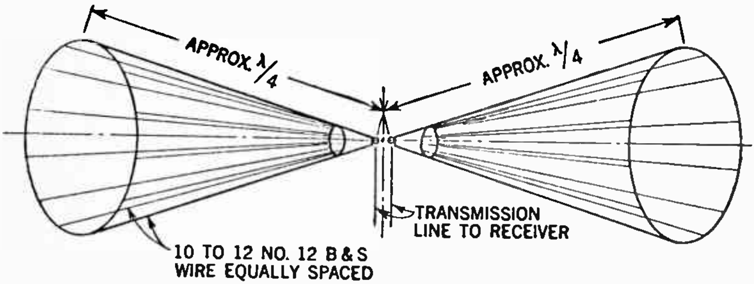


FIG. 17—Construction principles of conical antenna. The characteristics of the conical type are superior to the folded or straight dipole type of antenna from the standpoint of gain and band width. Actually the best arrangement would be the use of solid closed cones made of copper. This arrangement however, is impractical because of its weight which will be considerably increased in locations where the antenna will be exposed to sleet and snow. A satisfactory compromise employs 10 or 12 No. 12 B & S wire rods to take the place of the solid cones.

Conical Antennas.—An antenna in which the cross-section of each of the two halves increase smoothly outward from the center is termed a "conical" type. Because of its cone-like design, it will receive a very wide band of frequencies. Since this type of antenna has a large cross-sectional area, the length must be considerably reduced to keep resonance at the same frequency. Mechanically, however, problems arise in its construction, and its mounting on the roof will cause considerable difficulties.

In the case of television reception the first requirement should be extended to include the provision of a flatly tuned antenna system, able to respond fairly evenly over the waveband involved and also pick up the FM sound transmission. This compromise is often assisted by choosing the length of the antenna to resonate at a frequency intermediate between sound and video transmission.

The polarization of the waves to be received may be either vertical or horizontal. An antenna placed in the horizontal plane radiates horizontal polarized signals, whereas, an antenna placed in a vertical plane radiates vertically polarized signals.

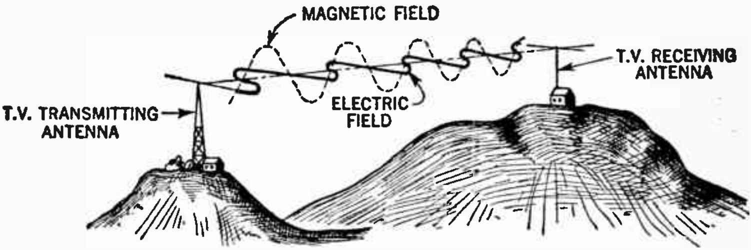


FIG. 18—Showing magnetic and electric field of horizontally polarized wave fronts.

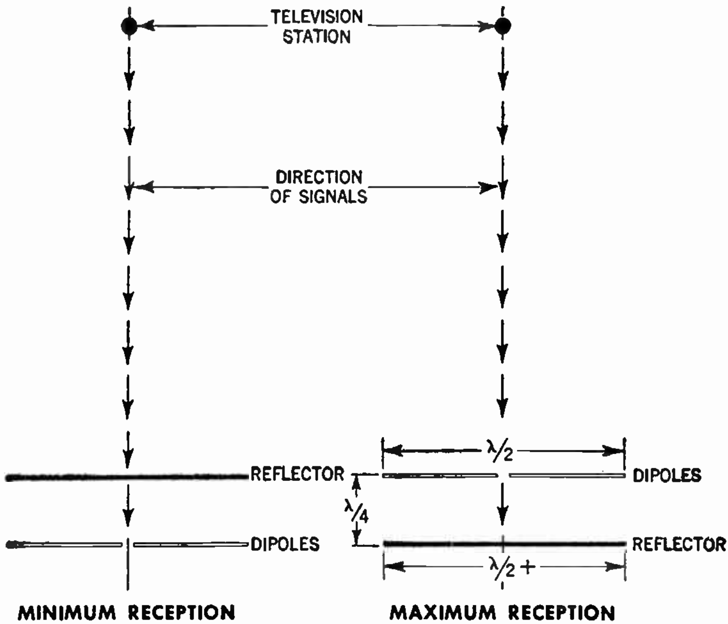
Television transmitting and receiving antennas in the United States use *horizontal polarization* and the receiving antennas are therefore *placed horizontally*.

Parasitic Elements.—A parasitic element, as employed in television antennas, is a dipole slightly too long or too short for exact resonance at the desired frequency. It is mounted at some fraction of a wave length before or behind the driven element. Parasitic elements are not cut at the center and are not connected to the transmission line. The center point of a parasitic element is electrically neutral and can be grounded. This is convenient for lightning protection, as it permits making the entire antenna structure of conductive tubing such as aluminum or stainless steel if desired, and grounding the central supporting mast at the base.

Current induced in a parasitic element by the advancing wave front produces a local field about it which couples it to the driven element by reason of their physical closeness. Spacing and tuning of parasitic elements are adjusted so that current produced in them by the received signal produces fields around them which add up in correct phase to reinforce the field of the received signal itself, in the driven element. For signals from the opposite direction, the action is exactly reversed, and the signal is substantially cancelled in the driven element.

Director and Reflector Elements.—A director element is about 4 per cent shorter than the driven element for average element spacing, and is mounted on a horizontal support member of wood or metal which holds all the elements in proper relationship. The spacing between director and driven element can vary from about 0.08 to about 0.15 wavelength in practical antennas. Closer spacing will increase the front-to-back ratio, but makes the array tune more sharply, which is bad where many widely separated television channels must be received on a single antenna. Wider spacing helps broaden the tuning of the array, but lowers the front-to-back ratio. It is possible to use several directors properly tuned and spaced in a line ahead of the driven element, but this complexity and expense is seldom necessary or justified.

A reflector element is about 5 per cent longer than the driven element at usual spacings, and is mounted on the supporting bar behind the driven element, the spacing varying from about 0.10 to 0.25 wavelength. Effects of changing the



FIGS. 19 and 20—Showing location of reflector element for maximum reception. The antenna elements should always be arranged broadside to the transmitting station, with the reflector approximately one-quarter wave length behind the half-wave dipole.

spacing are quite similar to those produced by similar changes in the director.

The effect of the reflector is critically dependent upon the spacing between reflector and dipole, which as previously noted should be one-quarter wavelength, when radiation from the reflector should exactly reinforce that from the dipole in a forward direction.

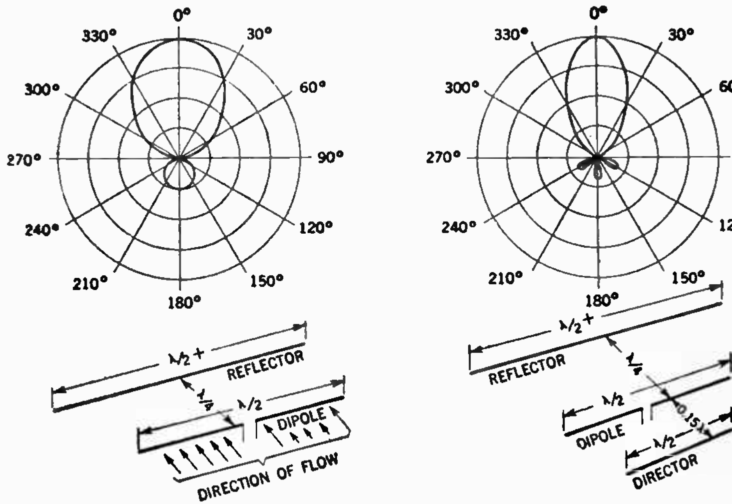
The explanation of this effect is as follows: Radiation from the dipole travels both forward and backward. In the latter direction it reaches the reflector, and induces a current in it. Since the radiation has travelled a quarter wavelength on its way to the reflector, it will reach it 90 degrees lagging in phase relative to that from the dipole where it originated. A current of this phase lag is therefore set up in the reflector, which in turn radiates.

By the time this secondary radiation has returned to the dipole it is a further 90 degrees late in phase, making a total phase lag of 180 degrees, but the oscillations in the dipole will have progressed through a half-cycle during this half-wave time interval, and will be 180 degrees ahead of the initial condition, when the radiation left on its way to the reflector. That is to say, the radiation from the dipole will be a half-cycle ahead of the reference point, while that returning from the reflector will be a half-cycle late, bringing the two to the same point in the period of an oscillation.

Being in identical phase, the radiations from the dipole and reflector reinforce each other in the forward direction, while an extension of the same argument will show that they tend to cancel in the backward direction.

If the current induced into a reflector was as great as that flowing in the dipole, each would produce the same radiated field strength. The forward radiation would therefore be doubled, while that to the rear would be exactly cancelled, giving zero backward radiation.

Since the problem of radiation and absorption by an aerial system are strictly reversible in all ordinary conditions, these directional effects, which are most easily explained when the antenna is regarded as a transmitter, will be exactly similar when it is used for reception, provided of course that waves arrive in the plane in which dipole and reflector are situated.



FIGS. 21 to 24—Showing typical response pattern of two and three element antennas, respectively. From the diagrams it may readily be observed that each additional parasitic element increases the directivity and narrowness of the antenna response. An antenna array with three or more elements of the single or stacked type are frequently employed in fringe areas where only one transmitting station is normally receivable.

In practice the resistance of a reflector will never be zero, and while the current in it can be made equal to that of the radiator if both are connected to a feeder, the current in a parasitic reflector must always be less than that in the dipole which gave rise to it. The forward radiation is therefore, never exactly doubled or the backward radiation fully prevented.

Antenna Directivity Pattern.—The horizontal antenna dipole is inherently directional, being most effective to signals arriving in the broadside direction and least effective to those arriving from a direction parallel to it. This effect is usually represented in the form of a polar diagram, or directivity pattern, in which the radius of the curve from the center of the antenna elements represent the relative response in any given direction.

The function of an antenna pattern is primarily to enable the service man to evaluate the efficiency of an antenna and assist in the proper orientation of it, on the site of installation.

Plotting an antenna pattern is generally accomplished as follows: A minimum usable value of signal strength is chosen on the basis of what the average television receiver will require for satisfactory reception. Then all the points in the area surrounding the antenna where exactly this value of field strength is found are plotted by bearing from true *North* or some other convenient reference direction, and distance in miles, or some other desired linear unit. With a sufficient number of points plotted, a continuous smoothly curving line is drawn joining them all, and it will be reasonably certain that all the area enclosed by this curve will provide at least the minimum required signal.

In practical service work, directivity patterns are always plotted in terms of voltage gain, as this unit is most convenient to use in connection with the survey meter, which is usually a part of the television service technicians equipment.

Antenna receiving patterns are usually made by rotating the antenna about its vertical axis and plotting values of voltage gain radially outward from the center of each change of angle.

The complexity of an antenna has a direct bearing on its efficiency, as well as its directional effects. Roughly, the voltage developed in the antenna is proportional to the combined length of the element multiplied by the field strength of the signal.

This length is measured in units of half-wavelengths. A reduction in the voltage realized at the antenna terminals results from the mutual coupling of the elements.

A comparison of the theoretical efficiency of various types of antennas are as follows:

Elements	*Type*	*Voltage gain*
1	Simple Dipole	1.0 (reference)
2	Dipole and Reflector	1.6
4	2-Bays	2.3
6	3-Bays	2.8
8	4-Bays	3.2

In the foregoing table, the reference value of 1.0 shown for a simple dipole is the universal standard of comparison. This reference dipole is cut to a half-wavelength for each channel measured.

As previously noted, the voltage developed by a half-wavelength antenna is proportional to the length of the antenna. Therefore for purposes of adding additional elements, multiples of half-wavelengths are used.

The receiving antenna height particularly in fringe areas, is an important factor in its efficiency, or signal capture, as shown in figure 25. The possibility of interference is shown by the irregularity of the curve representing signal on the high channel group. This particular effect, however, is not predictable and can only be determined by proper orientation.

The field pattern (directional response pattern) of a typical dipole antenna is shown in figure 27.

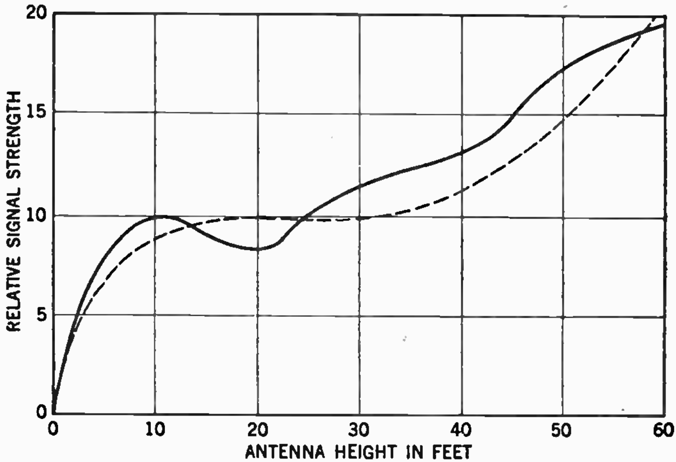
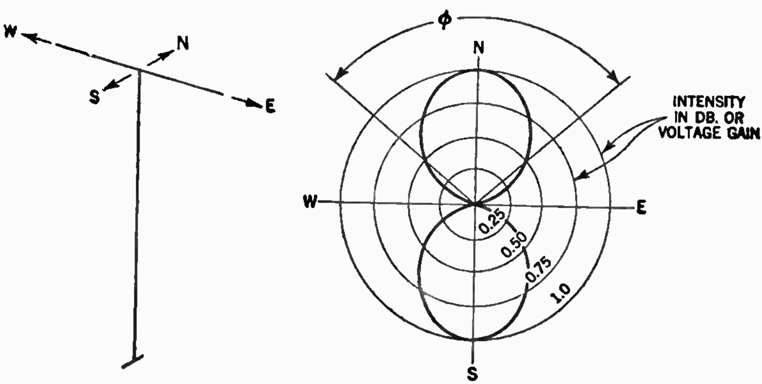


FIG. 25—Showing relative signal strength of antennas per height in feet. The above chart applies to antennas located in fringe areas or at a considerable distance from the transmitting station.



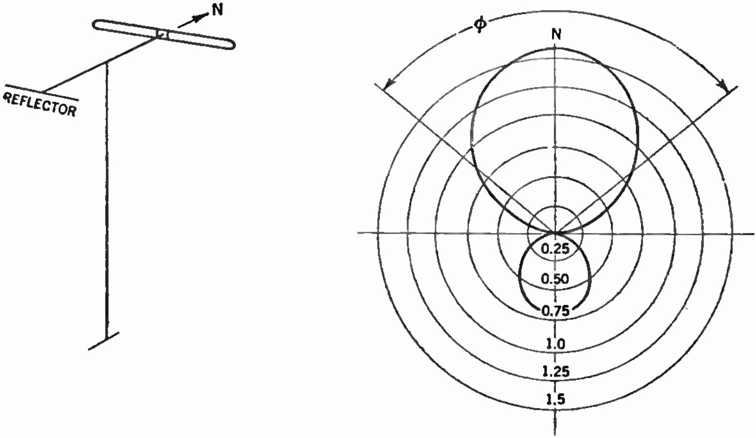
FIGS. 26 and 27—Showing directional response pattern of dipole antenna.

For the sake of simplicity the directions are given as North, South, East and West, in both the schematic antenna and the polar diagram. From this diagram, it will readily be observed that the maximum signal strength will be obtained when the antenna is broadside to the transmitter. Similarly the "signal capture" is not critical over the angle ϕ, which includes the rotation over which the antenna can be rotated before losing more than half of its effectiveness. In the diagram the concentric circles represent the voltage gain, where unity, or 1.0 is taken as reference for all comparisons.

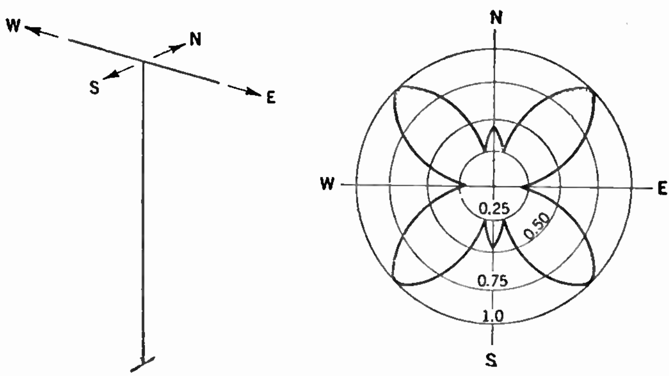
If a reflector be added to dipole, the gain and directional characteristics of the antenna are changed and the polar diagram will take the form as indicated in figure 29. It will be observed from the diagram that the angle ϕ, is still sufficiently wide, generally at least 80 degrees.

So far, an antenna operating only on the channel for which it was designed has been considered. It is the usual practice to use dimensions which give half-wave dipoles in the middle of the low channels. When used on the high channels, a third harmonic will result, giving an antenna pattern shown in figure 31.

A dipole operated in this way will have six lobes, and unless certain dimensions are revised, these lobes are symmetrical, and oriented as indicated. With reference to the field pattern, these lobes are too narrow and are pointing in a different direction, from that previously shown. This will make orientation difficult, or even impossible if the stations on the high and low channels are in the same direction. From this it follows, that no reliable antenna manufacturer would sell an antenna with these characteristics, without showing the relation of the lobes for each frequency.



FIGS. 28 and 29—Directional response pattern of folded dipole antenna with reflector.



FIGS. 30 and 31—Directional response pattern for dipole antenna showing the necessity for proper dimensioning of antenna elements.

The ratio between maximum and minimum voltage (measured with a voltmeter slid along the line) is called the *voltage standing wave ratio*, abbreviated SWR. It is obtained numeri-

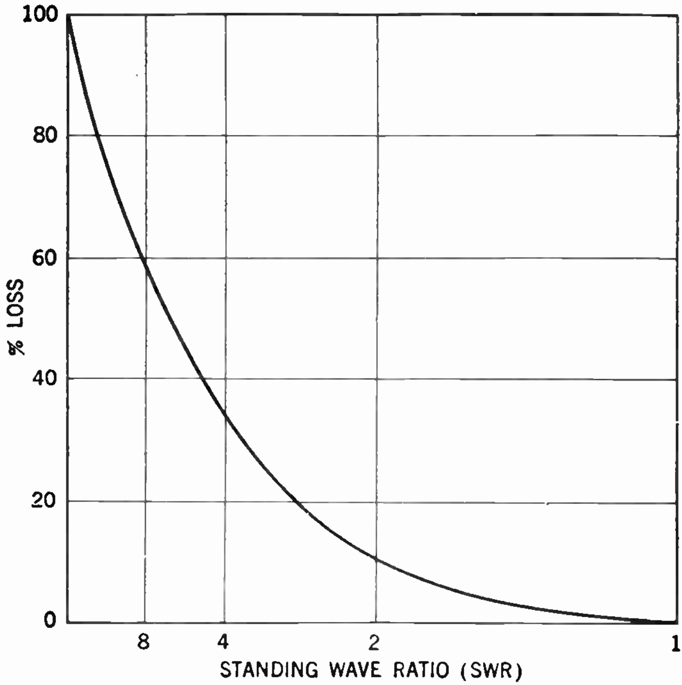


FIG. 32—Characteristic curve showing relation between voltage standing wave ratio and per cent loss due to mismatch in antenna installations.

cally by dividing the maximum by the minimum voltage. Thus maximum and minimum values of 15 and 5 would mean a SWR of 3.

If the SWR be plotted on a logarithmic scale against per cent loss the curve will take the form shown in fig. 32. Here it will be observed that a SWR of two will cause a loss of only 10 per cent, while a SWR of three will cause a loss of 25 per cent.

Antenna Impedance Matching.—Impedance matching is a very important factor in antenna installations. When the receiver input matches the impedance of the transmission line, the transmitted signal is completely absorbed and as a result there are no reflections or *standing waves* on the transmission line, and consequently no ghost image. In this connection it should be observed that the antenna impedance is important only from the standpoint of power transfer. It is only when the antenna impedance matches that of the transmission line that maximum power transfer takes place.

A condition which may easily arise is the mismatch of 300 ohms to 72 ohms; this produces a SWR of four and a loss of 37 per cent. This condition will be the result when a 72-ohm antenna is connected to a receiver having a 300-ohm input impedance. Mismatch, and consequent loss of gain also occurs when the antenna and receiver are not connected by transmission cable of proper characteristic impedance.

Impedance matching is most commonly accomplished by the use of the impedance inversion characteristic of a one-quarter wavelength section of cable. This is expressed by the simple relation: Input impedance times the output impedance is equal to the square of the characteristic impedance of the cable used for the one-quarter wave transformer.

That is:

$$(Z_0)^2 = Z_s Z_r$$

Where Z_0 = characteristic impedance

Z_s = input impedance

Z_r = output impedance

To illustrate an impedance matching application of a one-quarter wave linear transformer, when using the 72 ohms antenna connected to a receiver having a 300-ohm input impedance, we obtain:

$Z_0^2 = 72 \times 300$, from which
$Z_0 = \sqrt{21,600}$, or
$Z_0 = 147$ ohms (approx.).

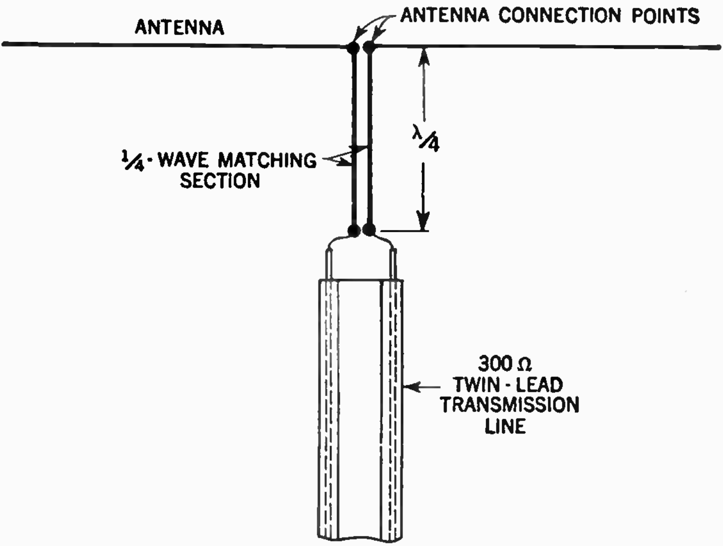


FIG. 33—Illustrating insertion of quarter wave matching section to obtain proper impedance match.

From our calculation it will be observed that one-quarter wave section from a 150-ohm twin conductor line will be very close to a perfect match. This should be spliced in between the end of the 72-ohm line and the receiver input with due attention to good connection.

Fringe Area Reception.—By the term *fringe area* is generally understood a receiver location which is considered as outside the normal service area of a transmitting station.

Specifically, a fringe area is considered to be the outlying part of a whole general area reached by the television signals from a given metropolitan center, where signals are so weak so as to require the use of high gain antennas, or masts higher than the standard single length or both.

Television reception in fringe areas is generally dependent upon the following factors:

1. Signal to noise ratio in the area.
2. Gain and directivity of the transmitting antenna.
3. Sensitivity of the receiver.

Factors which contribute adversely to distant reception are:

1. Transmitting stations with power of less than 20 *kw*.
2. Transmitting stations with an antenna of less than 1,000 feet in height.
3. Intervening obstructions between transmitter and receiver such as hills, mountains, forests, etc.

Since the gain and directivity of an antenna depends upon the number of dipole and parasitic elements assembled, a fringe area usually requires a somewhat more complex antenna array than that required in the intermediate service area.

The signal to noise ratio in any fringe area can usually be improved considerably by increasing the height of the receiver antenna and by selecting an antenna with a narrow horizontal and vertical pickup pattern. In some cases an antenna system alone will not suffice and an RF booster (preamplifier) may be required to increase the weak signal to usable value.

Stacked Arrays.—It has been found that additional antenna gain may be obtained by stacking the conventional dipole and reflector. This consists in arranging one driven element on top of another at a spacing that will cause the signals to be in phase at the terminals where the transmission line is connected to the antenna system.

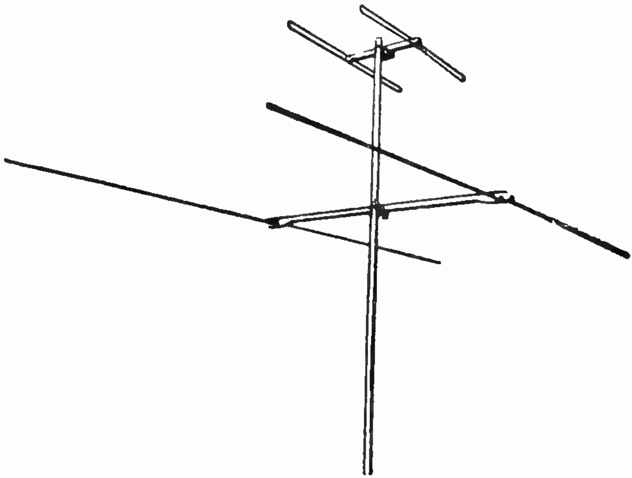
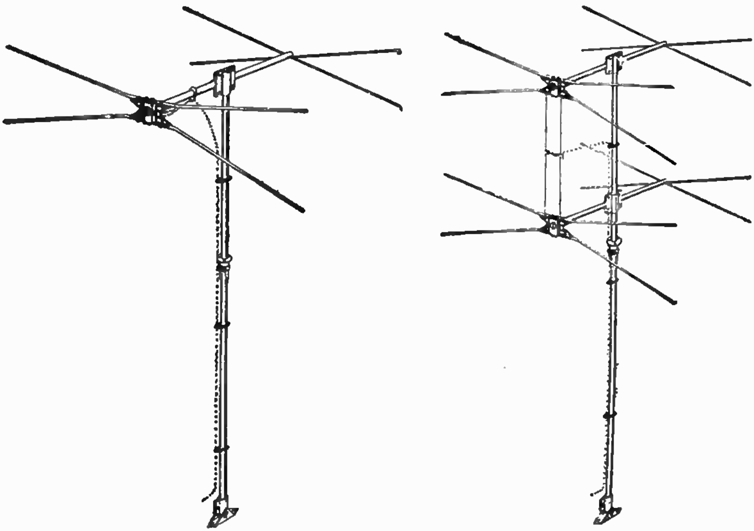


FIG. 34—Typical high and low band combination antenna.

There are many types of antennas available for fringe area reception. In general, the stacked dipole and reflector is better than the conical type on the low bands, but it is inferior on the high bands because of the smaller dimensions. It can be made broad-band so that one unit will operate over all the low channels; but for the high channels there must be another set of elements. For this reason, this type is made with two sets of elements, either above each other on the mast, or in line on the same cross-arm. Fig. 34 shows a typical arrangement of this type, which is generally known in the trade as the high-low combination antenna.

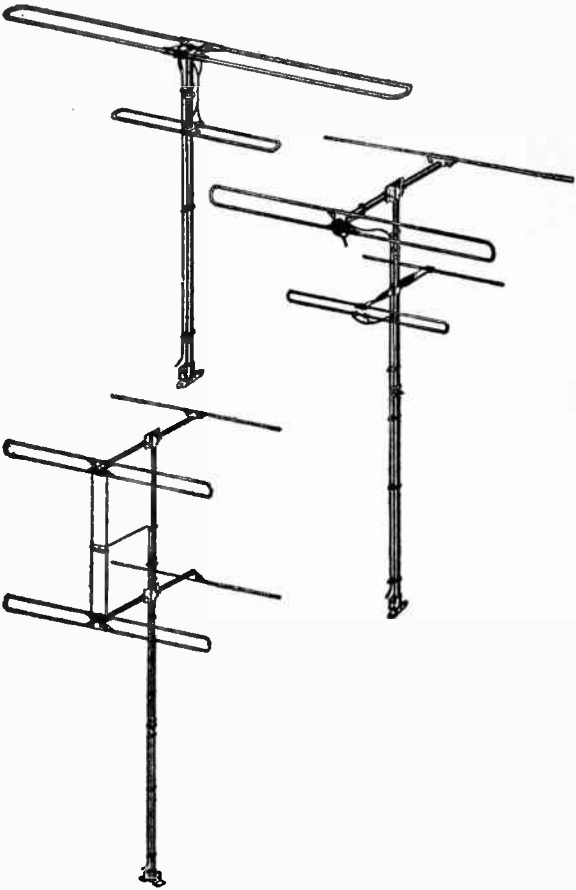
An effective compromise on directivity, gain and band width has been obtained with the introduction of a stacked in-line



FIGS. 35 and 36—Illustrating two types of conical antennas. These antenna arrays are sometimes termed "fan type" antennas.

antenna shown in fig. 41. This antenna combines the added signal on two-stacked folded dipoles and reflectors for a single transmission line.

Theoretically, one of the best types of television receiving antennas is the conical type. Because of its cone-like design it will receive a very wide band of frequencies and maintain an almost constant terminal impedance over the entire frequency



FIGS. 37 to 39—Three distinct variations of antennas for fringe area reception. Fig. 37 represents a folded high-low band type; fig. 38, high-low band folded dipole with reflectors; fig. 39, high-gain stacked array.

range it is designed to cover. Two types of stacked conical antennas are shown in figs. 35 and 36.

The Yagi array, fig. 42, is a high-gain antenna. The gain is roughly 2.2 times for one bay and 3.2 times for two bays. It has the disadvantage, however, of being a narrow band antenna, and for full gain a separate array must be used for each channel.

FIG. 40—Double folded dipole antenna with reflector. An antenna of this type will give an excellent forward gain and high forward-to-back ratio. The antenna requires only one transmission line to receiver and requires no special matching network to give excellent performance on high and low bands. It is used preferably where transmitting stations are located not too far apart.

The angle of orientation, including the one-half power points is about 40 degrees. It is frequently employed in fringe areas to pick up some station, and for this purpose it is probably the best type available. A typical Yagi type design having two, 4-elements stacked vertically for reception on channel four is shown in fig. 44.

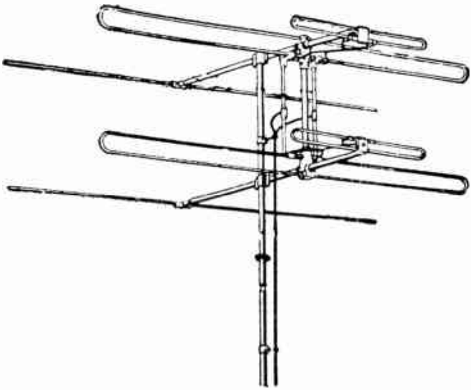
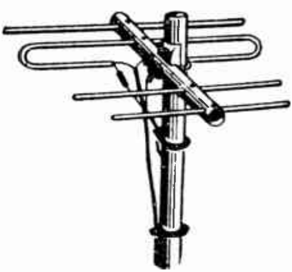
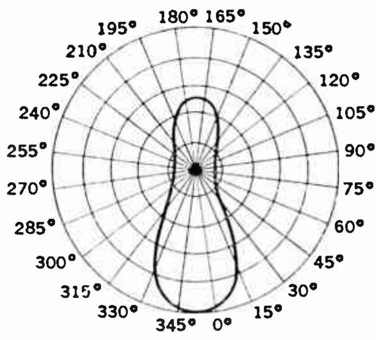


FIG. 41—Typical stacked in line folded dipole antenna array with reflectors.



YAGI ARRAY



DIRECTIVITY PATTERN

FIGS. 42 and 43—Typical Yagi array and associated directivity pattern.

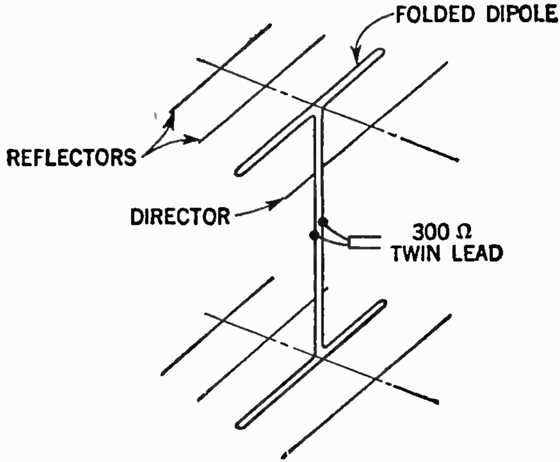
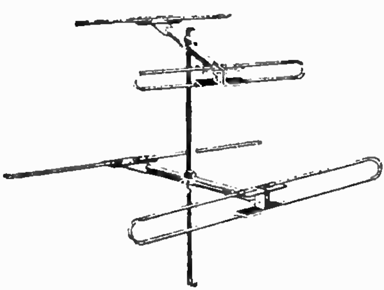


FIG. 44—Schematic diagram showing two, 4-element Yagis stacked vertically. This arrangement forms a highly directional and sensitive antenna. One 4-element array is satisfactory in many areas.



FIGS. 45 and 46—Typical folded dipole high and low band antennas. Fig. 46 incorporates in addition to the folded dipole with reflector for the low band, a Yagi array for use on the high band.

CHAPTER 34

Television Controls; Test Patterns and Adjustments

In common with the conventional radio receiving set, the television receiver requires certain controls for its proper operation.

The various controls on a television receiver may be divided into two classes, depending upon their frequent need of operation. They are:

1. Operating controls.
2. Preset controls (service adjustment controls).

Operating controls are those which control program selection as well as sound and picture quality and their functions are indicated in figs. 1 and 2.

The preset controls on the other hand, are those which usually require adjustment at the time the receiver is installed, but only rarely need attention thereafter.

Because of this, numerous manufacturers of television receivers have only the *operating controls* located at the front of the cabinet, whereas the *preset* or *service adjustment controls* are usually located at the rear of the chassis.

With reference to fig. 1, the operating controls generally consist of the following:

1. On-off switch and volume control.
2. Channel selector.
3. Fine tuning control.
4. Contrast control.
5. Brightness control.
6. Horizontal hold control.
7. Vertical hold control.

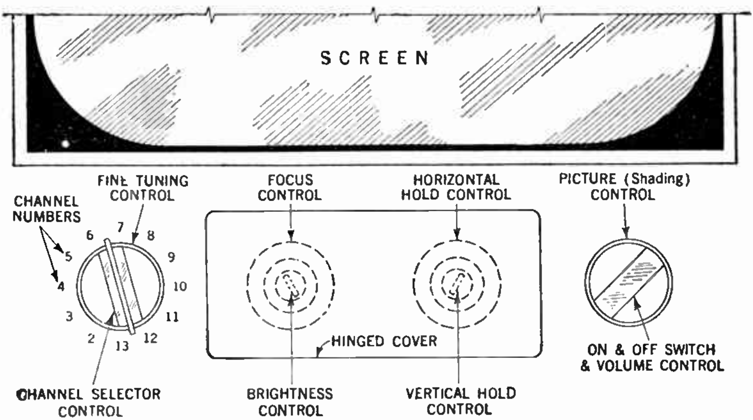


FIG. 1—Illustrating operating control location in typical receiver. It should be observed that only two dual operating controls are used in normal tuning of a television station. Behind the hinged cover are located two additional dual controls which may be adjusted under certain conditions to improve reception such as when receiving a weak station or in case of extreme interference.

Depending upon the design of the receiver, only four or five of the foregoing controls need to be operated during normal reception.

Dual Operation.—In order to simplify the operation, and to improve the appearance of the cabinet as well, numerous manufacturers arrange the control knobs for dual operation; that

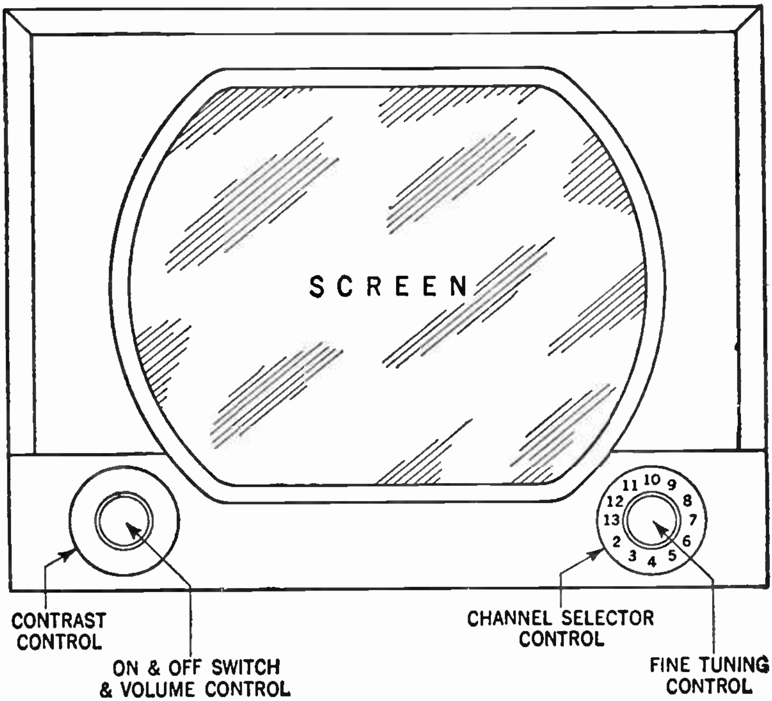


FIG. 2—Showing front view of another typical receiver with operating control location. These are two dual controls, consisting of a small and a large knob each, on the front panel of the receiver.

is, the controls are arranged in pairs of two, consisting of a small inner knob and a larger outer knob. Thus, for example, the *channel selector switch* and the *fine tuning control* are commonly of the dual type. The *contrast control* and *brightness control* are similarly arranged, as are the *horizontal* and *vertical* hold controls.

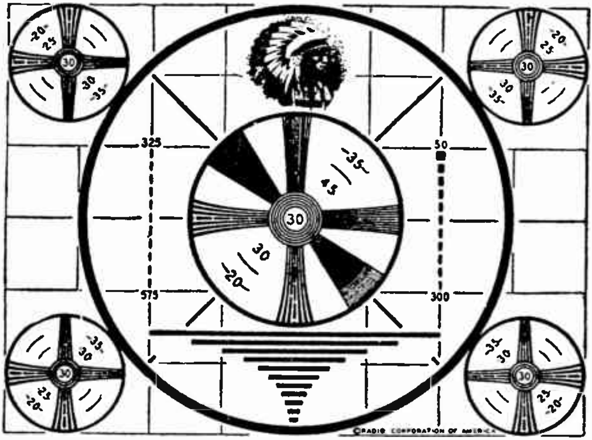


FIG. 3—Showing typical test pattern with receiver functioning normally.

Some manufacturers of television receivers arrange such controls as the *horizontal* and *vertical holds*, in addition to *focus* and *brightness control* underneath a hinged cover, since these usually do not need to be reset each time the receiver is operated, but are properly set at the time of installation. The purpose and function of the operating controls are as follows:

On-Off Switch and Volume Control.—The purpose of the on-off switch and volume control is to turn the receiver on and off and to adjust the sound volume to a desired level.

Channel Selector.—This consists of a simple selector switch by means of which the correct channel number of the desired television transmitter may be selected. The channels presently in operation are numbered from 2 to 13.

Fine Tuning Control.—This control turns the receiver for best sound and picture. After the proper channel is selected, adjust the fine tuning control to obtain the best picture quality.

Contrast Control.—A variation of the amount of background light or *picture shading* is provided by this control. Adjust to receive picture and obtain correct contrast between light and dark shades.

Brightness Control.—This control sets the picture brilliance. The brightness control should not be turned past the point at which the picture begins to grow larger, since detail will be lost due to loss of focus.

Horizontal Hold Control.—The horizontal hold is an adjustment of the horizontal picture synchronization circuits. Misadjustment of this control will cause the picture to move either right or left or in extreme cases, it will cause black horizontal lines to appear on the screen. This control should be adjusted until the picture appears and there is no horizontal movement.

Vertical Hold Control.—When switching from a strong local station to a weak station, it may sometimes be necessary to make adjustment of the vertical hold control. Principally the vertical hold is an adjustment of the vertical synchronization circuits. Misadjustment of this control will cause the picture to move either up or down. The control should be adjusted so that there is no vertical movement of the picture.

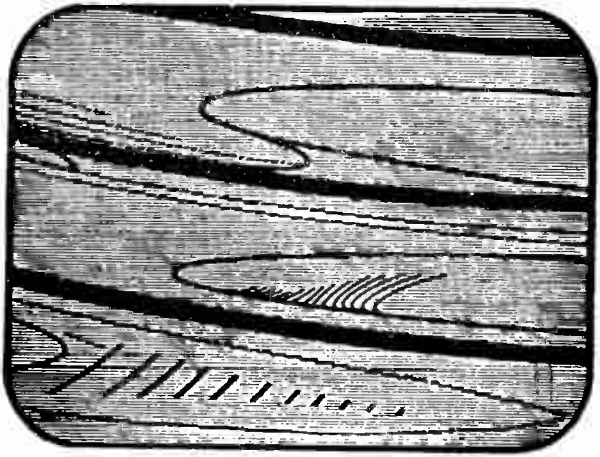


FIG. 4--Test pattern showing horizontal movement. To correct, adjust horizontal hold control.

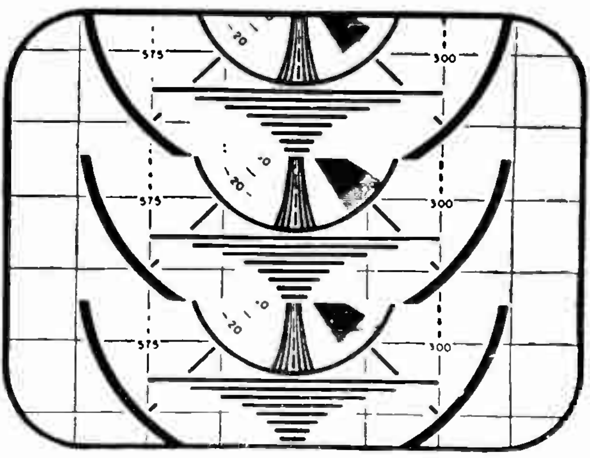


FIG. 5—Test pattern showing vertical movement. To correct, adjust vertical hold control.

Step by Step Tuning Procedure

In order to select a particular station and to adjust the various operating controls for correct picture and accompanying aural reception, proceed as follows:

1. Turn volume control about one-half turn clockwise. This supplies power to the receiver. Allow about two minutes for the tubes to reach operating temperature.
2. Turn the channel selector until it points to the number of the desired station channel.
3. Turn the tuning control for best detail of the picture.
4. Adjust contrast control to obtain the proper shading in the picture which means it should have good deep blacks, whites and intermediate shades of gray.
5. Readjust volume for most pleasing reproduction.

After the receiver has been adjusted as indicated, the volume control need only be used to turn *on* or *off* the receiver between the desired programs unless some other station is to be tuned in.

Before commencing the tuning operation, however, it may be well to check to be sure that a television transmitting station actually is on the air at the time it is desired to operate the receiver. Program schedules are usually published in the daily newspapers and many television stations will mail advance copies of their weekly broadcast schedule to set owners upon request.

It should also be noted that during intervals in which stations are only televising their test pattern, the sound will only be a sustained note. This test pattern, fig. 6, and special sound transmission is used by television technicians to adjust certain preset controls at the time of installation.

The Test Pattern

Prior to a detailed discussion of the operation and functions of the *preset controls*, it will be of assistance to know the part test patterns play in the proper adjustment of the receiver.

The function of any test pattern is to furnish an accurate means of comparing the picture that appears on the picture tube with that actually seen by the television camera. If the two were identical, it would indicate completely perfect transmission of the image through the entire transmitting and receiving system. The extent to which it is approximated gives a measure of the quality of the transmission.

The test patterns, therefore, provide a means for the proper diagnosis and adjustments, which may occur in a television receiver. Test patterns are broadcast regularly by most television stations, and assume several configurations of lines, circles and black bars, as shown in figs. 3 and 6.

Such factors as *picture aspect ratio*, *resolution*, *linearity*, *contrast*, and *brightness* in addition to *focus control* may easily be observed by an analysis of fig. 6.

The *aspect ratio* of a picture determines its proportions. By arbitrary choice the television broadcasting stations have settled on the aspect ratio of 4 to 3; that is, a picture whose width is 4/3 as great as its height. Thus, when the aspect ratio of the picture, fig. 6, is correct, the diameter of the large outer white circle (or part of a circle to be exact) is exactly 4/3 of the diameter of the large black circle. If this ratio is not maintained, then the aspect ratio of the picture is incorrect and should be adjusted.

By the term *resolution* is meant the extent to which the picture separates the details of the original scenes from one another.

Vertical resolution depends largely on the following:

1. The number of scanning lines employed.

2. Size of the scanning beams in both the camera tube and the picture tube.
3. Sensitivity of the camera tube, and other elements of the transmitting apparatus.

Horizontal resolution on the other hand is not affected to any great extent by the number of scanning lines and by the characteristics of the camera and transmitter.

FIG. 6—Normal (greatly reduced test pattern) as broadcast by CBS.

A check on the vertical resolution may be made by observing the horizontal wedges of our test pattern, fig. 6. If the lines of the wedges emanating from the central white circle are partially or completely blurred, there is a partial loss of resolution.

In a similar manner the vertical wedges may be used to check horizontal resolution.

Linearity refers to the uniformity of distribution of a regular pattern on the picture tube. When the condition of the electron beams on the picture tube are such that the beams do not move at constant speed, the objects in the picture will be distorted in shape, and as a result the picture is said to have poor linearity.

It should be observed that for a completely satisfactory picture, the receiver system should be free from all of the various defects which tend to impair its quality. This includes faulty interlace, improper focus of the beam, 60-cycle power frequency superimposed on deflection voltages, noise and other forms of interference.

Vertical and *horizontal linearity* may be checked by observing the large black circle shown on the test pattern. When perfect linearity is present, the circle is geometrically flawless.

Brightness and *contrast* must be present in suitable proportions for a pleasing picture. Brightness without adequate contrast actually reduces the clarity of the picture. Contrast depends upon the amount of change of the video voltage applied to the picture tube grid; that is, its peak-to-peak swing. Brightness of the picture depends upon the *d.c.* or average value of the video signal at the picture tube.

Contrast and *brightness* correctness may be observed by means of the several concentric circles in the test pattern. These are located between the large black circle and the white circular center area. These are of different shades from light gray to black. When the picture shows tone variations, the brightness and contrast controls are set correctly. If not, they should be adjusted.

Correct *focus control* may be determined by observing the center of the test pattern. When this white circle is perfectly round and sharp, the focus control is properly set. If not, an adjustment should be made.

Preset or Service Adjustment Controls

These are controls which have been factory adjusted for optimum performance, although it is usually necessary to make some adjustments of these at the time of installation. The service adjustment controls usually consist of the following:

1. Focus control.
2. Vertical size.
3. Vertical linearity.
4. Horizontal size.
5. Horizontal linearity.
6. Horizontal drive.
7. Picture width.
8. Picture height.

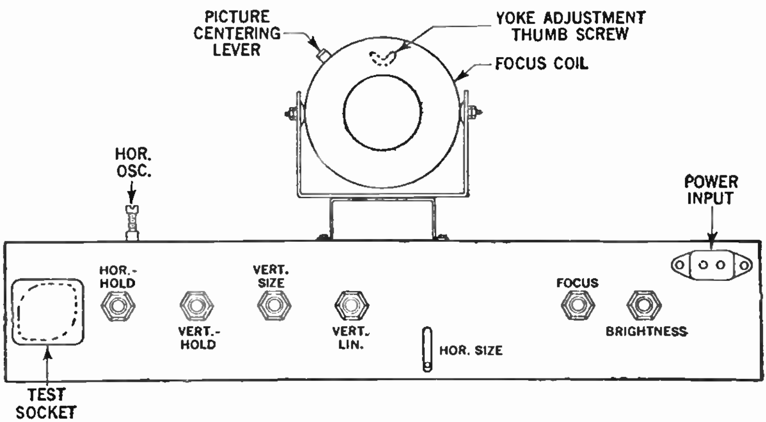


FIG. 7—Showing preset controls for receiver whose operating controls are shown in fig. 2.

Depending upon the design of the receiver some of these controls may be located at the front of the cabinet, whereas others may be located in the rear of the chassis.

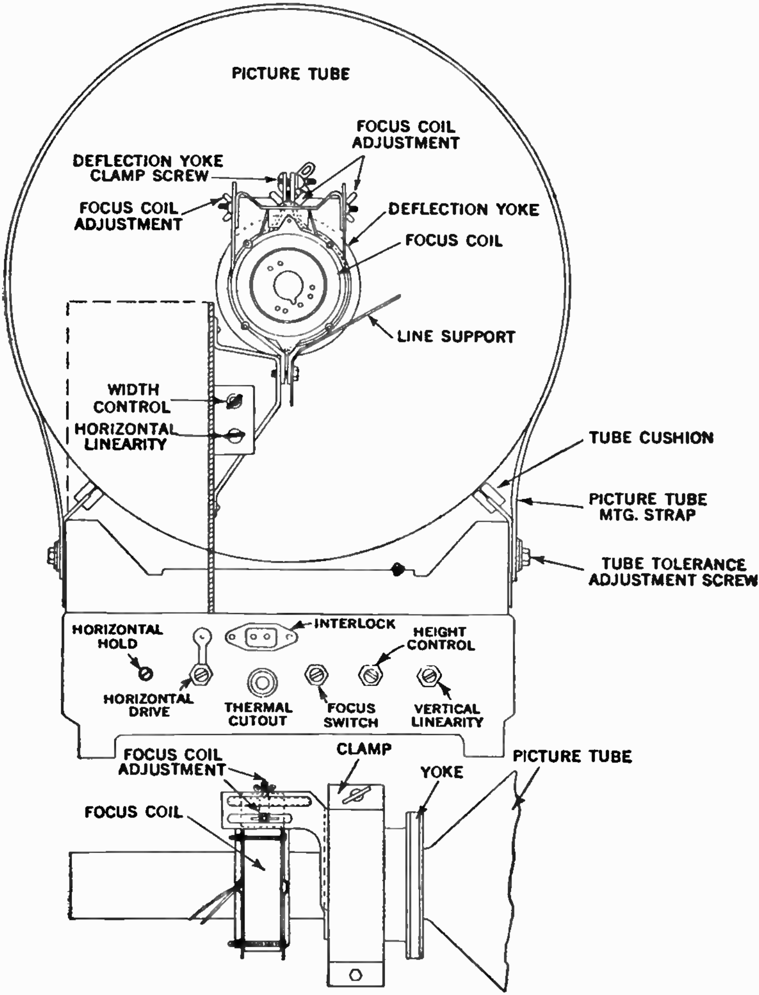


FIG. 8—Showing preset controls for receiver whose operating controls are shown in fig. 1.

Focus Control.—This control offers adjustment of the sharpness of detail of the picture. At long intervals the focus control may have to be readjusted for best clarity of the picture. This is done by turning the focus control in either direction until the picture shows best clarity. Observation of the picture slightly right of center when making this adjustment gives the most uniform focus. Tune for clarity of small objects or lettering in the picture.

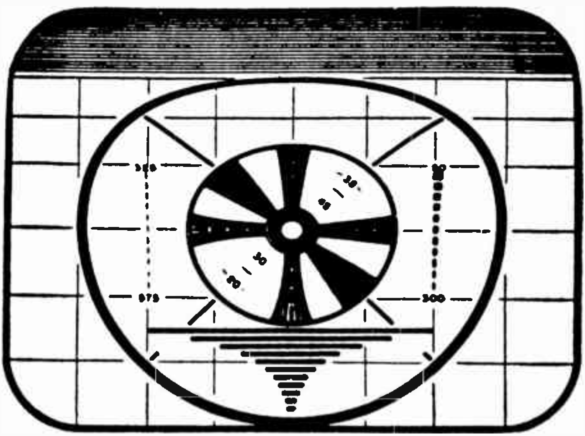


FIG. 9—Test pattern showing vertical distortion. To correct, adjust vertical linearity control.

Vertical Size and Vertical Linearity Controls.—These controls should both be adjusted at the same time and preferably while a test pattern is being transmitted. The linearity control affects the upper portion of the picture while the size control affects the lower portion. Adjust both controls simultaneously until the test pattern is symmetrical and fills the entire screen vertically. Readjust the vertical hold control if necessary.

Horizontal Size Control.—This control should be adjusted preferably when a test pattern is being transmitted. The size control should be adjusted until the test pattern fills the entire screen horizontally.

Horizontal Linearity Control.—This control should be adjusted for best possible horizontal linearity. In the event that proper horizontal linearity cannot be obtained by adjusting this control, then change the setting of the horizontal drive control.

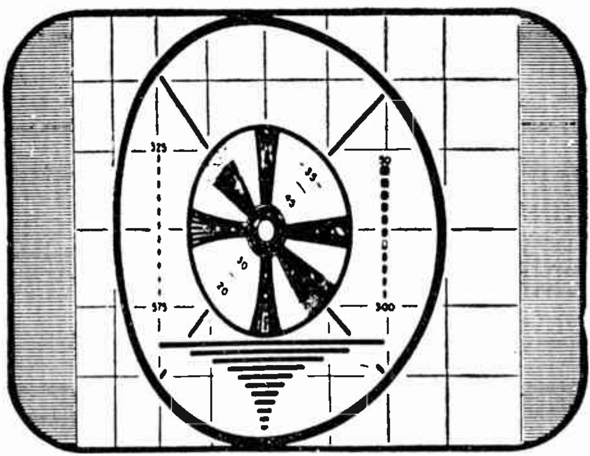


FIG. 10—Test pattern indicating horizontal distortion. To correct, adjust horizontal linearity.

Horizontal Drive Control.—The horizontal drive should be set approximately one-third of its total rotation from the counterclockwise end of its rotation. If white vertical bars or black beaded lines appear in the picture, the drive control in either direction should be adjusted to remove these white vertical bars or beaded lines.

Picture Width Control.—Control of picture size in the horizontal direction is accomplished by means of the width control. If abnormally low line voltage makes it difficult to obtain sufficient picture width when using the width control, then changing of the horizontal drive control may prove helpful.

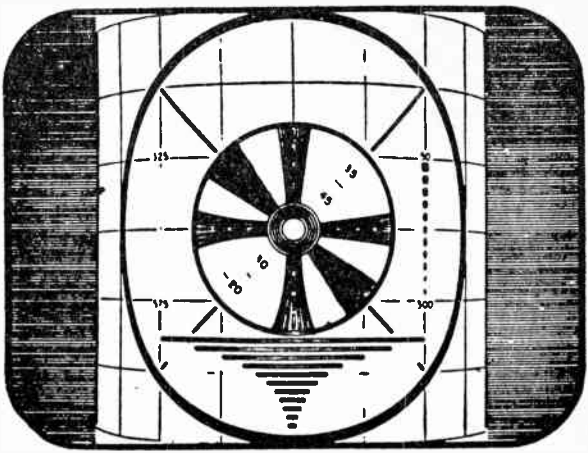


FIG. 11—Test pattern showing picture too narrow. To correct, adjust width control.

Picture Height Control.—Control of picture size in the vertical direction is accomplished by means of the height control. Height and width adjustment should be checked for all transmitting stations in order to ascertain that the picture fills the viewing area. It may be necessary to change the setting of the height control after the vertical linearity control is adjusted.

Straightening Tilted Raster.—This condition makes the test pattern or picture appear in a slightly tilted position. The remedy consists in a loosening of the deflection yoke locking

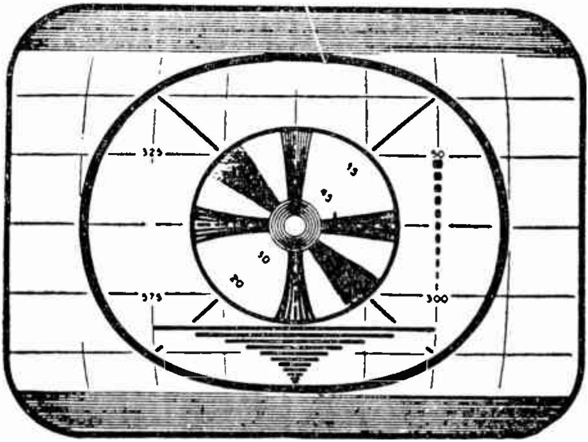


FIG. 12—Test pattern indicating picture too short. To correct, adjust height control.

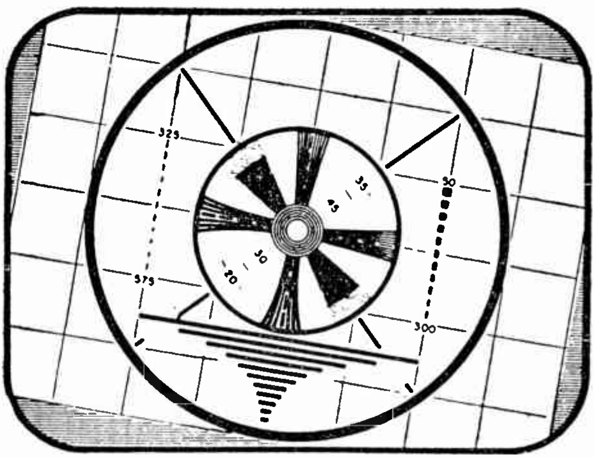


FIG. 13—Test pattern indicating tilted picture. To correct, adjust yoke position.

screw, and in rotating the yoke sufficiently to correct this condition. This locking screw should be retightened after the operation.

Centering.—To center the test pattern on the screen, adjust focus coil position. Readjust ion trap for maximum brightness on picture screen. Only in rare cases may it be necessary to rotate the picture tube.

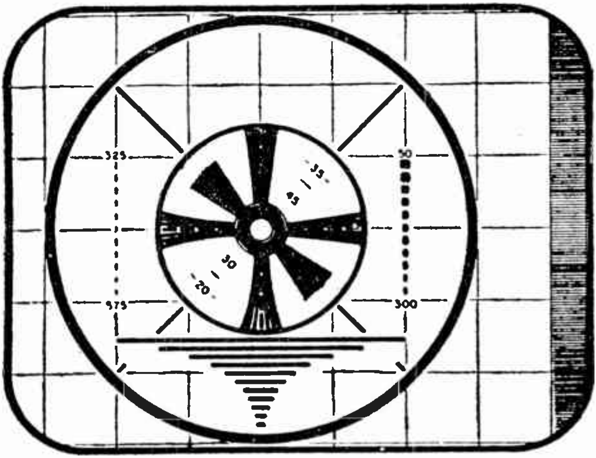


FIG. 14—Test pattern indicating picture off-center. To correct, adjust focus coil position.

Eliminating Semi-circular Shadow.—This shadow is caused by the electron stream striking the neck of the tube, and it can generally be corrected by applying one or a combination of the following procedures:

1. Make sure that the deflection yoke is positioned as far forward as possible.

2. Reposition the focus coil by readjusting the holding nuts to shift the coil forward.

3. In the event the neck shadow cannot be eliminated by the foregoing procedure raise or lower the entire yoke and focus coil assembly so that focus coil can be repositioned vertically with respect to the tube neck.

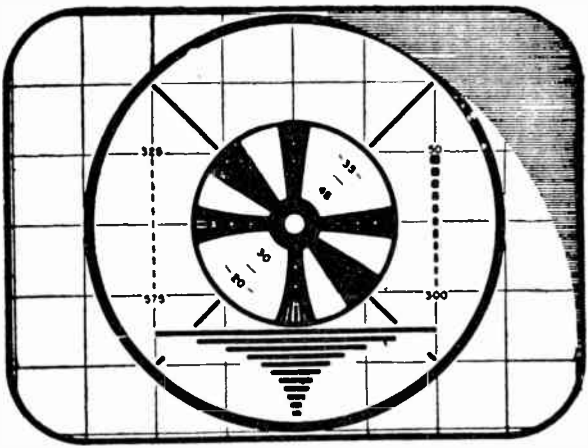


FIG. 15—Test pattern showing semi-circular shadow. For correction, see text.

For complete adjustment of ion trap, focus coil and deflection yoke, see pages following.

Adjustment of Ion Trap, Focus Coil and Deflection Yoke

Although these components are properly adjusted when the receiver leaves the factory, conditions of rough shipment make it possible for these to become misaligned. The following instructions will enable the service man to bring the parts to their

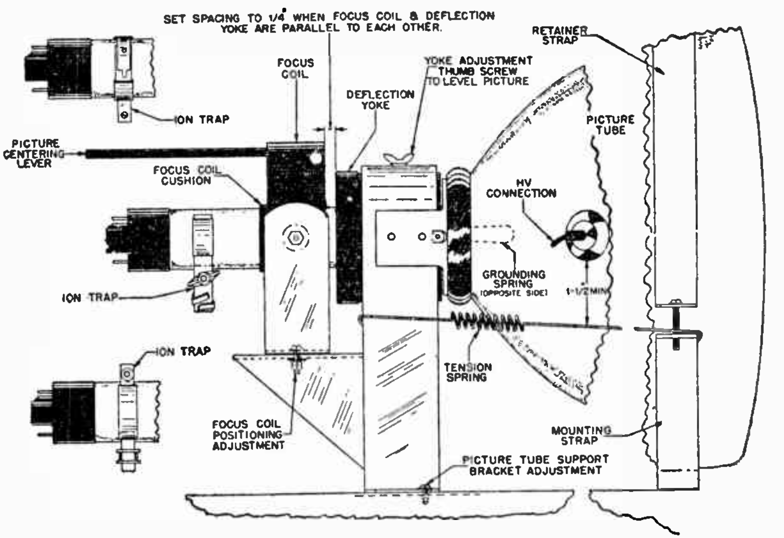
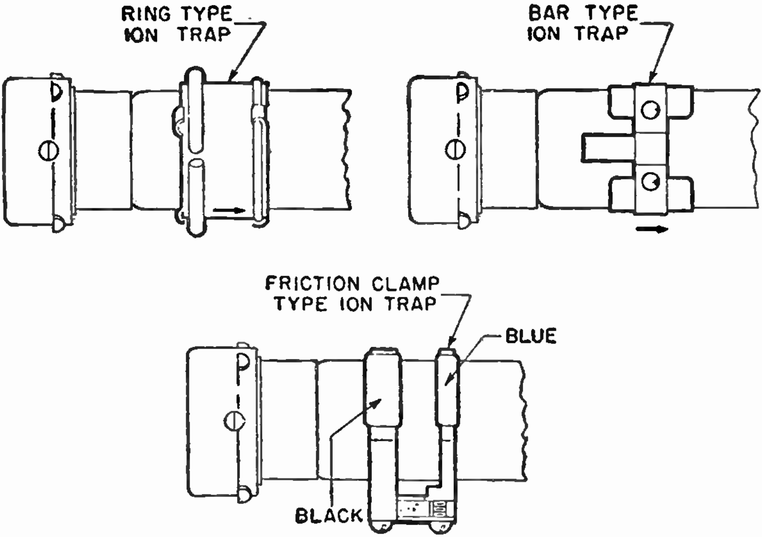


FIG. 16—Showing typical picture tube assembly with location of ion trap, focus coil and deflection yoke.

normal setting. See fig. 16 for adjustment locations. A mirror placed in the front of the receiver will make it possible to watch the picture while the adjustment is being made.

The Ion Trap Magnet.—The ion trap consists of a coil or permanent magnet fitted on the neck of the picture tube for the purpose of removing ions from the electron beam. The ions removed are molecules of matter which have been excited by the electron bombardment so as to have a negative charge.



FIGS. 17 to 19—Illustrating various types of ion trap magnets.

If allowed to remain in the electron beam the ions will eventually cause a dark spot in the center of the picture tube face. There are numerous types of ion traps, all differing in appearance but identical in action.

It is of major importance when installing a television receiver to properly adjust the ion trap magnet on the neck of the picture tube, since improper positioning of the magnet may cause areas of discoloration on the face of the bulb, thus injuring the picture screen.

Ion Trap Adjustment.—The ion trap magnet must always be adjusted for maximum picture brightness. With the tube operating and with brightness control adjusted for low intensity, the ion trap magnet is adjusted by moving it forward or backward and at the same time rotating it slightly around the neck of the picture tube until the raster on the screen is brightest.

If, in obtaining the brightest raster the ion trap has to be moved more than one-quarter inch from the internal pole pieces, or if it be pushed against the focus coil, the magnet is probably weak and a new magnet may be required.

As a final check, the ion trap magnet should again be adjusted for maximum raster brilliance, this time with the brightness control set to obtain a raster slightly above average brilliance and with the focus adjusted for a clear line structure to simulate actual operating conditions with a picture.

If the picture tube has been replaced, or the receiver moved to a new location, it is imperative that the brightness control be kept low until after the initial adjustment of the magnet, and also that adjustment of the magnet be made immediately after the receiver is turned on. After the proper adjustment, the ion trap mounting screws should be tightened to prevent shifting.

Focus Coil Adjustment.*—If a shadow falls on one corner of the picture or if the picture be not properly centered, adjustment of the focus coil will be necessary. To adjust, turn the focus coil adjustment screw in or out until a position is found where the picture is centered and there is no shadowed corners.

*When carrying out this adjustment, extreme care should be exercised so that no abnormal pressure is exerted on the neck of the picture tube.

In performing the adjustment, the screws should be turned so as to move the focus coil about its vertical and horizontal axis rather than closer to or farther from the face of the picture tube.

It should be observed that the tilt of the focus coil is limited by the clearance to the neck of the picture tube. Therefore, it is important for proper picture centering that the deflection yoke mounting bracket be moved forward until the rubber collar firmly supports the flare of the picture tube. It is also important that the deflection yoke bracket be orientated so that the focus coil will have equal tilt up, down, right or left.

Deflection Yoke Adjustment.—This adjustment controls the angle of the picture with respect to the horizontal. If the picture be not squared in the picture mask, loosen the wing nut and move it to the left or right so as to rotate the deflection yoke. The picture will tilt to the left or right with the deflection yoke rotation.

CHAPTER 35

Television Broadcasting

General.—Broadly speaking, television may be said to be a means of vision obtained of a distant object by means of various devices identified as the *transmitting* and *receiving apparatus*. The problem of television therefore is fundamentally:

1. Converting light signals into electrical signals.
2. Transmitting the signals to a distant station, and
3. Converting the transmitted electrical signals back into light signals.

With reference to figs. 1 and 2 the steps required to pickup transmit and reproduce a television picture are principally as follows:

The video signal (picture signal) released by the *iconoscope** camera fig. 1 is a series of electrical charges which represent the light distribution of the object being televised. Light reflected from the face of the object is collected by the lens system and focused on the plate of the television camera tube. This plate is covered with a material, which in effect, forms an innumerable quantity of minute photoelectric cells and is called a *mosaic*. This mosaic is swept or scanned by a thin stream of electrons from the electron gun incorporated in the camera.

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*The name *Iconoscope* relates to a type of television transmitting tube invented by Dr. V. K. Zworykin of the Radio Corporation of America. The word *iconoscope*, taken from the Greek word "*icon*" meaning "image" and "scope" meaning observation.

Scanning Method.—The scanning in the case of the iconoscope, is accomplished by deflecting the electron beam electromagnetically by means of coils external to the tube. These coils are excited at frequencies which cause the point of impact of the electron beam to move across the mosaic in approximately a horizontal line at a uniform speed, then fly back and scan another line, and so on until the entire mosaic has scanned 525 lines in the desired sequence. This complete scanning is re-

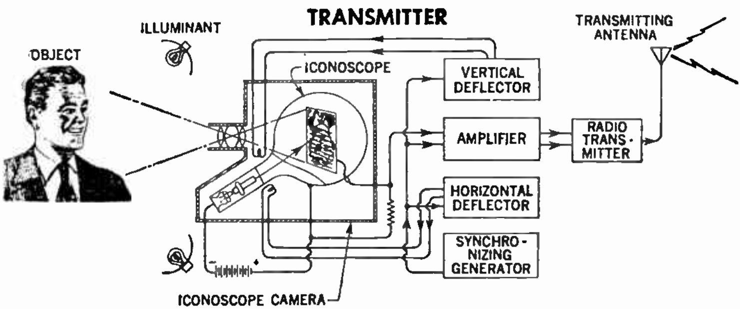


FIG. 1—Schematic diagram of simplified television transmitting system. (Sound portion of system not shown).

peated at the rate of 30 frames per second. Thus, in modern television systems, scanning consists of 525 horizontal lines, which are covered 30 times per second, making a total of 525×30 or 15,750 lines scanned per second, and 60 fields (two fields per frame).

When the electron beam falls upon an illuminated portion of the mosaic, current will flow through the output circuit of the iconoscope. When it falls upon a partially illuminated portion a smaller current will flow, and when it falls upon a dark portion very little current will flow.

In this manner, current pulses will be generated which will correspond in time sequence to the light and dark areas of the televised image as they are scanned by the electron beam.

The resulting voltage pulses, termed video signals, are then amplified and combined with special artificially manufactured signals for controlling the timing of the kinescope (receiver picture tube) deflection circuits and for extinguishing (blanking) the kinescope electron beam during the return time. The resulting composite signal is then used to modulate a high frequency transmitter.

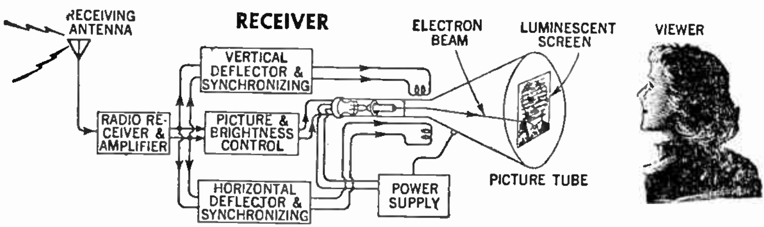


FIG. 2—Schematic diagram of simplified television receiving system. (Sound portion of system not shown).

In the standard interlaced scanning system, scanning of the horizontal lines is not performed in sequence, but the odd-numbered lines are scanned first, that is, 1,3,5, etc. and then the beam returns and scans the even-numbered lines, before the complete scene is scanned. Starting at the upper left extremity of the picture, as in fig. 3 line No. 1 is scanned. Instead of proceeding then, with line No. 2, the scanning spot drops two spaces and No. 2 is omitted. This is because the downward rate has been doubled—60 instead of 30 *c.p.s.* Line No. 3 then comes under scansion, followed by numbers 5,7,9 and every odd numbered line of the picture. Upon reaching the bottom of the picture, the scanning spot moves again to the top of the picture and begins another scanning field which is displaced from the first by the width of one line so that now lines 2,4,6,8 and all even numbered lines are scanned.

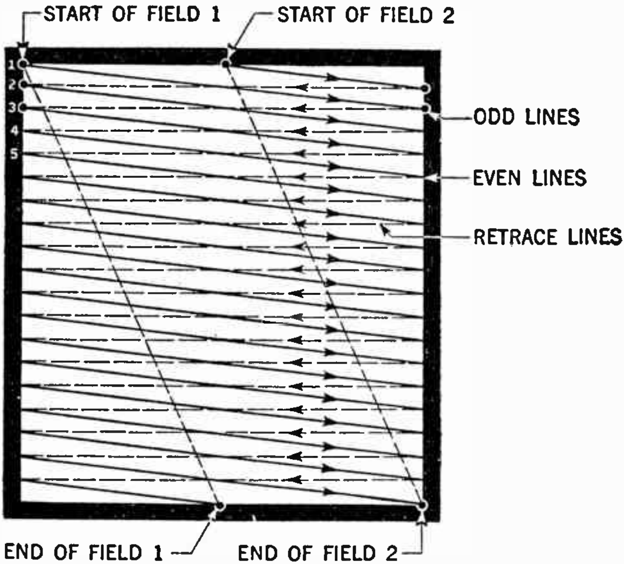


FIG. 3—Scanning raster showing interlaced pattern.

Since each field is completed in one sixtieth second, both fields consume one thirtieth second. Thus, 30 complete pictures are scanned in one second, each having been broken up into two projections as a means of flicker reduction.

Given a line frequency of 15,750 and a picture repetition rate of 30 *c.p.s.* the number of lines per picture is 15,750/30 or 525 lines, the number of lines per field being 262½.

Approximately 490 of these lines are active, the remainder occurring during the vertical retrace period during which time the viewing tube is blanked out. It is necessary of course, that complete synchronism be maintained between scanning at the transmitter and at the receiver. To effect this, synchronizing pulses are transmitted along with the video signal which locks the receiver oscillators, vertical and horizontal, into step with those at the transmitter.

Frequency Bands. -The F.C.C. (*Federal Communications Commission*) has up to the present time assigned two bands for television broadcasting. The frequencies of these bands are considerably higher than frequencies used in ordinary broadcasting. The low band covers frequencies from 54 to 88 mc. and the high band covers a frequency range of from 174 to 216 mc. The lower band consists of five channels as follows:

Channel Number	*Frequency (Megacycles)*
2	54-60
3	60-66
4	66-72
5	76-82
6	82-88

The higher band consists of seven channels and each channel has the following frequency allocation:

Channel Number	*Frequency (Megacycles)*
7	174-180
8	180-186
9	186-192
10	192-198
11	198-204
12	204-210
13	210-216

From the foregoing it will be observed that a single television channel is 6 mc. wide, in contrast to the entire commercial broadcast band, which is one mc. wide. Also one broadcast channel is only 10 to 20 *k.c.* wide. The reason for the wide television channel is because of the necessity to transmit video information with clarity and sharpness. It also serves to illustrate that video information must be transmitted on very high frequencies to obtain a satisfactory ratio of carrier frequency to bandwidth.

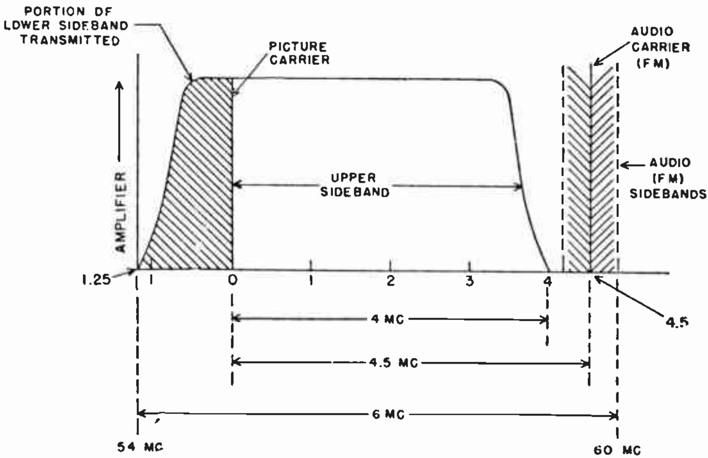


FIG. 4—Showing signal distribution in standard television channel.

Standard Television Channel.—A standard television channel is illustrated in fig. 4. As previously noted the bandwidth of each television channel is 6 mc., and both the video and sound signal must be transmitted within this limit. The amplitude-modulated picture signal is always at the low frequency end of each channel allocation and occupies approximately five and three-quarters mc. of the total six mc. bandwidth.

The frequency modulated sound signal is always at the high frequency end of the six mc. bandwidth and covers approximately one-quarter mc. or 25 *kc*.

An unusual feature of the amplitude-modulated picture signal is that the high frequency sideband is four and one-half mc. wide whereas the low frequency sideband is only one and one-quarter mc. wide. This unsymmetrical distribution permits transmission of a better definition picture using only a total bandwidth of six mc.

Such transmission of the picture signal and one sideband, as effected in television practice, is termed *vestigal sideband transmission* wherein the greater portion of the lower sideband is removed by a filter network.

Television Signal Components.—For successful transmission, the television signals must be separated into its components. Three types of information are transmitted on the picture carrier. They are:

1. The picture or video signal.
2. The synchronizing pulses (horizontal and vertical).
3. The blanking pulses (horizontal and vertical).

In the foregoing *the picture signal* consists of a progressive series of impulses which convey the light distribution to the scene to be televised.

The sync signal consists of a series of rectangular pulses, the function of which is to keep the iconoscope and kinescope (camera and receiver picture tube) locked in synchronism and to prevent the displacement of the pattern on the picture screen.

The blanking signal series of rectangular pulses are of longer duration than the sync pulses and as their name implies their function is to block out the fluorescent screen during all retrace intervals, making the retrace line invisible.

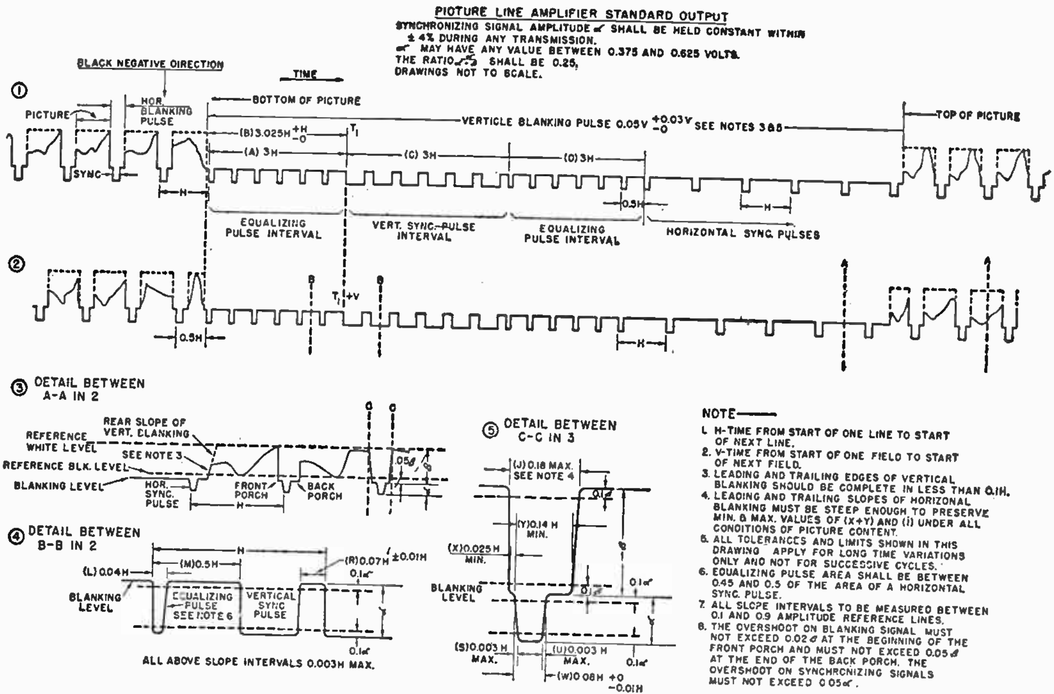


FIG. 5—Showing R.M.A. composite television signal for two successive fields. These wave shapes are for 525 lines per frame, 30 frames per second, 60 fields per second interlaced. The two wave shapes differ because of the requirement for interlacing. At the left are shown the last few lines of each field. At the end of each line is shown the horizontal blanking pulse. Details of composite signal are shown in the lower part of the illustration.

Another or fourth group of signals are termed equalizing pulses. These are of shorter duration than are the sync pulses and are transmitted to insure uniform spacing of the interlaced scanning lines, and to prevent loss of synchronism of the horizontal circuits during the retrace intervals between fields and frames.

In the composite standard video signal fig. 5, particular attention is directed to the polarity of transmission. An increase of signal power represents a dark portion of the picture, known as negative polarity of transmission. It is to be noted that the black level represents a portion of the viewing tube screen in which light is absent, that is, the beam has been blanked out. The synchronizing pulses represent a further increase of transmitter radiated power and so a darker spot upon the screen. However, since the beam has been wholly cut off at the black level and the screen is void of light, it cannot be affected by further cutoff and so the sync pulses produce no visible result. Their purpose and effect is evident, however, at the receiver scanning generators which are locked into step by these pulses. It is seen also that the sync pulses alone are not relied upon to blank out the beam during the retrace period. A blanking pulse serves this purpose, the sync pulses being superimposed upon the blanking pulse.

Should one long unbroken pulse be transmitted for vertical synchronization, the horizontal sync pulses during this time would be absent. During that time the horizontal (line frequency) scanning generators at the receivers would lack synchronization and drop out of step. In order that horizontal synchronization be maintained during the vertical retrace period, the vertical sync pulse is broken by serrations. These serrations then maintain horizontal synchronization during the vertical retrace period.

Between blanking (retrace) periods, the picture is being actively scanned. The picture signal is arbitrarily represented in fig. 5 as an irregular line.

All pulse shapes, their relative amplitudes and their duration are standardized. The only variable is the picture signal which varies from line to line as the subject is scanned.

Signal Standards.—Certain detailed facts of American standard television composite signals are given herewith. They are:

Channel width........................6 mc.
Picture aspect ratio...................4:3
Scanning (interlaced)..................525 lines
Horizontal scanning frequency..........15,750 *c.p.s.*
Vertical scanning frequency............60 *c.p.s.*
Frame frequency (picture repetition rate).30 *c.p.s.*

Camera Tubes.—The two most widely used camera tubes to-day are the *iconoscope* and the *image orthicon.*

The iconoscope, fig. 6 contains the following essential parts: 1. A photosensitive surface on which the image is focused and which generates the photo-current. 2. An electron gun to direct a narrow beam of electrons at the image surface, and 3. A device to deflect the beam rapidly across the image, causing it to strike each element in an orderly sequence.

The first two of the foregoing are enclosed in an evacuated glass envelope, whereas the third consists of deflection coils and their associated circuits outside the tube. The sawtooth currents, which pass through these coils, are of proper frequencies and amplitudes to cause the electron beam to scan the photosensitive surface upon which the image has been focused, in accordance with the standard interlaced scanning pattern.

Optical System.—Light is reflected from the objects in the scene to be televised, picked up by a lens, and projected through the flat front wall of the tube on to the image surface. The image is sharply focused so that light from any one element on the scene falls on only one tiny part of the photosensitive image surface.

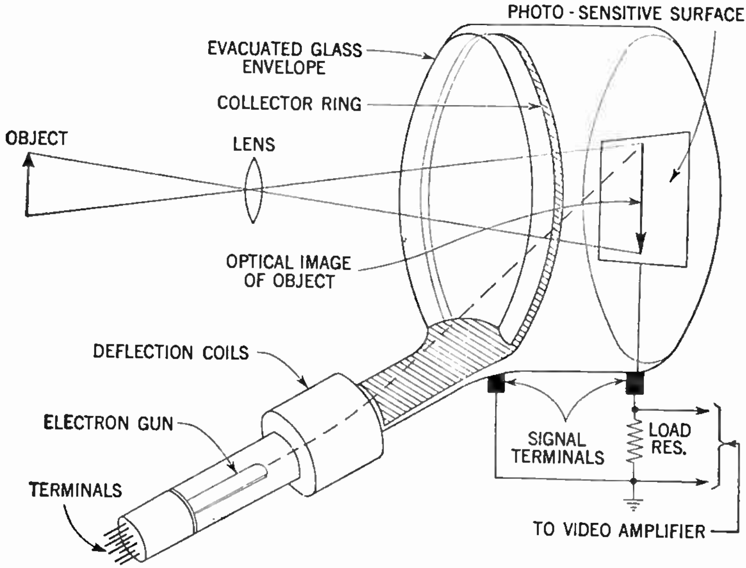


FIG. 6—Showing arrangement of parts of typical iconoscope.

The image surface consists of a thin sheet of mica three and one-half by four and three-quarter inches and approximately 0.001 of an inch in thickness. On the side which faces the lens, the mica strip is covered with myriads of tiny light sensitive globules, each of which forms one plate of a tiny condenser and each insulated from the other. On the other side is a flat conducting plate of collodial graphite which forms the signal plate.

The signal plate is connected to ground through a load resistor outside the tube. The actual signal circuit consists of the image surface, signal plate and collector ring.

The Mosaic.—The image surface covered with the photosensitive globules is called the *mosaic*. Each globule is made of silver, sensitized with a thin layer of cesium. The globules are not of uniform size, and are not arranged in a regular pattern, but they are so much smaller than the element of the image, that the total sensitive surface of each element is very nearly equal to that of each other element. The largest of the globules is about 0.001 inch in diameter and the scanning beam spot is about 0.008 inch.

Since the scanning beam has a spot size of about 0.008 inch in diameter, a large number of globules are being scanned at one instant. The area covered on the mosaic in any one instant by the scanning beam is called an *element*. The total number of picture elements in a modern television transmitting system is somewhat greater than 2×10^5.

Operation—The operation of the iconoscope is fundamentally as follows: An optical image is focused by a lens upon the surface of the mosaic. Under the lighter portions of the image, the individual silver globule photocells emit electrons, while less electrons are emitted by those under the dark or shaded areas. A loss of electrons constitutes a positive charge attained by the individual globule condensers and so is formed an electronic picture, the charge over any portion of the surface varying according to the amount of light present.

Now the electron beam is caused to scan this surface in the familiar way. As the electron beam strikes one of the surface elements, it supplies to it electrons that it had lost by reason of its photo-electric properties, therefore, the beam in effect, discharges the condenser which is formed by the globule, the mica dielectric and the back coating. In this connection it should be pointed out, that since the lens inverts the image on the mosaic, the scanning process of necessity must start at the bottom of the mosaic.

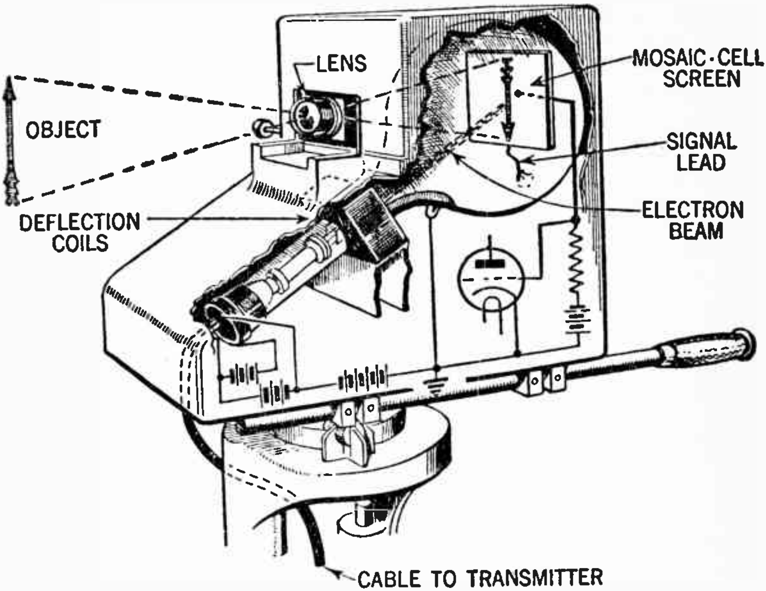


FIG. 7—Illustrating functional components of iconoscope camera. Roughly the camera consists of a lens arrangement similar to that of the ordinary camera which is focused on the scene to be televised. The image is projected upon the screen of the iconoscope which is mounted in the camera as shown.

With reference to fig. 6 it will be observed that the condenser discharge current passes through the tube load resistor, the potential thereby developed being applied to the video amplifier.

This potential is a function of the discharge current which, in turn, is a function of the amount by which the silver globules then under the scanning beam have been made positive by a loss of electrons. Since that is determined by the amount of light from the image at that point, it is evident that as the beam traverses the mosaic, a video signal is produced which represents the highlights and shadows of the televised scene.

The collector ring consists of a platinum band mounted on the inside surface of the iconoscope. Its function is to collect the electrons which leave the mosaic surface, in this manner completing the signal circuit through the load resistor.

The Image Orthicon—Because of the generation of a spurious dark spot signal resulting in low sensitivity in addition to the requirement of a high value of illumination, the iconoscope is at a disadvantage where it is necessary to work under a low value of illumination, such as that prevailing in all types of outdoor scenes, as for example, at football, tennis, golf games and the like.

Due to the foregoing deficiencies another type of television camera tube has been developed. This tube is called the *image orthicon*, the principle elements of which are shown in fig. 8.

Performance.—The image orthicon is a storage type of camera tube, having a sensitivity of from 100 to 1,000 times that of the iconoscope. It can therefore deliver an entirely satisfactory signal, with negligible noise voltage, from scenes illuminated by very low light levels.

The image orthicon achieves its high sensitivity in three ways. They are:

1. By using a conducting photosensitive surface, instead of an insulated mosaic, thereby increasing the photo emission response.

2. By scanning with a low velocity electron beam, thus eliminating the undesirable effects of secondary emission.
3. By using secondary emission at two different points in the tube so as to provide amplification of the signal by a factor of 100 to 500 without the generation of a corresponding noise voltage.

It has two relatively minor disadvantages, that is, the possible resolution of its picture is slightly less sharp than that of the iconoscope, and in addition it is not as well suited to operation at very high values of illumination.

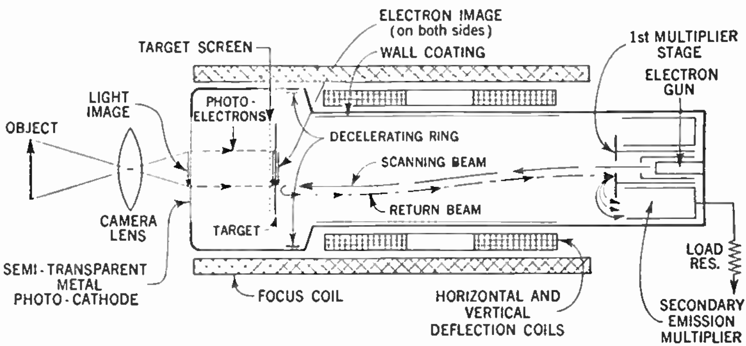


FIG. 8—Showing essential parts of image orthicon and their arrangement.

Structural Details.—This type of television camera tube is of a very compact design. It is approximately 15 inches in length, its external diameter being approximately three inches. With reference to fig. 8 the following fundamental differences from the previously discussed iconoscope are:

1. The light image is focused on one side of the photo cathode, while photo emission takes place from its other side.

2. The scanning takes place on a separate plate called the target, *not* on the photo emissive surface.
3. The image modulated current, constituting the video signal, comes from the beam electrons returning from the target toward the cathode from which they came.

One other feature in the illustration, is a focusing coil, wrapped around the entire length of the tube.

The Photo Cathode.—By observing the left side of the illustration fig. 8 it will be observed that the image of the scene is focused on a semi-transparent metal photo cathode. This represents an important improvement as compared to the iconoscope. A conducting surface like this has a higher photo sensitivity than an insulated surface, such as the globules of the iconoscope mosaic. Note, too, that the cathode is held at a constant potential of minus 600 volts; this is possible only because the photo electrons have a return path through the external circuit, so they are continuously replaced.

The photo cathode is made of such thin metal that light passes through it readily, as through tracing paper. Photo emission takes place from the back surface of the cathode. The emitted electrons are pulled by the strong electric field existing between the cathode and the target screen by reason of the potential difference of nearly 600 volts between them.

The target screen is made of incredibly fine metal wires, having from 500 to 1,000 meshes per linear inch. Better than 60% of its area is occupied by the holes, so the photo electrons can pass easily through it, and do not cast a "shadow" on the target beyond it.

Operation.—The operation of the image orthicon is fundamentally as follows: Light from the televised scene is picked in the conventional way by an optical lens system and focused on the photo sensitive surface behind the face of the tube.

The surface elements emit electrons in direct proportion to the amount of light striking them. These electrons, accelerated by a positive voltage and held on a parallel course by an electromagnetic field, flow from back of the photosensitive surface to a target.

Secondary emission from the target caused by the impact of the electrons, leaves on the target a pattern of varying positive charges, which correspond to the pattern of light from the televised scene.

The rear of the target is scanned by a beam of electrons which are generated by the electron gun in the base of the tube. This beam is modulated, as it scans, by the varying positive charges on the target which are representative of the light pattern of the televised scene.

The returning beam with picture information imposed upon it by the varying losses of electrons left behind in the target, is directed toward the first of a series of dynodes (electron multipliers) near the base of the tube. This multiplying process continues with the strength of the signal increasing at each dynode, until it reaches the signal anode and is conveyed to the external circuit.

Sound Transmitter.—The sound transmitter associated with the transmitting system is a conventional frequency modulation system consisting of audio amplifier, frequency modulator, high frequency transmitter and high frequency antenna. Thus, at the transmitting station, there are two transmitters, one for the picture signals, and one for the sound.

Television Broadcasting Practices.—In the foregoing overall description of a television system no attention has been given to the apparatus necessary in the broadcasting studios for a successful transmission of picture and sound. Most of the apparatus required to produce the conditions described are of necessity extremely complex.

The block diagram of the signal circuits of a typical modern television transmitter is shown in fig. 9. A separate transmitter supplies speech accompanying the scene. A camera selector affords the choice of ten cameras viewing one or more scenes from different vantage points any three of which may be selected simultaneously with control room monitoring of each.

Further selection is made by a channel selector feeding through a fader (volume control) the line amplifier. In addition, provision is made to preview the scene from a given camera prior to switching into the line amplifier.

The line amplifier also serves as a mixer for the injection of synchronization pulses which, along with the picture signal, make up the composite signal of the broadcast. An air monitor shows the picture as it is being transmitted.

The televising of live talent programs presents to the video broadcaster many of the same problems that have confronted the moving picture industry. Rather elaborate backgrounds are frequently necessary and they require the same attention to technical detail and to period authenticity that is evident in well staged plays and in high-grade motion pictures. As the video broadcast must be continuous, unlike the motion picture production which can be interrupted at will, the problems of set lighting and equipment placing require much planning and rehearsal prior to the actual broadcast.

Indoor, as well as outdoor televising usually requires that several cameras be strategically located so as to view the scene from various vantage points without sequential interruption.

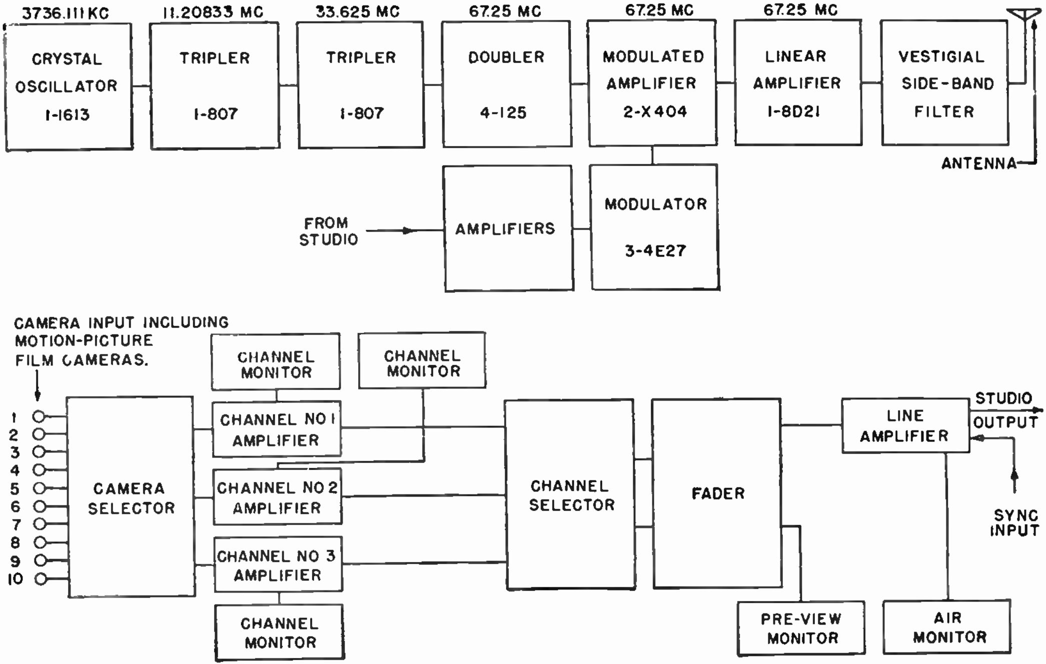


FIG. 9—Illustrating functional block diagram of typical television transmitter.

In addition to the telecasting of live program material, extensive use is made of motion picture film in television programming. For this purpose, special projectors are employed, which by a shutter arrangement, convert the 24 frame per second film projections into 30 frame per second television signals. The film picture is projected directly into the television camera tube, from which the electrical signal is conveyed to the control room over coaxial cable. Sound pickup from the film is in the normal manner.

Since the connection, by coaxial cable, from a remote place to the studio control room equipment is an economic impossibility, small ultra-high frequency radio relay links are employed to relay remote pickups.

The relay equipment is usually contained within a special truck which houses not only the relay transmitter but also complete control and monitoring facilities.

CHAPTER 36

Television Receiver Circuit Fundamentals

In the previous chapter a general discussion of the various factors affecting television broadcasting have been made. The function of a television receiver is to extract from space the signal transmitted by the broadcasting station, amplify it and employ it to produce visible pictures and audible sound which in all details conform with the original scene at the broadcasting station.

In the television receiver, therefore, the received signal is amplified and separated into its components. The components are amplied and applied in such a way as to produce variations in the intensity of the electron beam of the picture tube which is similar to a conventional cathode ray tube.

In the receiving picture tube, deflection is accomplished electromagnetically with coils external to the tube. The oscillators which furnish the energy for deflection operate at the same frequencies as the deflection oscillators associated with the transmitting camera tube and are held in synchronism by the transmissing synchronizing pulses.

Thus, the electron beam of the picture tube moves in synchronism with the electron beam of the camera tube, and the variations in brilliancy of illumination at the point of impact on the picture tube screen, correspond to the variations in illumination of the respective areas of the camera tube mosaic. In this manner, the image on the mosaic in the camera tube is dissected and the information on each element transmitted separately in a manner which permits the television receiver to take these pulses of information and employ them to produce corresponding variations in illumination on the picture tube screen and thus produce a picture of the original scene.

Present television receiver design practice is to use superheterodyne receivers with antenna and *r.f.* circuits which are sufficiently broad in frequency response to accept the entire pass band covered by the two carriers (sound and picture) and their transmitted sidebands. No separation occurs until after the first detector. The output of a single local oscillator is heterodyned with both sound and picture carrier signals to produce signals of two intermediate frequencies.

By having separate picture and sound intermediate frequency amplifying systems, each of which is tuned to the correct intermediate frequency, the television picture and sound signal may be separated. The sound amplifying system from that point on is in most respects similar to that of a conventional radio receiver.

Block Diagram of Typical Television Receiver.—In this connection it should be clearly understood that although television receivers may differ considerably as to circuit design (depending upon the manufacture of the particular receiver), they all operate on the same general principles.

In order to simplify the study of television receiver, it is customary to employ so called "*block diagrams*". By means of these, it is possible to separate the complete circuit into its various sections, each of which have been assigned to its particular function in the complete circuit.

Fig. 1 shows a block diagram of a typical television receiver.

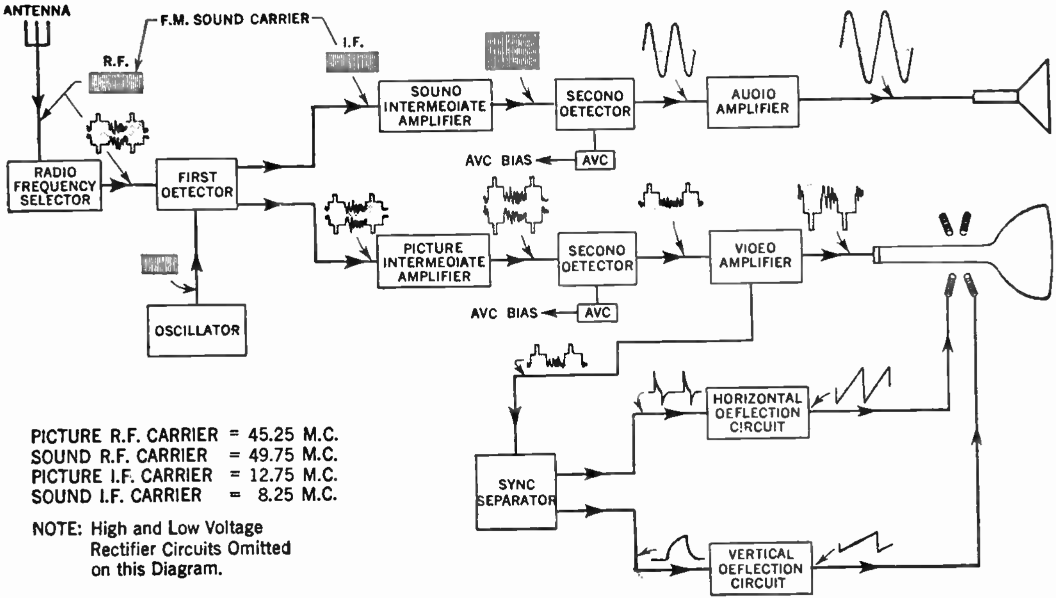


FIG. 1—Block diagram of typical television receiver.

The antenna receives both sound and picture signals. Thus, in a typical transmitter the picture carrier would be 45.25 mc. and the sound carrier 49.75 mc.

The *r.f.* circuits are sufficiently broad to pass both carriers with such portions of their sidebands as are transmitted. These are then passed on to the first detector where they are both heterodyned with a 58 mc. local oscillator signal. This produces two *i.f.* carriers, one at 12.75 mc. modulated with the picture signals, and another at 8.25 mc. modulated with the accompanying sound signals.

The *i.f.* signals with sound modulation are amplified by the sound *i.f.* amplifier, and the *i.f.* signals with picture modulation are amplified by the picture *i.f.* amplifier. In order to prevent cutting of the high frequency side bands in the sound *i.f.* amplifier when the receiver is slightly mistuned, the sound *i.f.* transformers are designed to pass a band up to 100 k.c. wide. As this type of transformer reduces the gain per stage, two sound *i.f.* amplifier stages are used to obtain the necessary amplification. The sound *i.f.* signals are impressed upon the sound second detector and are converted into aduio frequencies in the usual manner. These are then amplified and reproduced as sound by a conventional audio amplifier and loudspeaker.

The picture *i.f.* signals are amplified by a picture *i.f.* amplifier system which is tuned to 12.75 mc. and which passes a band of 2.5 mc. to 4 mc. depending upon the quality of the receiver. For vestigal side band transmission within the band widths allocated for television, this will allow modulation frequencies corresponding to video frequencies up to 4.0 mc. An *i.f.* amplifier which will pass a band of this width must necessarily have a low gain per stage and consequently five picture *i.f.*

stages are used in this typical receiver to secure the desired amount of amplification.

The amplified picture *i.f.* is applied to the picture second detector and converted into the television signal represented on page 758 The output of the picture second detector is supplied simultaneously to the picture *a.v.c.* system, to the video amplifier and to the synchronizing separator. The picture *a.v.c.* system utilizes some of the television picture signal to produce a variable *d.c.* voltage which after suitable filtering is applied as negative grid bias to the picture *i.f.* stage to control their gain.

The video amplifier amplifies the *a.c.* portions of the television picture signal and applies them to the grid of the picture tube to control the relative illumination of the elemental areas and to blank the beam during the return periods. A portion of the output of the video amplifier is rectified by a tube called the "*d.c.* restorer" and the *d.c.* voltage thus produced is applied as variable bias voltage to the picture tube grid. This function is usually referred to as the *automatic brightness control* and is necessary when the video amplifier is not a *d.c.* amplifier in order to reproduce correctly the average brightness or illumination of the scene being televised and to secure correct blanking during the return time.

The synchronizing separator incorporates circuits which separate the synchronizing pulses from the remainder of the signal. The horizontal synchronizing pulses are then separated from the vertical synchronizing pulses by suitable circuits and both are then applied to control the timing of the deflection oscillators with which they are associated.

FIG. 2—Illustration showing antenna assembly method. (Courtesy American Phenolic Corporation.)

CHAPTER 37

Circuit Description of Typical Television Receiver

The material presented under the foregoing heading has been supplied by the courtesy of *Motorola Inc.*, and while this information has direct reference to their *12T* and *12K* model receivers, it will prove helpful to television students and servicemen in servicing other sets since much of this data is of a general nature.

Chassis.—Television chassis fig. 1 contains 19 tubes exclusive of the picture tube. The picture, sound and scanning circuits, together with a selenium rectifier, voltage doubler "B" supply, are contained on a single chassis.

Tuning Range.—Channels 2 through 13.

I.F. Frequency.—*Channels* 2 *to* 6; Sound 21.9 mc.; Picture 26.4 mc.; *Channels* 7 *to* 13; Sound 27.3 mc.; Picture 22.8 mc.

Antenna Impedance.—300 ohms.

Power Supply.—117 volts, 60 cycles, *a.c.* current only.

Power Consumption.—160 watts.

Audio Output.—4 watts

Chassis Tube Complement

Ref. No.	Tube	Function
V-1	6CB6	*r.f.* Amplifier
V-2	12AT7	Mixer-Oscillator
V-3	6AU6	1st *i.f.* Amplifier
V-4	6AU6	2nd *i.f.* Amplifier
V-5	6AG5	3rd *i.f.* Amplifier
V-6	6AL5	Video Detector
V-7	6AH6	Video Amplifier
V-8	6AU6	Audio Driver-Limiter
V-9	6AL5	Ratio Detector
V-10	6J5GT	Audio Amplifier
V-11	6V6GT	Audio Output
V-12	6SN7GT	1st and 2nd Clippers
V-13	6J5GT	Vertical Sweep Generator
V-14	25L6GT	Vertical Sweep Output
V-15	6AL5	Phase Detector
V-16	6SN7GT	Horizontal Oscillator
V-17	6BQ6GT	Horizontal Output and High Voltage Generator
V-18	6W4GT	Damping Diode
V-19	1B3GT	High Voltage Rectifier
V-20	12LP4	Picture Tube

Low Voltage Power Supply.—The low voltage power supply fig. 2 provides plate voltage for all tubes except the high voltage applied to the second anode of the picture tube. The heater transformers supply heater voltage to all tubes except the *h.v.* rectifier, which is energized by horizontal sweep current.

One low voltage secondary of *T-7*, the step down filament transformer, supplies filament voltage to all tubes except the audio driver-limiter (*V-8*), the vertical output tube (*V-14*), the picture tube (*V-20*), and the horizontal damping diode (*V-18*).

Since the damping diode (*V-18*) develops a high voltage pulse at its cathode, and its cathode is tied to the filament to prevent breakdown in the tube, it is necessary to provide a separate, low-capacity, well insulated transformer (*T-8*) to heat this filament.

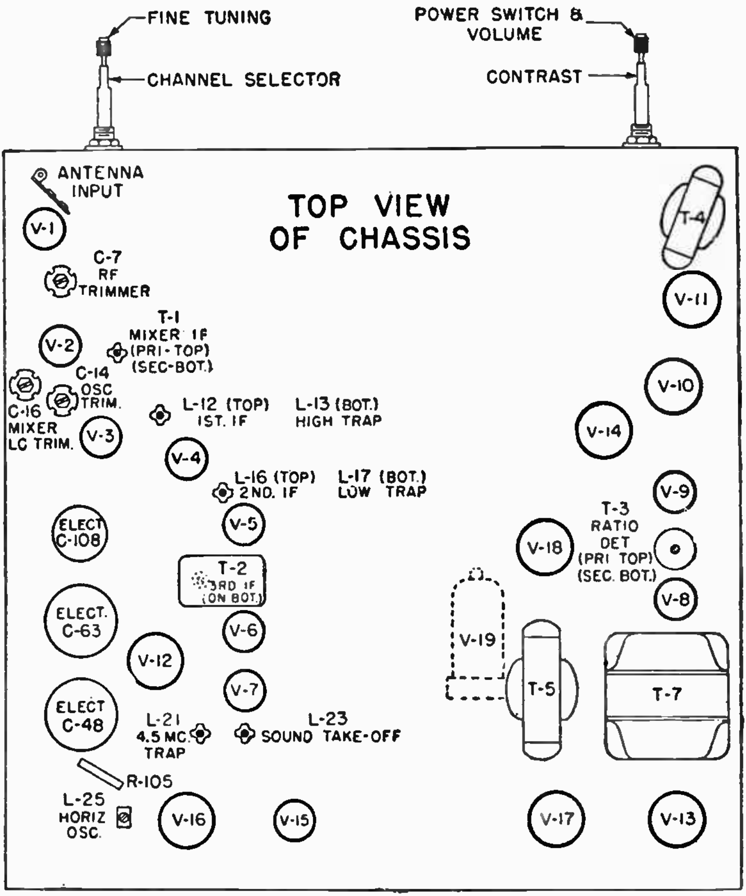


FIG. 1—Top view of typical chassis showing tube and adjustment location.

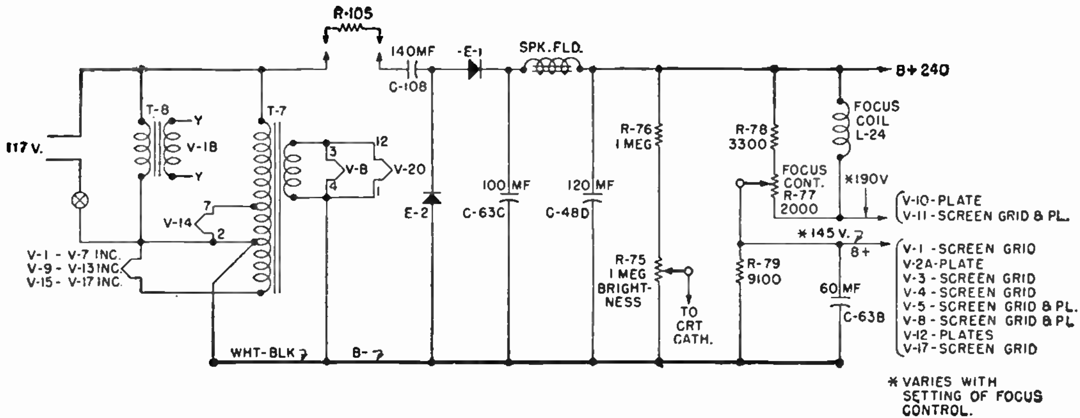


FIG. 2—Simplified schematic of low voltage power supply.

The vertical output tube (*V-14*) requires a 25 volt filament supply, and hence is provided with a separate 25 volt tap on the transformer. *V-8* and *V-20* are supplied by an additional winding, which in sets of late designs, is connected series opposing with the primary to increase the 6.3 volt filament supply voltage slightly to insure that the *r.f.* oscillator will operate on low line voltage.

The "B"+ plate supply uses a voltage doubler. *R-105* is a limiting resistor to protect the rectifiers from initial current surges and also serves as a fuse in case of "B"+ shorts. When the polarity of the applied 117 volts *a.c.* is such as to make the side of the line connected to *R-105* negative, *E-2* will conduct and charge *C-108* (140 *mf.*) to peak line voltage.

On the next alternation, *E-1* will conduct and the voltage applied to it is now the peak line voltage plus the peak charge stored in *C-108*. This results in a charge of about 260 volts on *C-63C* (100 *mf.*). The speaker field is used as a filter choke. The focus coil and the resistor network, which controls the current through it, act also as a voltage divider to supply plate and screen voltages to several tubes, as shown in fig. 2.

Another voltage divider from "B"+ to "B"−, consisting of *R-76* (1 meg.) and the potentiometer, *R-75* (1 meg.) provides a variable bias on the cathode of the picture tube, to serve as a brightness control.

The R.F. Tuner.—Fig. 3 is a simplified schematic of the tuner. The antenna input coil, *L-1*, couples the balanced line to the single ended input circuit for the *r.f.* tube, *V-1*. Optimum antenna coupling for all channels is obtained by the coupling coils *L-5A*, *L-5B*, *L-5C*, and the coupling leads on channel positions 8, 10 and 12 of switch wafer *S-1A*. These can be considered the primary of the antenna transformer.

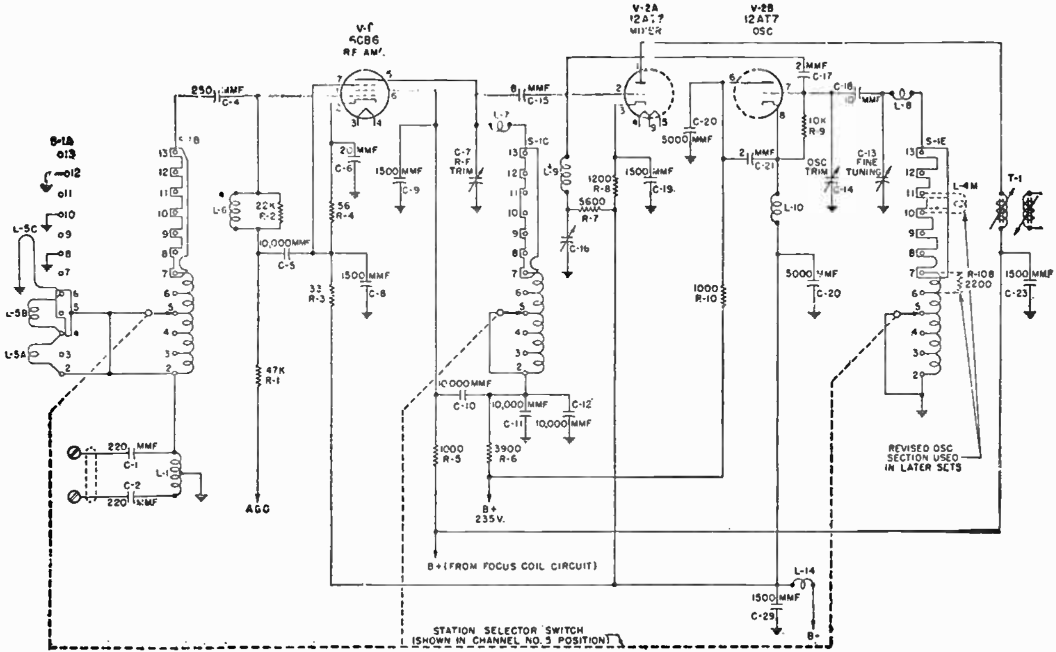


FIG. 3—Simplified schematic of RF tuner.

The secondary, or tuned grid circuit, includes also the continuous, tapped coil mounted on wafer *S-1B* for the low channels (2-6) and the stamped metal plate in series with the coil for the high channels (7-13). The purpose of the antenna coil, coupling leads, and the secondary circuit, is to match the 300 ohm impedance of the transmission line from the antenna to the input impedance of the *r.f.* amplifier grid circuit and to tune this circuit for the channel selected. Referring to fig. 3, it will be seen that the switch in progressing from channel 2 to 13, shorts out the unused portion of the secondary winding or stamped metal plate. The bandwidth of channels 7 through thirteen is about 8 mc. The stamped metal plate is carefully designed so that with this bandwidth no alignment adjustment is needed on the high channels.

R.F. Amplifier.—The grid of the *r.f.* amplifier *V-1* (6CB6) is returned to the automatic gain control bus through *L-6* and a bypass capacity (*C-5*). The plate load of this tube consists of another tapped coil for the low channels and a stamped metal plate for the high channels mounted, in this case, on switch wafer *S-1C*. Here again, the switch progressively shorts out the unused sections of the inductance in tuning from channel 2 to 13. In this case, however, a trimmer *C-7* and a choke *L-7* are provided to center the high channel response while the low channel coils may be tuned by expansion or compression.

The Mixer.—The mixer uses one-half of *V-2* (12AT7). *C-15* (8 *mmf.*) couples the *r.f.* amplifier output to the mixer grid. Oscillator injection is accomplished by *C-17* (2 *mmf.*). *L-9* and *C-17* form a series resonant circuit tuned to the center of the *i.f.* response, to prevent interaction between the *i.f.* and the mixer input.

The Oscillator.—The oscillator uses the other half of *V-2* (12AT7) in a Colpitts circuit. Here again, the tuning inductance consists of the tapped coil for the low channels and the stamped metal plate for the high channels mounted on wafer *S-1E*. *L-8* and *C-14* are provided to set the center frequency on the high channels while the low channels are aligned by spreading or compressing the individual coil sections. *C-13* is provided as a fine tuning control for customer use.

The oscillator operates above the *r.f.* on the low channels and below the *r.f.* on the high channels except that in later production the circuit was modified to avoid interference by operating the oscillator on the high side for channels 11, 12 and 13.

The I.F. Amplifier.—The *i.f.* amplifier uses two 6AU6 tubes and one 6AG5 tube. Fig. 4 is the schematic of the *i.f.* amplifier. *T-1* couples the mixer plate to the first *i.f.* grid. Coupling between primary and secondary, which are individually slug-tuned, is fixed and is designed for proper bandwidth. The plate choke *L-11*, of the first *i.f.* tube *V*-3 (6AU6), is coupled to the grid coil, *L-12*, of the second *i.f.* tube *V-4* (6AU6) through *C-30* (220 *mmf.*). At *i.f.* frequencies, the impedance of *C-30* is negligible and for all practical purposes, *L-11* and *L-12* can be considered as being in parallel, *L-12* being slug-tuned.

A similar method is used between the second and third *i.f.* tubes. The third *i.f.* plate is coupled to the detector by *T-2*, a unity coupled transformer. The *i.f.* circuits are stagger-tuned for proper bandwith. *L-13* and *L-17* are separately tuned trap windings on *i.f.* coil forms *L-12* and *L-16*, respectively. Together with *C-31* and *C-38*, they form absorption type trap circuits which steepen the high and low skirts of the *i.f.* response for better picture quality and to stabilize the audio response with intercarrier sound.

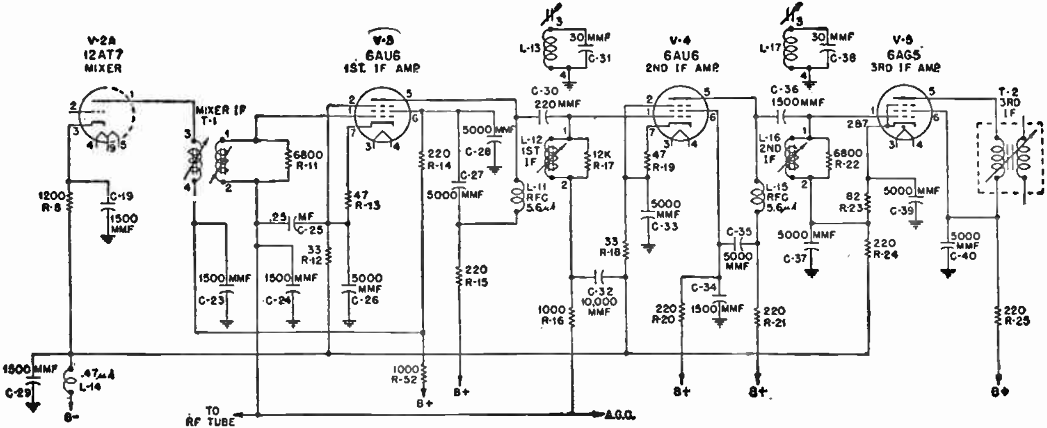


FIG. 4—Simplified schematic of IF amplifier.

Decoupling has been used not only in the plate supply and a.g.c. circuits, but also in the filament circuits to prevent regeneration.

The Video Detector.—One-half of *V-6* (6AL5) is used as the video detector. Fig. 5 is a schematic of the video detector,

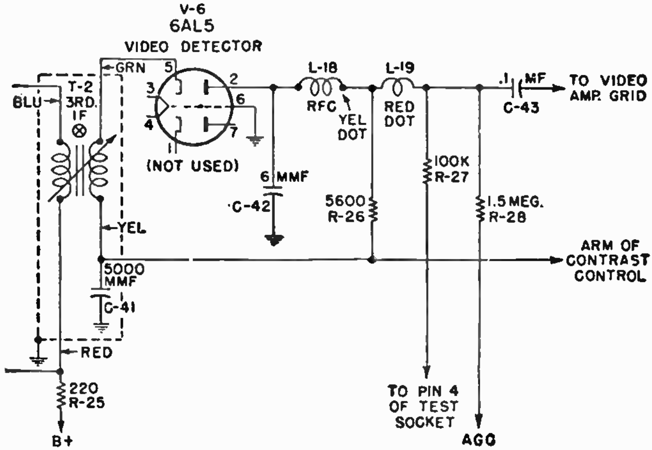


FIG. 5—Simplified schematic of video detector.

Since for noise limiting purposes it is desirable to apply a signal with negative going sync pulses to the grid of the video amplifier, the detector load *R-26* (5600) is placed in the plate circuit of the diode. *L-18*, *L-19*, and *C-42*, form a low pass filter to keep *i.f.* frequencies off the grid of the video amplifier.

Since this chassis operates on the intercarrier sound system, the detector heterodynes the video and sound *i.f.* frequencies, and produces the 4.5 mc. beat frequency which becomes the new audio *i.f.* frequency. The negative *d.c.* voltage developed at the high side of the detector load *R-26* (5600) will be a function of carrier level. This voltage is fed to the a.g.c. bus through *R-28* (1.5 meg.) and controls the gain of the *r.f.* and first and second *i.f.* amplifiers.

The Video Amplifier.—The video amplifier *V-7* (6AH6) not only amplifies the video signal but also the 4.5 mc. audio *i.f.* beat. Fig. 6 is a schematic of the video amplifier. In its plate

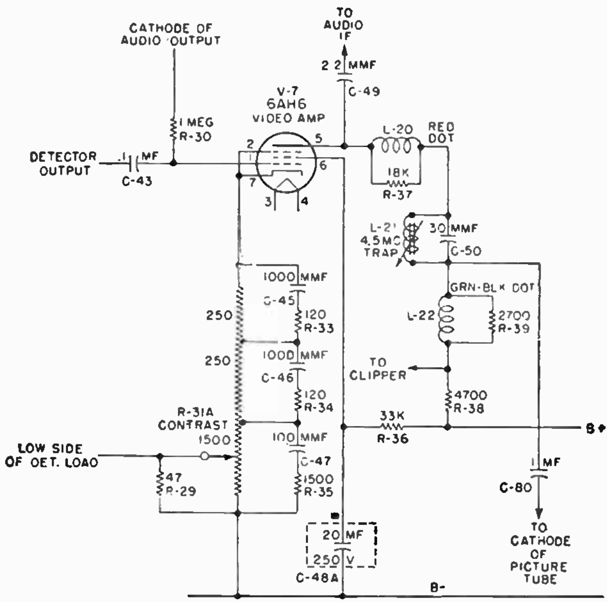


FIG. 6—Simplified schematic of the video amplifier.

circuit, this beat is separated from the video signal and fed to the grid circuit of the audio driver-limiter tube *V-8* (6AU6) by *C-49* (2.2 *mmf.*) and *L-23*, the sound take-off coil. The 4.5 mc. trap, *L-21* and *C-50*, is a parallel resonant circuit which, when properly tuned, offers a high impedance to this frequency, to prevent its reaching the picture tube.

By applying a negative signal to the grid of the video amplifier, a noise limiting action is achieved because noise pulses of amplitude greater than the sync level will drive the tube to cut off and, therefore, will not be present in the plate circuit. Since a single video amplifier tube is used, the signal at its plate will be positive and, as might be expected, is used to modulate the cathode of the picture tube rather than the grid, because the blanking pulses must cut the picture tube off and the polarity of the video information must be such that dark picture elements result in making the grid more negative with respect to the cathode.

L-20 and *L-22* are peaking coils to extend the high frequency response of the amplifier. The contrast control, *R-31A*, is placed in the cathode circuit of the video amplifier and controls the bias and, therefore, the gain of this tube. The network of resistors and condensers across taps on the contrast control decreases degeneration at the higher frequencies and, therefore, helps to extend the high frequency response. The composite video signal is fed to the picture tube cathode through coupling condenser *C-80* (.1).

The Automatic Gain Control (A.G.C.).—The negative *d.c.* voltage developed across the detector load resistor, *R-26* (5600), is the a.g.c. voltage. It will be noted that the low side of this resistor is connected to the arm of the contrast control potentiometer, *R-31A*. *R-29* (47) is shunted across the arm of the contrast control and B−. In weak signal areas, this arrangement results in delay in the a.g.c. action. For a weak signal, minimum bias is desired on the video amplifier, therefore, the arm of the contrast control will be closest to the cathode end of the potentiometer.

Because *R-29* is then shunted across the entire contrast control, most of the plate current will flow through it and develop a positive voltage of approximately one volt at the arm with respect to B−. Since the low side of the detector load is tied to this positive voltage, no a.g.c. voltage will develop until the signal is strong enough to overcome this positive voltage and, therefore, no a.g.c. bias is applied to the controlled tubes under weak signal conditions. In a strong signal area, however, where the arm of the contrast control approaches the B− end of the control, *R-29* is shorted out and full a.g.c. voltage is developed.

The Audio System.—The audio system employs a driver-limiter. *V-8* (6AU6); a ratio detector *V-9* (6AL5); a first audio amplifier, *V-10* (6J5), and an audio output tube, *V-11* (6V6). Fig. 7 is a schematic of the audio system. The driver-limiter is operated at low plate and screen voltages to act as a partial limiter to minimize any amplitude modulation. A conventional ratio detector and audio amplifier are used.

The Clipper.—The clipper uses a 6SN7GT tube. The clipper schematic is shown in fig. 8. The composite video signal with positive going sync is applied through *R-55* (10K) and *C-66* (.005) to the grid of the first clipper from the plate circuit of the video amplifier. Under no signal conditions, the tube is unbiased.

The positive signal, however, will cause the tube to draw grid current and the voltage drop across *R-54* (1 meg.) negative at the grid, will charge *C-66* to such a value that only the most positive part of the signal, which is the sync pulse, will cause plate current to flow. Therefore, the video information and the blanking pulses are clipped off and only the sync pulses,

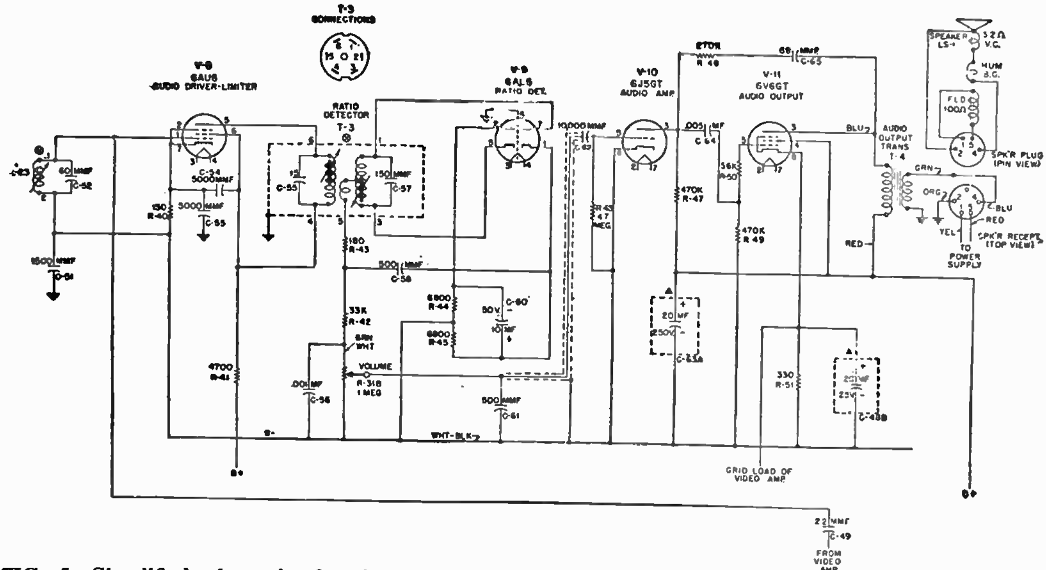


FIG. 7—Simplified schematic of audio system.

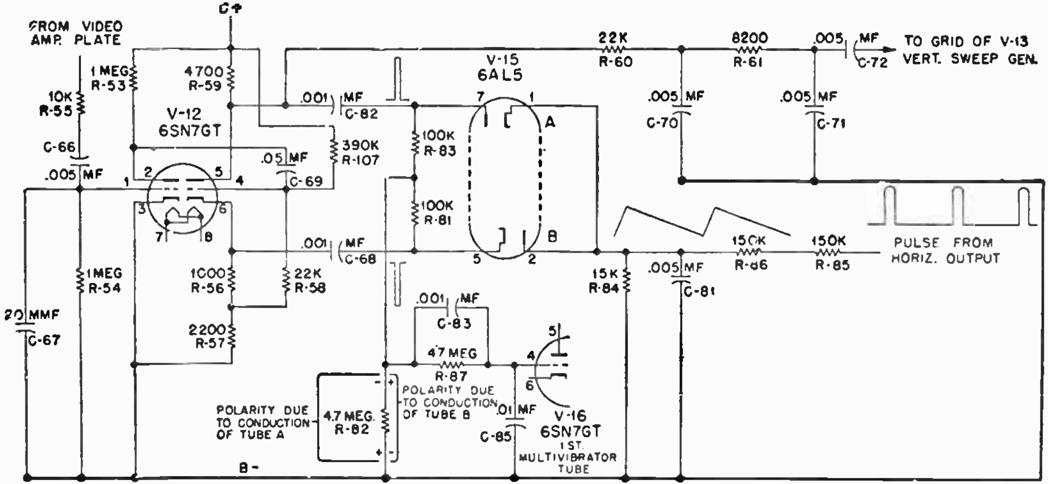


FIG. 8—Simplified schematic of clippers and phase detector.

now negative in polarity, appear in the plate circuit. The second clipper is so biased that the peaks of the sync pulses will drive the tube to cut-off, which results in squared pulses of positive polarity in the plate circuit of this tube. A slight increase in sync pulse amplitude is obtained by a small positive voltage applied to the grid of the second clipper by *R-107* (330K).

The Vertical Scanning System.—Fig. 9 is a schematic of the Vertical Scanning System.

The integrating network, shown in fig. 8, composed of *R-60*, *C-70*, *R-61*, and *C-71*, changes the vertical group of sync pulses into a single pulse of suitable amplitude to trigger the vertical oscillator. The vertical oscillator is an asymmetrical multivibrator using two tubes *V-13* (6J5) and *V-14* (25L6). *V-14* also serves as the output tube.

A multivibrator can be considered as a resistance coupled amplifier in which the output of the second tube is coupled back to the input of the first tube. *V-13* is the automatic switch which charges and discharges the sawtooth forming condenser *C-74* (.05), connected in its plate circuit. The circuit components of the multivibrator are chosen so that *V-13's* conductance period is about seven percent of the entire cycle, to insure that retrace time of the scan will have the proper relationship with the trace time.

This circuit is modified from the conventional resistance coupled multivibrator in that the plate of the output stage, which is also the second multivibrator tube, has a fairly large value of inductance, introduced by the output transformer stepping up the yoke inductance. When the tube is cut off, a positive pulse of several hundred volts is developed across this inductance. A portion of this pulse, obtained by means of

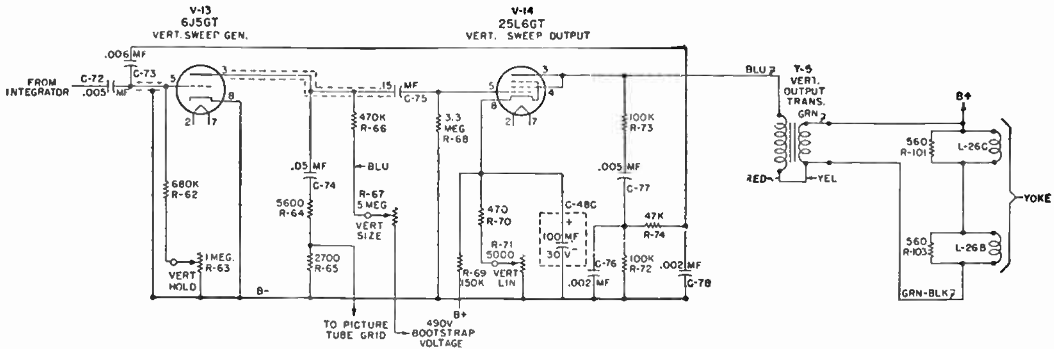


FIG. 9—Simplified schematic of vertical scanning system.

the feedback network, *R-72*, *R-73*, *R-74* and *C-76*, *C-77* and *C-78*, is used to cause the discharge tube *V-13* to go into heavy conduction.

For purposes of explaining the circuit action, assume a time has been reached in the cycle when the trace period is almost completed. During this trace period, *V-13* is cut off and *V-14* is conducting. *C-73* has been discharging through the grid resistors of *V-13*, *R-62* (680K) and *R-63* (the vertical hold control) and resistors *R-74* and *R-72*. This discharge circuit makes the grid end of *R-62* negative and biases the tube beyond cut-off.

When the energy stored in the condenser has decreased sufficiently, the grid of *V-13* reaches the threshold of conductance and the tube begins to draw current. Condenser *C-75*, which has been charged to nearly the B+ voltage, now starts to discharge through *V-13* and *R-68* (3.3 meg.) and this discharge current makes the grid end of *R-68* negative tending to cut off *V-14*, and initiates the retrace. With the sudden change of plate current in *V-14* developed across the plate inductance, a positive pulse is applied to the grid of *V-13* through the feed-back network driving this tube into heavy conduction. *C-74* will then discharge through *V-13*.

The voltage developed at the plate of *V-13* will be the combination sawtooth and pulse voltage shown in fig. 12 (1). The pulse is formed by the peaking resistors *R-64* and *R-65*. When *V-13* goes into conduction, the voltage at the plate of *V-13* drops suddenly to a value determined by the relationship of the plate resistance of *V-13* to the total resistance in the discharge circuit of *C-74*, which consists of *R-64*, *R-65* and the plate resistance of *V-13*.

After this initial instant, the charge on *C-74* decreases, causing the voltage decrease at the plate shown between points "c" and "d" of fig. 12 (1). When the positive pulse on the grid of *V-13* has decreased to the value where the negative charge on *C-73* becomes operative and cuts off *V-13*, the voltage on the plate of *V-13* and correspondingly on the grid of *V-14*, rises quickly to point "a" on the curve, the start of the trace.

The negative pulse shown between points "b" and "a" of fig. 12 (1) acting on the grid of *V-14*, tends to cut the tube off and raises its plate resistance to the larger value required to dissipate the energy in the plate circuit inductance during the short retrace period.

Since the plate circuit of the vertical output stage *V-14* has inductance, and as the time constant of an inductive circuit decreases with an increase of resistance, just the opposite of an RC circuit, the increase in plate resistance of the tube is used to obtain the short time constant circuit required for proper retrace time.

By returning the grid of the picture tube to the junction of the two peaking resistors, *R-64* and *R-65*, a negative pulse of suitable amplitude to cut the picture tube off during retrace is obtained, resulting in elimination of retrace lines on the screen.

The feedback network to the grid of *V-13* also serves to filter out horizontal pulses which are present in the plate of *V-14* due to coupling in the yoke and which are coupled to the plate through the output transformer. The windings of the vertical output transformer are connected series opposing, which reduces the step-down ratio and, hence, the inductance in the plate of *V-14* in order to shorten the retrace time. The controls found in this circuit are:

1. *The Vertical Hold Control R-63* (1 meg.). This control varies the resistance in the discharge circuit of *C-73* (.006) and, hence, provides a means of varying the frequency of the multivibrator. In practice, this control is adjusted so that the incoming positive sync pulses, which are of constant amplitude, will fire the tube in exact synchronization with the transmitting station's vertical scan.

2. *The Vertical Size Control R-67* (5 meg.). This control varies the charging current into *C-74* (.05) and, hence, the amplitude of the voltage developed across it. Variation of this voltage varies the drive on the grid of *V-14* and controls vertical size.

3. *Vertical Linearity R-71* (5000). This control, by bleeder action through resistor *R-69* (150K) and the output tube's plate current, sets the bias and determines the tube's operating point on its plate current curve. Since this curve is not linear, some distortion can be introduced to counteract any non-linearity in the sawtooth grid voltage.

Since all of these controls are also in the multivibrator circuit and have an effect also on its frequency, there will be some interaction between them. Usually readjustment of size or linearity will require readjustment of the hold control.

Horizontal Scanning System.—The horizontal scanning system comprises a phase detector *V-15* (6AL5), and a cathode coupled multivibrator *V-16* (6SN7), the output tube *V-17* (6BQ6) and a damping diode *V-18* (6W4). Fig. 10 is a simplified schematic of this system.

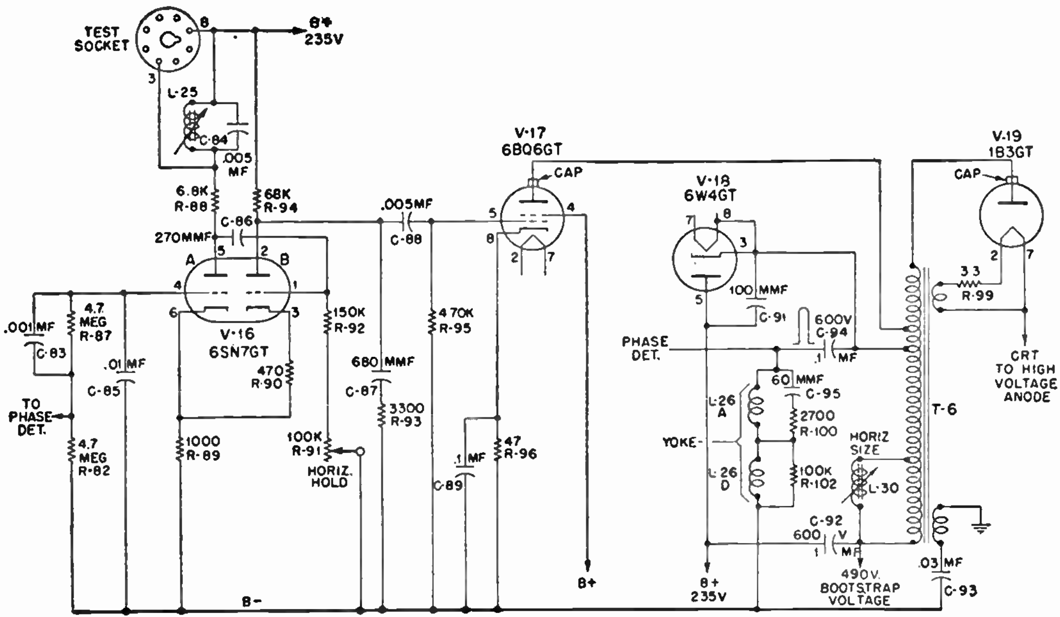


FIG. 10—Simplified schematic of horizontal scanning and high voltage system.

Horizontal Oscillator.—In order to see how the phase detector automatically corrects for multivibrator frequency change, it will be necessary to understand how the correction voltage affects the multivibrator. It will be noted that this circuit differs from the vertical multivibrator in that only one coupling condenser is used but that the two tubes have a common cathode resistor. This arrangement is known as a *cathode coupled multivibrator.*

The operation is as follows. Assume that the trace period is almost completed. At this time, tube "A" is conducting, tube "B" is cut off. *C-86* is discharging through tube "A", *R-92* (150K) and *R-91* (the hold control). The discharge current of *C-86* is still high enough to keep the grid of tube "B" negative and cut off. Bias is being applied to both tubes by current flow through *R-89* (1000) the common cathode resistor.

When the energy stored in *C-86* is reduced to the point where its discharge current no longer holds the grid of tube "B" below conductance, tube "B" starts to pass current and this current causes a greater voltage drop across *R-89*, the common cathode resistor, which increases the bias on tube "A" reducing its plate current.

The resulting increase in voltage at the plate of tube "A" begins to charge *C-86* and this charging current applies positive voltage to the grid of tube "B". The resulting heavier conduction of tube "B" develops a pulse of voltage across *R-89* which cuts tube "A" off and results in a positive pulse at the plate of tube "A" which throws tube "B" into heavy conduction.

This allows *C-87*, the saw-forming condenser to discharge through tube "B" and *R-93*. When *C-86* becomes charged the charging current through *R-92* and *R-91* decreases and the positive voltage on the grid, which has far exceeded the bias developed across *R-89*, is reduced. This results in reducing the plate current through tube "B" and, therefore, the bias applied to tube "A" by the voltage drop across *R-89*. Tube "A" starts to conduct and condenser *C-86* starts to discharge, cutting tube "B" off. *C-87* begins to charge, starting the next trace.

L-25 and *C-84* in the plate circuit of tube "A", form a resonant circuit which is tuned to the horizontal frequency (15,750 cps). The 15,750 cycle sine wave generated by this circuit, if properly phased, will insure that the positive pulse at the plate of tube "A", which throws tube "B" into conduction, will be more frequency stable.

C-87 and *R-93*, the peaking resistor, will produce the same combination pulse and sawtooth voltage shown in fig. 12 (1). This action was explained in the vertical circuit.

The Phase Detector.—The foregoing explanation is based on the assumption that tube "A's" grid is returned to a fixed potential point. It can be seen that if this grid is returned to a point which varies in potential with frequency of the multivibrator, it would be possible to make this variation a means of frequency control.

Assume that the grid of "A" in fig. 10 is made more positive. This causes the bias of "B" to increase because of the increased drop across the common cathode resistor *R-89*. Capacitor *C-86* will then discharge for a longer time before "B" conducts, thereby decreasing the frequency of oscillation. If the grid were made more negative, the bias across the common cathode resistor would be less and *C-86* would discharge for less time before "B" started to conduct, thereby increasing the frequency.

Fig. 8 is a simplified schematic of the clipper and phase detector circuits. The phase detector *V-15* (6AL5) is so connected that a comparison of the phase of the incoming sync pulses and a sawtooth derived from the horizontal output system is made. A positive sync pulse from the plate of the second clipper *V-12* (6SN7) is fed through *C-82* (.001) to the plate of diode "A" of *V-15*. A negative sync pulse from the cathode of *V-12* is applied through *C-68* (.001) to the cathode of diode "B" of *V-15*.

A sawtooth, derived from the integration of a pulse in the horizontal output circuit, at the yoke, by the integrating network, composed of *R-86* (150K), *R-85* (150K), and *C-81* (.005) is applied to the cathode of diode "A" and the plate of diode "B", which are tied together and returned to B− through *R-84* (15K).

The load for diodes "A" and "B" consists of resistors *R-83* (100K) and *R-81* (100K) whose junction returns to the high side of the grid resistor *R-82* of the first horizontal multivibrator tube *V-16* (6SN7). The voltage applied to the two diodes will be a function of the amplitude of the sawtooth, the amplitude of the sync pulses and the phase relationship between the pulses and the sawtooth.

If the sawtooth, whose phase and frequency are a function of the multivibrator's phase and frequency, is operating in the middle of the lock-in range, the sync pulse will occur in the center of the retrace time. See fig. 11 (1). The sync pulses have an amplitude of from six to eight volts while the sawtooth amplitude is about two volts.

The RC time constant in the pulse input circuit to the diodes is long enough to maintain an average pulse voltage of six to eight volts for two or three horizontal lines, which means that in the "on" frequency condition shown in fig. 11 (1), the diodes conduct only on the pulses and since these are equal in amplitude and develop voltages of opposite polarity across *R-82* in the first multivibrator grid circuit as shown in fig. 8, no control voltage is applied to the grid of *V-16*.

If the oscillator tends to increase in frequency, with respect to the sync pulses, the phase relationship shown in fig. 11 (2) exists at the diodes. The phase of the sawtooth has now shifted

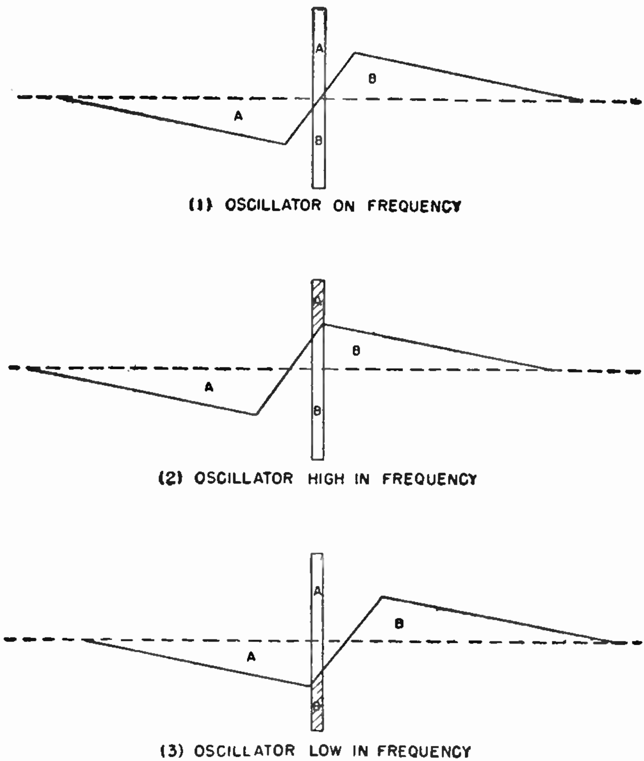


FIG. 11—Wave forms at phase detector.

so that at the same instant that the pulse is applied to the plate of diode "A" the positive saw is also applied to its cathode, so that only the shaded portion of the pulse causes conduction of diode "A". Diode "B", however, still conducts on the total amplitude of the negative pulse applied to its cathode aided by the positive saw applied to its plate at the same time.

Since current flow through diode "A" makes the grid end of *R-82* negative, with respect to B−, the decreased current flow caused by the sawtooth voltage bucking the pulse voltage at diode "A" results in a more positive voltage across *R-82* applying a more positive voltage to the grid of *V-16* which, as we have seen, results in decreasing the oscillator's frequency.

If the oscillator tends to decrease in frequency, with respect to the sync pulses, the phase relationship shown in fig. 11 (3) exists at the diodes. At the same instant that the negative pulse is applied to the cathode of diode "B", the negative saw is applied to its plate so that only the shaded portion of the pulse causes conduction. Diode "A", however, conducts on the full amplitude of the positive pulse applied to its plate aided by the negative saw applied to its cathode at the same time.

Since current flow through diode "B" makes the grid end of *R-82* positive, with respect to B−, the decreased current through diode "B" results in applying a more negative voltage to the grid of *V-16* which, as we have seen, results in increasing the oscillator frequency. *C-83*, *R-87* and *C-85* provide two time constant filters which are necessary to obtain "fly-wheel" action of this *a.f.c.* sync circuit.

The Horizontal Output System.—The combination sawtooth and pulse waveform developed across *C-87* (680) and *R-93* (3300) by the multivibrator circuit, is fed to the grid of the horizontal output tube *V-17* (6BQ6). Fig. 10 is a simplified schematic of the horizontal output system. It will be noted that in this system an auto-transformer is used. In the horizontal scan it is necessary that retrace be completed in about seven microseconds.

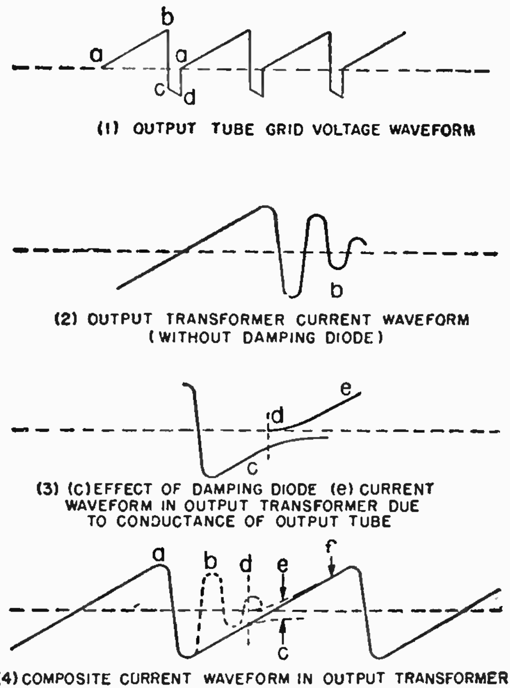


FIG. 12—Wave forms in horizontal scanning system.

In order to accomplish reversal of current in the inductance of the output transformer and the yoke in this short a time, it is necessary to make this circuit resonant at such a frequency that the half cycle time will equal seven microseconds, because only by shock exciting such a circuit into oscillation will retrace be accomplished in the time allowed. The circuit is made resonant by the inductance of the output transformer and yoke, the distributed capacity and the tube capacity.

Bearing this in mind, the operation can be explained as follows. Referring to fig. 12 (1), assume that the voltage on the grid of the output tube is increasing, point "a". The grid is now being made less negative and the output tube starts to draw current which is supplied from B+ through the damping diode. When point "b" is reached on the grid voltage waveform, the output tube is suddenly cut off because its grid has been made highly negative, (point "c" on the grid voltage waveform).

With the tube cut off, the resonant plate load is undamped and the circuit is shocked into oscillation. The reversal of current through the output inductance produces a positive voltage pulse which makes the cathode of the damping diode (*V-18*) positive, with respect to its plate; therefore, it cannot conduct. *C-91* (100) is placed across the diode to provide a low impedance for the oscillatory current. If the damping diode *V-18* were not present, this oscillation would continue and current would flow in the output transformer as shown in fig. 12 (2).

In order to insure a linear trace, however, this oscillation must be stopped and the damping diode serves this purpose. When the current nears its maximum negative value, the polarity and amplitude of the voltage pulse on the damping diode is such that its plate becomes positive, with respect to its cathode, so that the tube conducts heavily and loads the circuit sufficiently to prevent continuation of the oscillation.

The current then follows the decay curve shown at "c" in fig. 12 (3). At the time ["d" in fig. 12 (3)] the voltage at the grid of the output tube has become less then cut off [point "a" in fig. 12 (1)] and the tube again demands current. The rising current in the tube results in superimposing the waveform "e" of fig. 12 (3) on the current flow already in the output transformer due to the decaying current which resulted from the damped oscillation. Combination of these two currents results in the linear trace current indicated at "f" in fig. 12 (4), which is a composite waveform of the entire action.

During the peak conduction of the damping diode, *C-92* (.1) charges and its polarity is such that when the output tube calls for current the charge on the condenser will be in series with the B+ supply so that the voltage at the output tube plate is raised from the 250 volt B+ supply to about 475 volts by this so-called "bootstrap" voltage. When the grid voltage waveform of the output tube again reaches point "b" of fig. 12 (1), the tube is cut off and another cycle starts.

In order to properly match the yoke inductance to the required output inductance for the tube, the yoke is connected to a tap on the winding which effectively makes an autotransformer of this section. The positive pulse of voltage at this tap is coupled to the yoke through *C-94* (.1) and results in a sawtooth of current through the yoke. It will be remembered that a portion of this pulse is also fed to the phase detector for the *a.f.c.* action through *R-86* and *R-85*.

The small additional winding, one terminal of which is connected to chassis while the other terminal is connected to B– through *C-93* (.03) is used to cancel the pulse of voltage which is placed on the chassis by induction from the output transformer. By connecting this winding in such a way as to place a pulse of suitable amplitude on the chassis 180 degrees out of phase with the induced voltage, cancellation of the induced voltage will take place.

High Voltage.—To take advantage of the large voltage pulse developed across the output inductance by the heavy current flow caused by the retrace oscillation, the plate winding is made the primary of an auto-transformer whose step-up ratio is such as to develop pulses of about 12 *kv*. at its high end. These pulses are rectified by *V-19* (1B3) and the resulting *d.c.* is applied to the second anode of the picture tube. The filament voltage for the 1B3 rectifier is obtained from an additional winding on the output transformer.

Controls.—*L-25* is the coil of the sine wave generating circuit in the horizontal multivibrator circuit and should be tuned to 15,750 cycles. *R-91* is the horizontal hold control which can be adjusted for correct frequency operation of the multivibrator. *L-30*, paralleling a small portion of the output choke acts as a size control.

CHAPTER 38

Television Picture Tubes

The television picture tube also called *cathode ray tube, viewing tube, pickup tube, receiving tube*, etc. is very similar to the well known test oscilloscope tube employed in all types of electronic testing and research work.

With reference to fig. 1 the principle elements are as follows:

1. A containing envelope of glass for the purpose of maintaining vacuum in the tube.

2. A cathode (indirectly heated) for the production of free electrons.

3. A control grid for controlling the beam current.

4. A focusing electrode identified as the *first anode* for concentrating the electrons into a cathode ray or beam.

5. A high voltage anode referred to as the *second anode* for further acceleration of the electrons.

6. Two sets of electrostatic deflection plates for deflecting the electron beam. These are known as the horizontal and vertical deflection plates.

7. A screen which is coated on the inner surface of the enlarged end of the tube with a material which shows a fluorescent glow at the impact point of the electron beam. This is termed the fluorescent screen.

The Electron Gun.—The electrodes consisting of the *cathode control grid, first and second anode* are collectively known as the *electron gun*, inasmuch as their function is to generate a beam of electrons and to direct it toward the viewing screen.

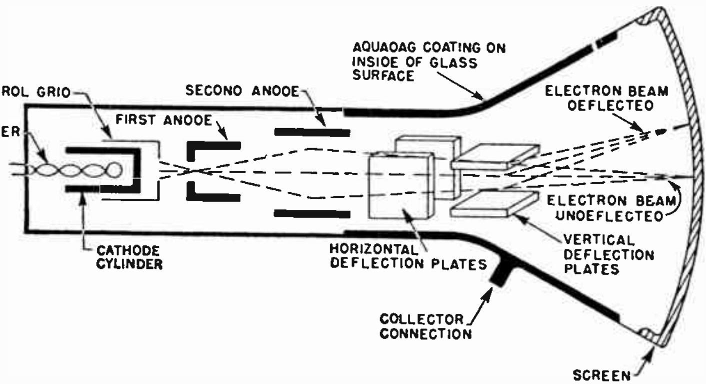


FIG. 1—Showing schematic arrangement of electrodes in a picture tube of the electrostatic deflection type.

The Electron Beam.—Since the electron beam consists of rapidly moving electrons, it constitutes a current having both electromagnetic and electrostatic properties. Because no material conductor is required to carry the electrons, the beam has negligible mass and negligible inertia. Due to this inertia-less characteristic, the electron beam can be deflected easily and rapidly by either electrostatic or electromagnetic fields.

Method of Focusing.—Focusing may be accomplished by either of two methods, namely:

1. By electrostatic means, and
2. By electromagnetic means.

Both methods of focusing will achieve the desired results, that is, a narrow concentrated beam of electrons.

In the picture tube shown in fig. 1 the deflecting force takes the form of an electrostatic field produced by a voltage applied across the deflecting plates.

Another type of picture tube is shown schematically in fig. 2.

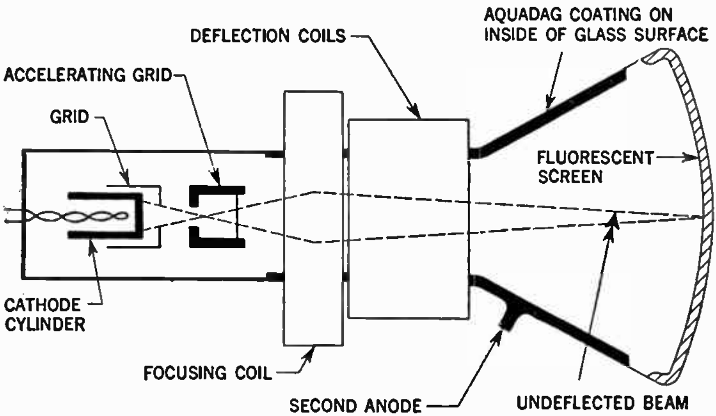
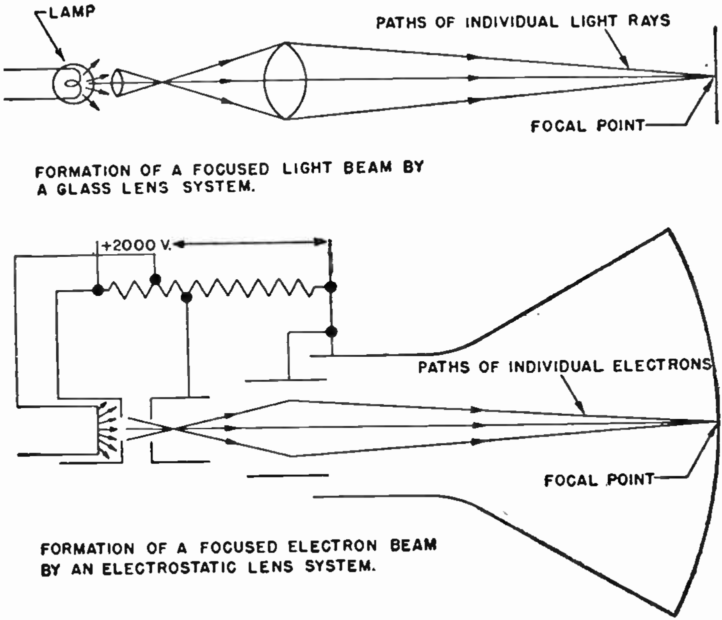


FIG. 2—Schematic arrangement of electrodes in a picture tube of the magnetic deflection type.

In this case no electrostatic deflection plates are used. Here deflection of the electron beam both horizontally and vertically is accomplished by means of two electromagnetic fields, produced by two external pair of coils. This latter type of picture tube is known as the *magnetic deflection type* and is the most common type used for picture tubes.

Also in the magnetically focused picture tube, the first anode is replaced by an accelerating grid which gives the initial acceleration of the beam of electrons.

The second anode of this type of tube is not always a part of the main section of the cylindrical electron gun. Instead it is in the form of a coating on the inner surface of the glass extending from the tube neck up toward the fluorescent screen.



FIGS. 3 and 4—Illustrating focusing method of a simple lens system as compared to electrostatic focusing. In the familiar glass lens system, the lens may be used to collect a divergent bundle of light rays, converging them to a point and in this manner accomplish the focusing of light. The light lens system may be a simple lens or a compound of several individual elements. An electron lens may be employed to control the many electrons leaving the cathode in exactly the same manner that an optical lens controls the light leaving the lamp. Focusing is accomplished by varying the potentials of the electron lens as illustrated and is due to the electrostatic fields established between successive elements.

In either method of focusing, whether electrostatic or electromagnetic, the amount of focus potential (or current) is varied while observing the fluorescent screen for sharpness of image detail.

Picture Scanning.—In scanning, the beam is focused to a spot of small diameter at the fluorescent screen, and it now remains to deflect the beam for scanning in an orderly sequence.

Here again, may be employed either an electrostatic or an electromagnetic method. The former is illustrated in fig. 1, and shows two sets of metallic plates, one set for vertical deflection and one set for horizontal deflection.

Creation of an electrostatic field between any one set of plates will cause the electron stream, which passes between them, to be deflected from its normal path in one direction or the other, depending upon the polarity of potential applied. There is a linear relationship between magnitudes of deflection and applied potential. Therefore, by the application of potential to both vertical and horizontal deflection plates, the electron spot may be caused to move to any desired point on the fluorescent screen. For example, to cause the spot to move upward, the top vertical plate must become positive with respect to the bottom vertical plate.

For downward spot displacement, the polarity is reversed. A similar application to the horizontal plates above will cause either right hand or left hand spot movement and a spot at the upper right hand corner of the screen would indicate equal displacements in both the vertical and the horizontal directions.

Therefore, for scanning, a linear rise of potential is applied to the horizontal plates at a high repetition rate (15,575 cycles in present day standards) while a slow repetition rate is applied to the vertical plates (60 cycles). These scanning potentials are illustrated in fig. 5.

A linear rise of potential causes the beam to be deflected linearly across the screen. After it has traversed the screen, it suddenly returns to the side from whence it started, only to again take up its slower motion in the scanning direction (left to right).

As previously mentioned, a high repetition rate of scanning is applied to the horizontal plates, and a much slower rate to the vertical. Hence, analyzing the spot motion, it is found that

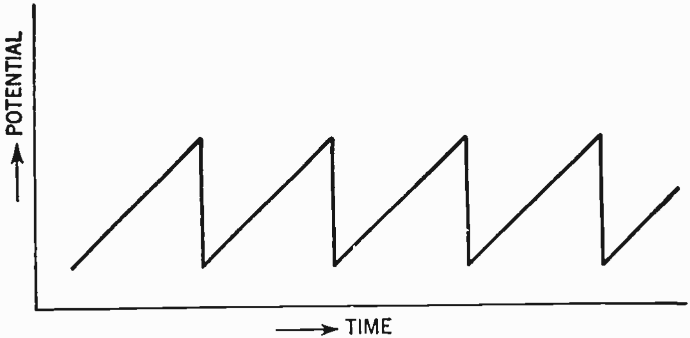


FIG. 5—Showing typical sawtooth scanning potentials.

during the time that it has traveled across the screen, left to right, it has traveled downward by but a very small amount. At the start of the second horizontal cycle, therefore, the slow downward motion has caused the spot to be moved downward in amount equal to the spot size. The second horizontal cycle then carried the spot parallel to and immediately adjacent to the travel of the first cycle. A third cycle finds the downward motion again equal to the spot size and a third scansion is completed.

The same general outline may be applied to electromagnetic scanning. In this case, the deflection plates are omitted and a set of deflection coils are placed over the tube neck. There are four coils, that is, two vertical coils (one above and one below the neck of the tube) and two horizontal coils. Instead of a sawtooth of potential, as used with the deflection plates, a sawtooth wave form of current is used which produces a sawtooth of magnetic flux. It has previously been shown that a sawtooth of voltage applied to the deflection coils does not produce a sawtooth of current and that special pulses of voltage must be produced. The complete set of coils, horizontal and vertical, which is placed over the tube for magnetic deflection is known as a *deflection yoke*.

Although it is possible to employ the electrostatic method of deflection in television picture tubes, this is seldom done for several reasons. They are:

1. The deflection potentials necessary in a large tube are very high, requiring large high voltage amplifier tubes.

2. A screen giving green colored light as in oscillograph tubes operating on the electrostatic deflection principle is used for reason of visual efficiency. Television use, however, dictates that a white or blue-white light be used for esthetic reasons and that the decay time of the light be short. Phosphor (screen materials) exhibit the property of remaining lighted for a short time after the electron excitation has passed.

3. Focus of the electron beam is not maintained over the entire screen in an electrostatic type of tube. This would give an image which is "fuzzy" or poorly focused over a portion of its area.

For these reasons the television picture tube employs magnetic focusing. Certain electrical properties of the picture tube will now be treated. These being *halation* and the *ion spot*.

Halation.—This is the glowing of a phosphor on the fluorescent screen, in a region immediately surrounding the scanning spot. It signifies one undesirable property of the picture tube.

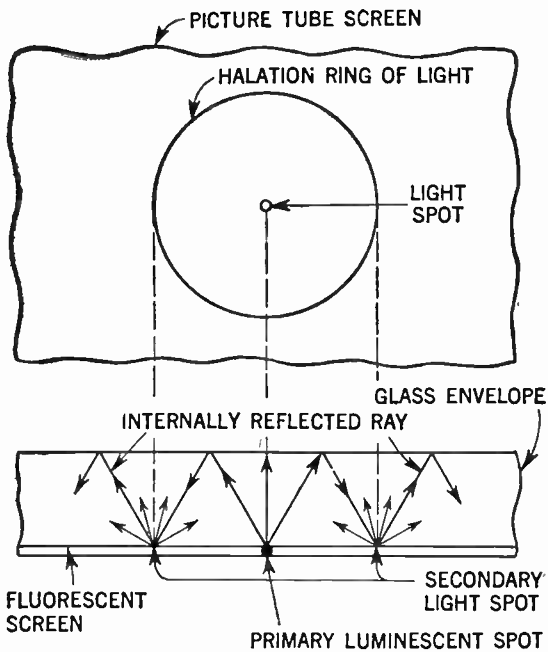


FIG. 6—Showing typical halation effect on picture tube screen.

The face of the tube must have appreciable thickness in order to withstand the atmospheric pressure. A pin point source of light appearing at the inside surface of the face will radiate light in all directions, being not restricted to the desired direction (straight out from the tube). Such a source is the phosphor being bombarded by a beam of electrons. As illustrated in fig. 6 internal reflections of the light within the glass wall, from surface to surface, give rise to one or more rings of light which surround the original desired point. This effect is known as halation.

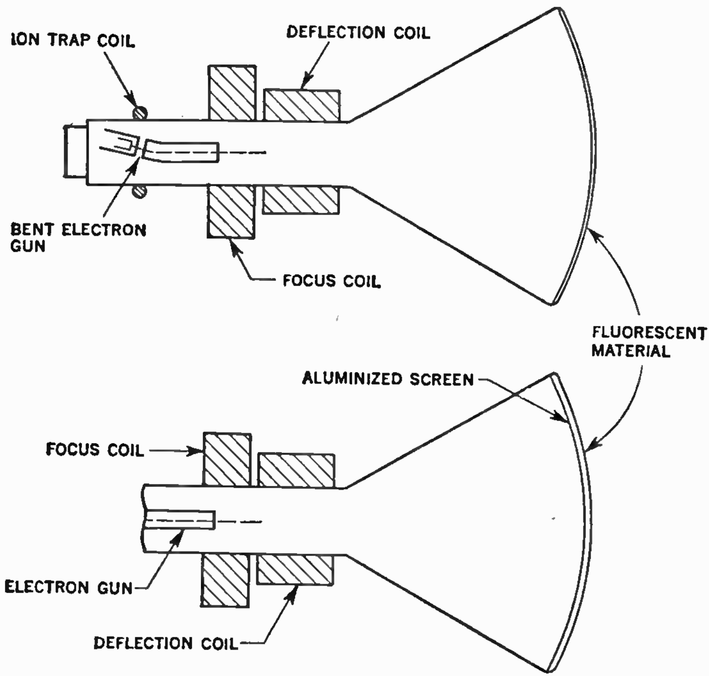
The Ion Spot.—A second property of the tube is the formation, after some hours of operation of a darkened area near the center of the screen, known as an *ion spot.*

An ion spot is the result of the bombardment of the phosphor by charged particles known as ions. This bombardment results in the deterioration of the phosphor which then produces less light, upon being struck by the electron stream, than does that portion of the surface which has not been so bombarded. The ions travel down the tube in a rather wide angle stream, impinging upon the screen near its center.

There are several methods leading to the elimination of this difficulty, one of which is the use of a completely electrostatic tube which is not troubled with this difficulty. In television practice, two methods used are (1) the use of a bent gun tube and (2), a metallic coating on the inside surface of the phosphor.

The bent gun tube fig. 7 is one whose electron emitting element is not in line with the axis of the tube, that is, its electron stream is directed toward the side of the tube neck. Since the ion stream is not much effected by a magnetic field, a magnet is placed over the neck of the tube which bends the electron stream, directing it axially down the tube in the normal path, allowing the ion stream to continue in its original course. It strikes the side of the tube, where it does no damage.

The metallic coating which is placed upon the inside surface of the phosphor coating accomplishes two advantages. It



FIGS. 7 and 8—Methods of ion spot prevention on magnetic deflection type of picture tubes. In the bent electron gun method, fig. 7, the actual cylindrical elements of the electron gun are mounted at an angle with respect to the tube axis. As the electrons and ions leave the electron gun they come under influence of the magnetic field generated by the external bending or ion trap coils. This magnetic field is of the proper strength and polarity to return the electrons to the center line of the electron tube axis. The ions on the other hand, because of their greater mass cannot be deflected, and therefore strike the collecting walls to be dissipated, thus separating the ions from the electrons. The second method of ion spot prevention as illustrated in fig. 8 consists of a metallic coating of aluminum which because of its thinness is actually an aluminized screen. This aluminized screen will effectively transfer electrons causing them to strike the fluorescent material. The ions, however, having a greater mass will not penetrate the aluminized screen but are dissipated by it and do not reach the fluroescent screen of the picture tube.

increases the light which is emitted from the front of the tube by a considerable amount and it disperses the ions so that they cause no damage to the phosphor. This coating is extremely thin, about the wavelength of light.

Commercial Picture Tubes.—These are manufactured in a large variety of shapes and sizes. With the advance of television science the public demand for larger and better pictures has resulted in a great improvement in the size and reliability of picture tubes until at present standard tubes of up to 22 inches in diameter and larger are available.

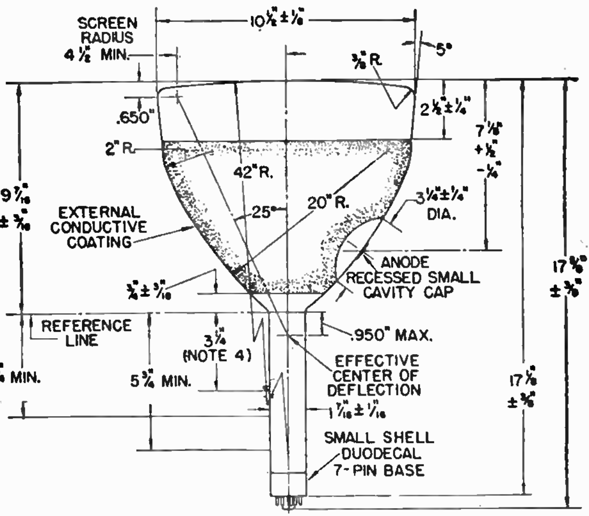


FIG. 9—Outline dimensions of a 10BP4 direct view picture tube.

As previously noted, magnetic deflection is the most common deflection method used, although a few of the smaller size picture tubes employ electrostatic deflection.

A listing of the most common types of commercial picture tubes and their characteristics is provided by means of picture tube data charts given on pages 820 to 821. From these data charts much useful information in a practical form with reference to operating voltages and general characteristics of the tubes will be obtained. Many of the later manufactured picture tubes have an external conductive coating in addition to the internal second anode coating. In such tubes a high voltage filter capacitor of approximately 500 *mmf*. is formed by the two coatings and the glass which serves as a dielectric. In tubes so equipped the external coating is grounded.

Using the Data Chart.—There are several important factors which must be considered by the service technician when using the tube data charts as an index to tube interchangeability. These are as follows:

a. Tube types with identical bulb outlines present no problem of interchangeability with respect to chassis layout, unless the difference in overall length is so great that the two types in question would not be compatible in the same cabinet design.
b. When a high focus current tube is replaced for a low focus current tube, it may be necessary to increase the focus current range of the receiver, otherwise, a stronger focus coil must be employed.
c. It is important that the proper external magnet be used with the ion trap of the tube, particularly when changing from a double to a single magnet. Since these components are relatively inexpensive, it would seem practical to keep them on hand.
d. If a tube without external coating is replaced for a tube with external coating, a 500 to 1500 *mmf*. capacitor connected between the high voltage output lead and ground will insure proper set operation.

e. In general there are three types of connectors to the anode of television tubes, the cavity and ball connectors in all glass types, and the clip connector for types with a metal cone envelope. When making tube changes, the appropriate connector must be used.

f. In practice, the same deflection yoke usually may be employed with all tube types having deflection angles of less than 66 degrees.

g. Type numbers are assigned to picture tubes and other cathode ray tubes by the *Radio-Television Manufacturers Association*. The first number, made up of one or two digits, represents the largest dimension of the face of the tube to the nearest one-half inch. For round tubes this would be the diameter and for rectangular tubes it would be the diagonal dimension. The letter following the first number is assigned in order of registration and has no significance other than this. The letter *P*, together with the last number designate the type of phosphor used. Thus, the *10BP4* is a 10 inch picture tube with *P4* phosphor. Similarly, the *12AP4* is a 12 inch picture tube with *P4* phosphor.

h. In some cases an additional letter is added as a suffix to the type number. An example is the type *17BP4A*. The reason for this suffix is that there has been a change in the design of *17BP4*, but not great enough change to justify the use of a new type number. The new tube with the suffix in its type number, will always operate in the same circuit as the original tube, but the old tube may or may not work in all circuits where the new tube is used. In this way it is possible to take advantage of the latest development in picture tube design whenever it may be necessary to replace the old tube

Television Picture Tube Data Chart (Magnetic deflection and focus)

Type[1,7]	Basing	DIMENSIONS (inches) Overall Length	DIMENSIONS (inches) Diameter	DIMENSIONS (inches) Min. Useful Diameter	Deflection Angle (degrees)	Radius of Face Curvature (inches)	Envelope	Contact	Ion Trap Magnet	MAX. DESIGN CENTER VALUES Anode Volts	MAX. DESIGN CENTER VALUES Grid No. 2 Volts	COMPARATIVE OPERATING CONDITIONS** Focus* Current (Ma.)	COMPARATIVE OPERATING CONDITIONS** Anode Volts	COMPARATIVE OPERATING CONDITIONS** Nom. Grid No. 1 Cut Off Volts	COMPARATIVE OPERATING CONDITIONS** Grid No. 2 Volts
10BP4 10BP4A[8]	12D	17⅝	10½	9	50	42	Glass†	Cavity	Double	12,000	410	132	12,000	33-77	300
10CP4	12D	16⅝	10½	9	50	42	Glass†	Ball	None	12,000	410	—	12,000	33-77	300
10DP4[2,4]	12C	17⅝	10½	9	50	42	Glass	Cavity	None	12,000	410	—	12,000	33-77	300
10EP4	12D	17⅝	10½	9	50	42	Glass	Ball	Double	12,000	410	132	12,000	33-77	300
10FP4[4] 10FP4A[8,4]	12D	17⅝	10½	9	50	42	Glass†	Cavity	None	12,000	410	115	12,000	33-77	300
10MP4 10MP4A[8]	12G	17	10½	9⅛	52	42	Glass†	Cavity	Double	12,000	—	—	12,000	33-77	300
12JP4[a]	12D	17½	12	11	56	20	Glass	Ball	None	12,000	410	158	12,000	33-77	300
12KP4[4] 12KP4A[8]	12D	17⅝	12 3/16	11¼	54	40	Glass†	Cavity	None	12,000	410	140	12,000	33-77	300
12LP4 12LP4A[8]	12D	18¾	12 3/16	11	54	40	Glass†	Cavity	Double	12,000	410	114	12,000	33-77	300
12QP4 12QP4A[8]	12D	17½	12 3/16	11	55	40	Glass	Ball	Single	12,000	410	148	12,000	33-77	300
12RP4	12D	17½	12	11	56	20	Glass	Ball	Single	12,000	410	148	12,000	33-77	300
12TP4	12D	18¾	12 3/16	11	54	40	Glass	Cavity	Double	12,000	410	114	12,000	33-77	300
12UP4 12UP4A[8] 12UP4B[3]	12D	18⅝	12 3/16	11⅜	54	27	Metal	—	Double Double Single	12,000	410	—	12,000	33-77	300
12VP4 12VP4A[8]	12G	18	12 3/16	11	55	40	Glass	Cavity	Double	12,000	—	—	12,000	33-77	300
14BP4[5,8]	12D	16 13/16	9 11/16x12½	8⅝x11½	70 diag.	27	Glass†	Cavity	Double	12,000	410	115	12,000	33-77	300
14CP4[5,8]	12D	16¾	9 23/32x12 17/32	8⅝x11½	70 diag.	27	Glass†	Cavity	Single	14,000	410	95*	12,000	33-77	300
14DP4[5,8]	12D	16¾	9 23/32x12 17/32	8⅝x11½	70 diag.	27	Glass	Cavity	Double	14,000	410	104	12,000	33-77	300
14EP4[5,8]	12D	16 5/32	9 27/32x12 17/32	12½ diag.	70 diag.	27	Glass†	Cavity	Single	14,000	410	110*	12,000	33-77	300
14FP4[5,8]	12D	16⅛	9 11/16x12½	8⅝x11½	70 diag.	27	Glass	Cavity	Single	14,000	410	115*	12,000	33-77	300
15AP4[6]	12D	20½	15½	14	57	45	Glass	Ball	None	15,000	410	159	12,000	33-77	300
15CP4	12D	21½	15½	14	57	45	Glass	Cavity	Double	15,000	410	133	12,000	33-77	300
15DP4	12D	20½	15½	14	57	45	Glass	Ball	Single	15,000	410	140	12,000	33-77	300
16AP4 16AP4A[8]	12D	22¼	15⅞	14⅜	53	27	Metal	—	Double	14,000	410	89	12,000	33-77	300
16CP4	12D	21½	15⅞	15	52	56 9/16	Glass	Cavity	Double	15,000	410	110	12,000	33-77	300

Television Picture Tube Data Chart (Magnetic deflection and focus)

16EP4 16EP4A[8]	12D	19⅜	15⅛	14⅜	60	27	Metal	——	Double	14,000	410	105	12,000	33-77	300
16FP4	12D	20¼	16⅛	15	62	27	Glass	Ball	Single	16,000	410	140	12,000	33-77	300
16GP4[3]	12D	17 11/16	15⅜	14⅜	70	40	Metal	——	Single	14,000	410	100*	12,000	33-77	300
16HP4 16HP4A[8]	12D	21¼	15⅞	14½	60	56 5/16	Glass†	Cavity	Double	14,000	410	110	12,000	33-77	300
16JP4 16JP4A[8]	12D	20¾	16⅛	15	60	27	Glass†	Cavity	Double	14,000	410	120	12,000	33-77	300
16KP4[5,8]	12D	18¾	11½x14¾	10⅛x13½	70 diag.	27	Glass†	Cavity	Single	16,000	410	97*	12,000	33-77	300
16LP4 16LP4A[8]	12D	22¼	15⅜	14½	52	56 5/16	Glass†	Cavity	Double	14,000	410	110	12,000	33-77	300
16MP4 16MP4A[8]	12D	21⅜	16⅛	14¾	60	27	Glass†	Cavity	Double	14,000	410	110	12,000	33-77	300
16QP4[5,8]	12D	19 5/16	11½x14¾	10⅛x13½	70 diag.	27	Glass	Cavity	Double	16,000	410	125*	12,000	33-77	300
16RP4[5,8]	12D	18¾	11½x14¾	10⅛x13½	70 diag.	27	Glass†	Cavity	Double	14,000	410	100*	12,000	33-77	300
16SP4 16SP4A[8]	12D	17 5/16	15⅜	14½	70	56 5/16	Glass†	Cavity	Double	14,000	410	110	12,000	33-77	300
16TP4[3,8]	12D	18⅛	11½x14¾	10⅛x13½	70 diag.	27	Glass†	Cavity	Single	14,000	410	100*	12,000	33-77	300
16UP4[5,8]	12D	18⅛	11½x14¾	10⅛x13½	70 diag.	27	Glass	Cavity	Single	15,000	410	100*	12,000	33-77	300
16VP4[3]	12D	17 5/16	15⅞	14½	70	56 5/16	Glass	Cavity	Single	15,000	410	110*	12,000	33-77	300
16WP4[3] 16WP4A[8]	12D	17¾	15⅞	14½	70	56 5/16	Glass Glass†	Cavity	Double	15,000 16,000	410	110*	12,000	33-77	300
16XP4[5,8]	12D	18¾	11½x14¾	10⅛x13½	70 diag.	27	Glass	Cavity	Double	15,000	410	100*	12,000	33-77	300
16YP4[8]	12D	17 5/16	15⅛	14½	70	56 5/16	Glass†	Cavity	Single	14,000	410	100*	12,000	33-77	300
16ZP4[3]	12D	22¼	15⅞	14½	52	56 5/16	Glass†	Cavity	Single	14,000	410	110*	12,000	33-77	300
17AP4[5,8]	12D	18⅝	12¼x15⅜	10¾x14¼	70 diag.	27	Glass	Cavity	Single	16,000	410	100*	12,000	33-77	300
17BP4A[8,8]	12D	19¼	16⅜	14¼x10¾	70 diag.	27	Glass†	Cavity	Single	16,000	410	95*	12,000	33-77	300
19AP4 19AP4A[8] 19AP4B[3,8]	12D	21½	18⅝	17⅜	66	28	Metal	——	Single	19,000	410	140	12,000	33-77	300
19DP4 19DP4A[8]	12D	21½	18⅞	17⅜	66	60	Glass†	Cavity	Double	19,000	410	140	12,000	33-77	300
19EP4[3,8]	12D	21⅛	17x13⁵⁄₇	12x16	70 diag.	27	Glass†	Cavity	Double	19,000	410	140*	12,000	33-77	300
19FP4[8]	12D	22	18⅞	17⅜	66	60	Glass	Cavity	Double	19,000	410	97-126*	12,000	33-77	300
19GP4[8]	12D	21¼	18⅞	17⅜	66	60	Glass	Cavity	Single	19,000	410	107-126*	12,000	33-77	300
20BP4	12D	28	20	18¾	54	30	Glass	Metal Cap	None	20,000	410	122	12,000	33-77	300
22AP4 22AP4A[8]	12D	22⅞	21 5/16	20¼	70	27	Metal	——	Single	19,000	410	108*	12,000	33-77	300

Tube specification notes:

1. All the types listed have heater values of 6.3 volts, 0.6 amps.
2. These types employ electrostatic focus.
3. Types employing gray filter face plate.
4. Type employs metal-backed screen.
5. Rectangular type.
6. Face plate incorporates an anti-reflective feature.

* Types employ RMA Focus Coil #109 (approx. 470 ohms), all others RMA focus coil #106 (approx. 264 ohms).

a. For replacement see Type 12RP4.

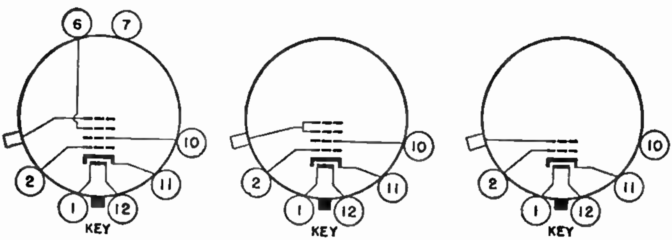
b. For replacement see Type 15DP4.

† Types have external conductive coating.

7. All types employ a white fluorescence .material of medium persistence.

** These values are for comparison only and do not imply typical operating conditions.

Data based on latest information from RMA Data Bureau.



12C 12D 12G

FIGS. 10 to 12—Base diagram symbols. By using the picture tube data chart on pages 820 and 821, the proper base connections will be found under the heading of "Basing". Thus, for example, to obtain the correct base connections for the 10BP4 picture tube, a reference to "Basing" on the picture tube data chart shows 12D as the correct base diagram to use. In a similar manner the base connection for any picture tube represented in the chart may readily be found.

Replacement of the Picture Tube

Chassis Removal.—Ordinarily the removal of the chassis from the cabinet is accomplished as follows:

1. Remove the control knobs from the front of the cabinet.
2. Remove the wood screws that hold the rear cover to the cabinet, and remove the rear cover.
3. Remove the two wood screws from the block located on the top (inside) of the cabinet, and remove the block.
4. Disconnect the built-in antenna feeder from the antenna terminals.
5. Release the antenna stub from the top of the cabinet by pulling out the thumb-tack.
6. Remove the two screws that secure the antenna assembly to the top of the cabinet.
7. Remove the trimmer assembly and rubber coupling sleeve by carefully pulling the coupling sleeve off the drive shaft.
8. Temporarily tape the drive shaft to the top of the cabinet to avoid breakage.
9. Remove the bracket that clamps the shutter frame to the bottom of the cabinet. This bracket is located near the front (inside) of the cabinet and can be released by removing the screw from the under side of the cabinet.
10. Remove the hex-head chassis bolts from the under side of the cabinet.
11. Remove the chassis by pushing the front of the chassis against the left side of the cabinet, and then easing the chassis out of the cabinet while moving the rear of the chassis gradually toward the right. The chassis must leave the cabinet at an angle so that the shutter mechanism will clear the antenna drive pulleys. This step must be performed cautiously to prevent scratching the plastic front plate.

Picture Tube Replacement.—After the chassis has been removed from the cabinet, the picture tube may be replaced as follows:

1. Back off the screen locking the shutter actuating link to the magnifier control shaft.
2. Remove the two self-tapping screws that secure the shutter assembly frame to the chassis.
3. Remove the two self-tapping screws that secure the shutter assembly frame to the brace bars.
4. Remove the wing nut and lock washer from the stud on top of the picture tube strap.
5. Remove the shutter assembly by lifting the bronze strap over the stud and sliding the complete assembly forward.
6. Remove the ion trap magnet and the picture tube socket.
7. Loosen the picture tube cushion screws, the focus coil wing screws, and remove the screw from the picture tube strap.
8. Remove the defective picture tube and insert the replacement through the deflection yoke and focus coil, exercising the caution necessary when handling picture tubes.
9. Replace the screw in the picture tube strap and tighten the strap about the tube just enough to hold the tube in place.
10. Replace the shutter assembly and tighten the self-tapping screws only. Do not tighten the picture tube strap wing nut or the set screws on the magnifier control shaft.
11. Position the picture tube so that the clearance between the tube and the mask is approximately one-thirty-second inch.

Handling of Cathode Ray Tubes

The cathode ray tube bulb (picture tube) due to its large surface area and high vacuum contained within it, is subjected to high air pressure over its entire surface. To understand what takes place when an accidental fracture of the tube takes place, it is only necessary to recall the violent blast which occurs when a small conventional light bulb be imploded. Although the tube face is fairly thick, a fracture of the glass by a blow, or scratch, may cause a sudden collapse, and the force of the implosion, may throw pieces of glass with dangerous violence in every direction.

The following suggestions regarding handling of the picture tube should be put into practice, to avoid damage to the tube or possible personal injury from breakage of it. To prevent injury from picture tube breakage, proceed as follows:

1. Do not unpack the picture tube until ready for use. Exposing it unnecessarily at any time will increase the chances of possible tube damage and injury to personnel.
2. Wear safety goggles when handling the tube and insist upon all persons nearby being similarly equipped with eye protection.
3. Do not allow the metal part of the tube to contact or be brought near any magnetized material. This portion of the tube may become magnetized by such contact, resulting in picture distortion which cannot easily be corrected.
4. Do not handle the picture tube at the bell-shaped glass portion which has been coated with a special insulating material. Finger marks, grease, or other foreign particles may cause high voltage leakage paths under humid conditions.

Safety Precautions

Although every practical safety device possible has been incorporated in television receivers, certain precautionary measures should be observed in their servicing.

It should be clearly understood that servicing of any television receiver, especially when the receiver is on the service bench and possibly with the safety shield removed, offer many shock hazards to the serviceman and work on the receiver should not be attempted by any one who is not familiar with the necessary precautions while working with high voltage circuits and picture tubes.

The following safety regulations should be observed at all times while servicing television receivers.

Precautions when Working with High Voltage

1. Respect high voltage circuits and keep away from them.
2. Do not depend upon interlock switches for protection, always disconnect the power cord if any possible danger exists. Interlock switches are not foolproof.
3. Do not attempt to change tubes or make adjustments in the high voltage circuits when the receiver is turned on.
4. Always use a long-handled well insulated screwdriver to short circuit the large capacitor terminals to ground before working on them.
5. Do not attempt to operate the receiver with the high voltage compartment shield removed.
6. Do not attempt to reach within the cabinet while the interlock switch is closed to effect some minor adjustments.

CHAPTER 39

Trouble Shooting

In order to facilitate the trouble shooting procedure the following trouble shooting charts are given. The *charts* are subdivided according to the *symptoms* as they affect the *picture* or *sound* so that it is an easy matter to find the symptoms observed on the particular receiver. The *second column* of the charts indicate the part or section to be checked. Circuit components referred to in the text matter are shown on pages 838, and 839.

*Picture Quality Defects**

Symptom	*Check*	*Refer to*
1. No picture, no raster, no sound.	a. Power supply.	
2. No picture, no raster, sound normal.	a. Picture tube. b. High voltage power supply. c. Ion trap.	
3. No picture, no sound, raster normal.	a. *r.f.* and video *i.f.* circuit.	See Note 1. (page 832)
4. No picture, raster and sound normal.	a. Video amplifier.	See Note 7. (page 833)
5. Poor focus.	a. Focus coil. b. Focus coil circuit.	See Pages 749 and 750

*For picture quality defects see also pages 734 to 746.

Picture Quality Defects—Continued

Symptom	*Check*	*Refer to*
6. Poor focus and picture blooming.	a. For gassy picture tube.	See Note 14.
7. Neck shadow.	a. Focus coil adjustment. b. Ion trap adjustment. c. Yoke assembly adjustment.	See Notes 33, 34 and 36.
8. Ghost.	a. Antenna orientation. b. Antenna lead-in.	See Pages 696, 697 and 720.
9. Snow.	a. Antenna installation.	See Ch. 33.
10. Poor detail.	a. *r.f.* and video *i.f.* circuits. b. Picture control circuit.	See Notes, 1 and 4.
11. Insufficient brightness.	a. Ion trap adjustment. b. Picture tube. c. Pix tube anode or bus voltage.	See Note 34.
12. Excessive contrast.	a. Sync. Section.	See Note 30.
13. Excessive contrast with shaky picture.	a. Sync. Section.	See Note 31.
14. Very bright, fuzzy picture.	a. Picture tube circuit.	See Note 16.
15. No picture on one channel.	a. Channel switch.	See Note 6.
16. Distorted picture.	a. Video amplifier.	See Note 7.
17. Smeared picture.	a. Video amplifier.	See Note 10.

Raster Defects

Symptom	*Check*	*Refer to*
1. Raster not centered.	a. Focus coil adjustment.	See Note 33.
2. Tilted raster.	a. Focus coil adjustment.	See Note 33.
3. Excessive raster size.	a. Low anode voltage to pix tube.	
4. Raster width too small.	a. Circuit of horizontal sweep output tube. b. Width control shorted or misadjusted.	
5. Raster height too small.	a. Height control circuit. b. Circuit of vertical sweep output tube.	See Note 37.
6. Unsymmetrical, trapezoidal raster.	a. Deflection yoke position.	See Note 35.
7. Barrel distortion.	a. Deflection yoke position.	See Note 35.

Sweep and Sync Defects

Symptom	*Check*	*Refer to*
1. No horizontal or vertical sync.	a. Clipper circuit of V10.	See Note 22.
2. Insufficient sweep width.	a. Horizontal sweep circuit.	See Note 18.
3. No raster, one horizontal line.	a. Vertical sweep circuit. b. Vertical deflection yoke.	See Notes 23, and 35.
4. No raster, one vertical line.	a. Horizontal deflection yoke.	See Note 35.
5. Raster not stable.	a. High voltage power supply.	

Sweep and Sync Defects—Continued

Symptom	*Check*	*Refer to*
6. Poor horizontal linearity.	a. Horizontal sweep circuit. b. Horizontal linearity control.	See Note 19.
7. Poor vertical linearity.	a. Vertical linearity control. b. Vertical sweep circuit.	See Note 25.
8. Picture not centered.	a. Focus coil adjustment. b. Horizontal sweep circuit.	See Note 20.
9. Unstable horizontal sync.	a. Horizontal sweep circuit.	See Note 21.
10. Unstable vertical sync.	a. Vertical sync input.	See Note 27.
11. Reduction of height.	a. Height control. b. Vertical sweep circuit.	See Notes 25, 26 and 28.
12. Small picture.	a. Picture tube circuit.	See Note 16.
13. Retrace lines increasing towards top.	a. Picture tube circuit.	See Note 15.
14. Vertical does not sync.	a. Vertical sweep circuit.	See Note 24.

Audio Defects

Symptom	*Check*	*Refer to*
1. No sound, picture normal.	a. Audio section.	See Note 38.
2. Hum or buzz.	a. Audio section.	See Note 39.
3. Distortion.	a. Crystal Y1. b. Audio *i.f.* alignment.	

Miscellaneous Defects

Symptom	*Check*	*Refer to*
1. Sound bars.	a. Picture tube circuit.	See Note 13.
2. Light and dark vertical bars, poor horizontal linearity.	a. Damper tube.	
3. Two heavy black horizontal bars across screen.	a. Power supply (electrolytic capacitor).	
4. Excessive contrast with bright lines on bottom and top.	a. Sync. section.	See Note 31.
5. Picture distorted and reverse action of picture control.	a. Sync. section.	See Note 32.
6. Picture flutters at 60 cycles rate.	a. Capactitor C251 in video *i.f.* circuit.	See Note 5.
7. Window shade effect.	a. Picture tube circuit.	See Note 16.
8. Barkhausen oscillation.	a. Drive control R369. b. 19BG6 tube.	
9. "Busy background" on trailing edge.	a. Video amplifier.	See Note 8.
10. Black lines across picture.	a. Video amplifier.	See Note 9.
11. Very bright picture with black lines.	a. Video amplifier.	See Note 11.

NOTES ON TROUBLE SHOOTING

(RF and Video IF Circuit)

1. Misalignment of *r.f.*, video *i.f.* stages or sound traps will cause poor picture detail. If some stages are totally detuned, the signal might not get through at all, failing to produce a picture.

2. If the oscillator circuit fails to produce the required frequencies, no *i.f.* signal is formed and no signal will get through: No picture and no sound will be the result. Any defective component in the oscillator circuit may have this effect.

3. Any interruption of the signal path through the *r.f.* and video *i.f.* stages will result in a distorted picture or no picture at all. The location of an open component is easily accomplished by methods used in radio service work.

4. An overloading of the stages will result in loss of picture detail; check picture control circuit.

5. In case the capacitor C251 is short circuited, sound bars will appear in the picture, and trailing white shadows. If this capacitor opens up, the picture will flutter at a 60 cycle rate and at minimum picture control audio motorboating will start.

6. A defective channel switch will result in intermittent reception of one channel or in extreme cases a channel might be interrupted completely. Clean switch with a cleaning fluid or bend the contacts to increase contact pressure. In some cases it is best to replace head-end unit.

Video Amplifier

7. If the path of the signal within the video amplifier is broken, the picture will be distorted or wiped out completely. This may be caused by open chokes, L259, L261, L262 or coupling capacitor C268.

8. Misalignment of the 4.5 mc trap will cause a "busy background" effect on the trailing edge of the picture.

9. If choke L264 or coupling capacitor C275 is open, there will be always enough coupling capacity to carry along at least a fraction of the signal. The resultant picture will have black lines across it.

10. Open or shorted resistances are easily located. Before resistors open up completely, they often show high resistance value. If this happens with the resistors R269 and R272 the effect will be a smeared picture. A high resistance of R273 will cause picture distortion at high values of picture control.

11. A shorted capacitor C275 will have the following effects: The picture is very bright with black lines across it. Brightness control does not reduce the brightness.

Picture Tube Circuit

12. A defective picture tube can be the cause of a faint picture, a distorted and unsteady picture or no picture at all.

13. Parts of the electron gun structure might vibrate under the influence of a strong loudspeaker output, resulting in sound bars in the picture.

14. A gassy picture tube will cause a blooming picture which is out of focus.

15. In case the capacitor C279 on the cathode of the picture tube breaks down, a high voltage will be right on the cathode blanking out the picture. If this capacitor opens up, horizontal lines appear on the picture increasing towards the top.

16. A leaking capacitor C278 will cause a small picture with poor brightness and vertical linearity. If the other capacitor C277 becomes defective, the following effects will occur: A shorted capacitor will produce a fuzzy and very bright picture while an open capacitor will produce a bright horizontal area advancing towards the top with increasing brightness control setting ("window shade" effect).

Horizontal Sweep Section

17. No raster on the picture tube indicates a lack of high voltage or horizontal sweep voltage. This may be caused by a defect in the high voltage rectifier circuit, or in the horizontal sweep output circuit, the horizontal oscillator may not be functioning properly or there may be a short in the horizontal deflection circuits.

18. Insufficient sweep width may be caused by defective components in the horizontal deflection circuits. Check the secondary circuits of T351 for defective components. When L353 is shorted or has shorted turns, the picture will be too narrow and L353 will have no or little control on the width.

19. Poor horizontal linearity may be caused by a short in L352 resulting in L352 having no control on the horizontal linearity. High leakage in capacitor C370 will cause poor linearitv and also will increase the width.

20. A short in capacitor C377 will change the *d.c.* component through the horizontal deflection coils which will shift the picture horizontally such that it may not be centered with the focus coil setting.

21. Poor horizontal sync with good vertical sync may be caused by a defect in the circuits of V11, or V12 or–B.

22. No vertical or horizontal sync may be caused by defects in the clipper circuits of V10.

Vertical Sweep Section

23. The vertical sweep generator contains a multivibrator circuit which is made inoperative by the defects of the following capacitors; shorted capacitor C304, C305 or C308. If the capacitor C305 is open, the oscillator is stopped.

24. The frequency of the generator is thrown off by a short circuit of the capacitors C301 and C302 with the effect that the vertical does not sync.

25. The linearity of the vertical sweep is impaired when the electrolytic capacitor C309 loses its capacity to an appreciable extent. If it opens up completely, the height reduces to approx. one-fifth of the normal size.

26. If the paper capacitor C308 develops any leakage, the vertical size is reduced so that the height control R308 does not suffice to obtain the desired height.

27. In case the capacitor C302 has an open circuit, the vertical sync becomes less stable.

28. If the B+ voltages supplied to the circuit is too low, the deflection voltages will not suffice to deflect the beam across the entire surface of the tube.

29. Microphonic tubes might give rise to a very unstable operation, resulting in a jumpy picture.

Common Sync Section

30. A shorted capacitor C354 on pin 1 of V10 tube will produce excessive contrast which cannot be reduced to normal by the picture control. If this capacitor opens up, both horizontal and vertical sync will be inoperative.

31. An open capacitor C353 on the plate (pin 5) of tube V10 will produce a shaky picture with excessive contrast, while an open capacitor on the grid (pin 4) of tube V10 (C351) will produce bright lines on bottom and top together with poor horizontal and vertical sync which is independent of picture control setting.

32. Distorted picture and reverse action of picture control is caused by an open capacitor C261 on the picture control. If C261 is open, increasing picture control will decrease picture control and vice-versa.

Focus Coil, Ion Trap and Deflection Yoke

33. To obtain good focus and centered raster, the focus coil must be carefully positioned as outlined under "Focus Coil Adjustment," page 749. No sharp picture will be possible with an open or shorted coil. A partial short will throw the picture out of focus. Before looking for obscure trouble, be sure to check the focus control circuit for defective components.

34. The correct adjustment of the ion trap will result in maximum brilliance and at the same time will insure long tube life. For adjustment of this trap, see page 749.

35. Any unsymmetry of the deflection yoke will cause picture distortion. A shorted coil or shorted turns will cause barrel distortion and unsymmetric trapezoidal distortion. An open deflection yoke will produce a horizontal or vertical line across the screen. An open horizontal deflection coil produces a vertical line, while an open vertical deflection coil produces a horizontal line. For deflection yoke adjustment, see page 750.

36. The yoke assembly must be pressed against the bell of the picture tube to avoid neck shadow.

37. The correct picture size is obtained by adjusting the width and height control, as outlined under "Preset or Service Adjustment Controls," pages 739 to 746.

Audio Stages

38. The FM modulated signal can reach the 1st audio tube only when the two *i.f.* transformers are aligned properly. In localizing defective components, follow normal radio trouble shooting procedure.

39. In case of improper alignment especially of discriminator secondary, a buzz or hum is heard when receiving a television station.

40. In case of no sound output the following components should be checked in turn; tubes, output transformer, capacitors and defective speaker.

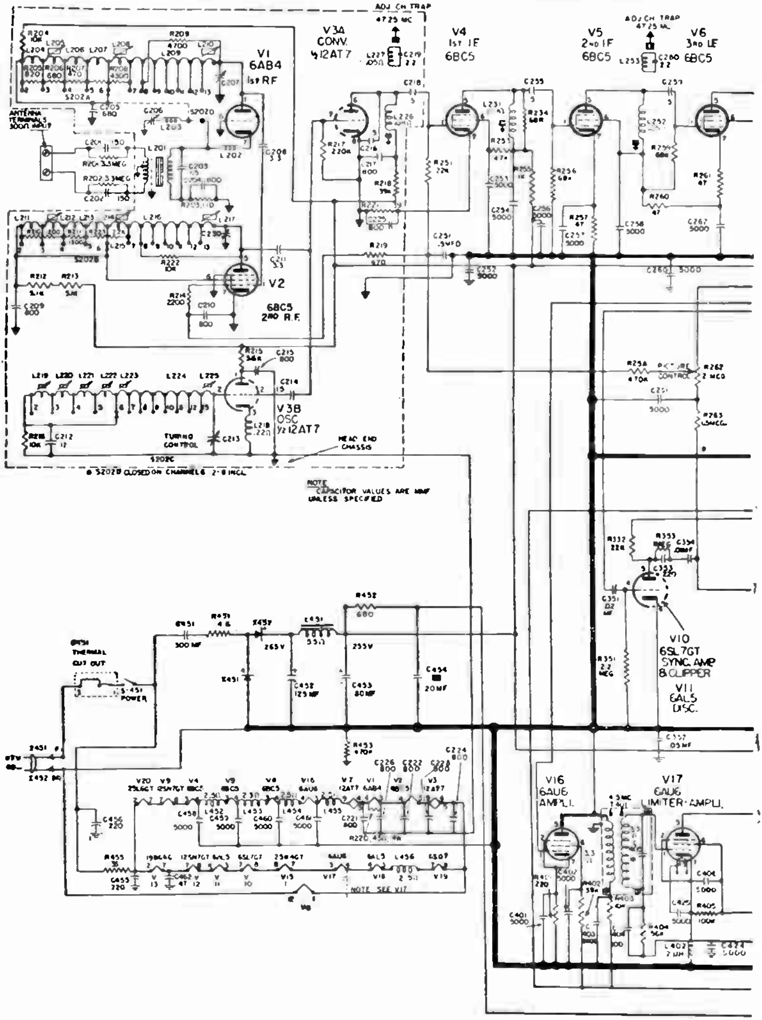


FIG. 1—Schematic diagram of *General Electric Model 12T7* television receiver (for continuation of diagram see opposite page).

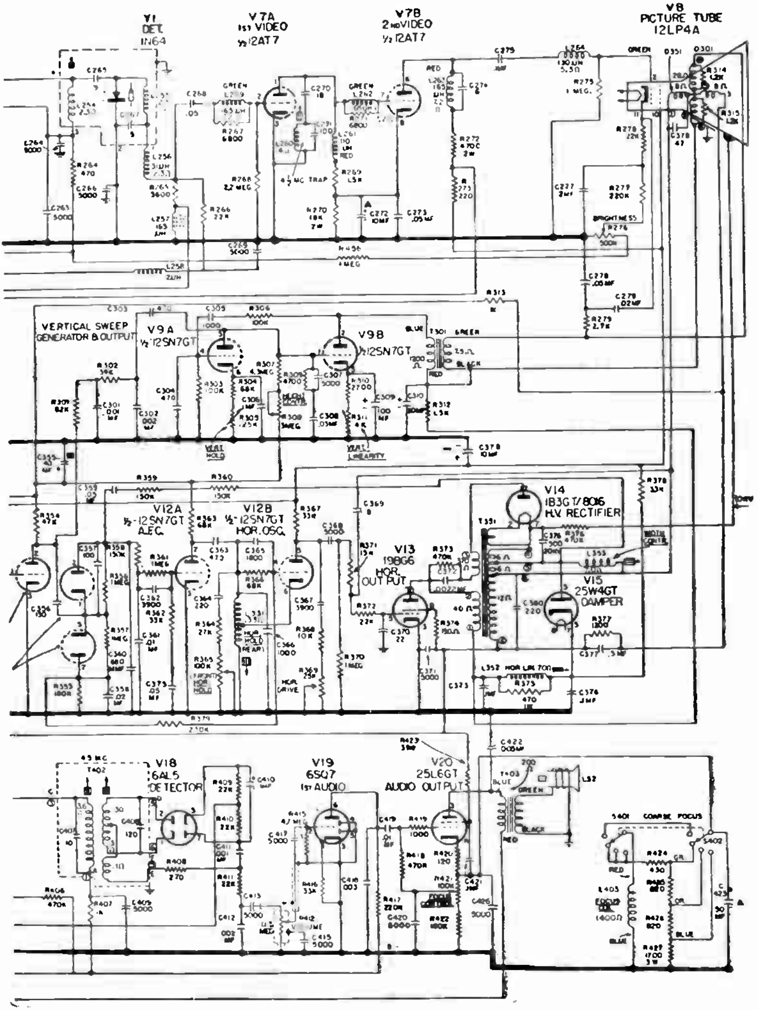


FIG. 2—Schematic diagram of *General Electric Model 12T7* television receiver (for continuation of diagram see opposite page).

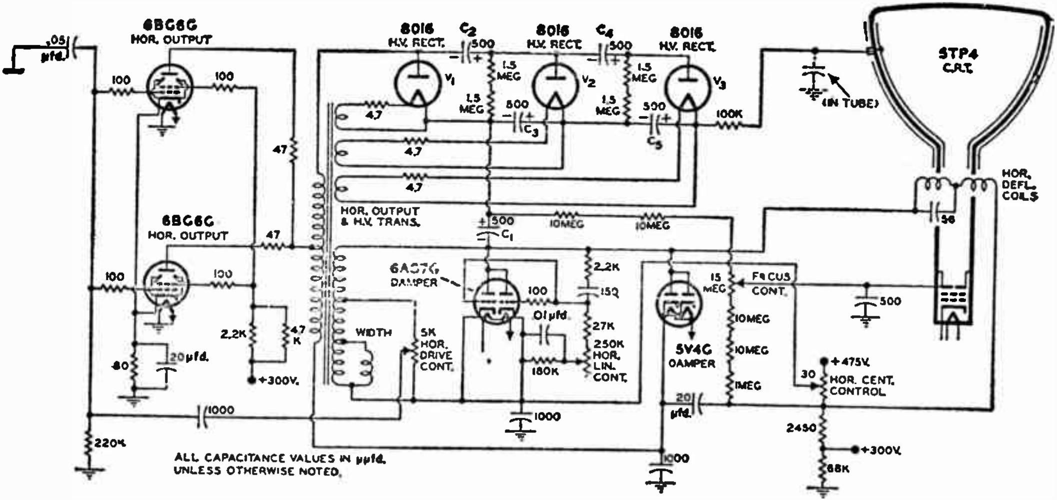


FIG. 3—Circuit diagram of a high voltage flyback power supply unit capable of producing 27 kv. for a projection type picture tube.

INDUSTRIAL ELECTRONICS *AND* RADAR SECTION

CHAPTER 40

Photoelectric Cells

Light or Photo Sensitive Tubes.—The fact that certain light sensitive materials emit electrons in vacuum when exposed to a source of light has been known since the time of Hertz, 1887, but the utilization of this phenomena in science and industry in form of the modern photoelectric cell or tube has taken place only during the last eight to ten years.

The modern rugged uniform long-lived phototube has found an extensive use in industry, in fact its employment is limited only by the inventive ability of the user.

Applications in which the phototube is used include photoelectric control, counting, sorting, alarms, the sound-motion-picture industry, illumination control, robot control for ships, etc.

Light Sensitive Metals.—It has been found that the light sensitive metal group includes rubidium, lithium, potassium, sodium and caesium. If the surface of a light sensitive metal is exposed to the air atoms at atmospheric pressure or 760 millimeters mercury, the emission of electrons is largely prevented, but if the metal is put in a vacuum and then exposed to a beam of light the electrons are free to be thrown off the metal into the surrounding space. See figs. 1 and 2.

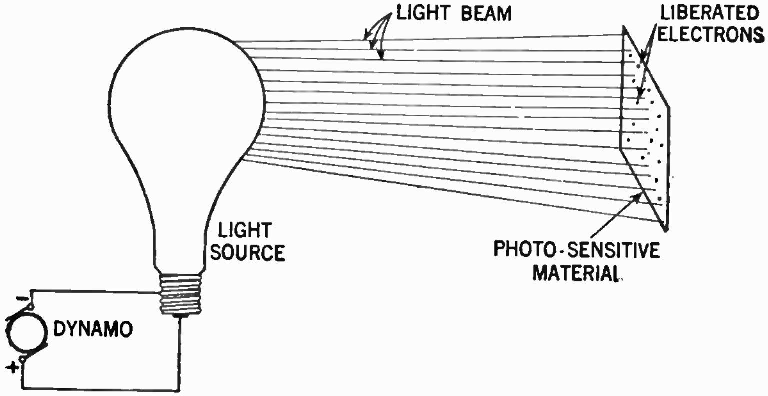


Fig. 1.—Illustrating how a body consisting of photo-sensitive material emits electrons by means of light.

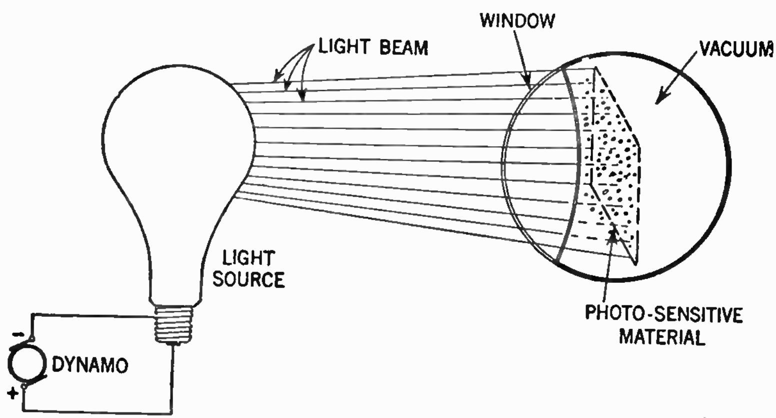


Fig. 2.—The electron emission will be largely increased when the photo-sensitive material is placed in vacuum.

The body which emits or throws off the electrons is called the emitter or cathode, and the body which receives or to which the emitted electrons are attracted is called the anode or plate. It may be mentioned in this connection that the velocity of emission is independent of the temperature of the cathode and is also independent of the intensity of the light with which the cathode is illuminated.

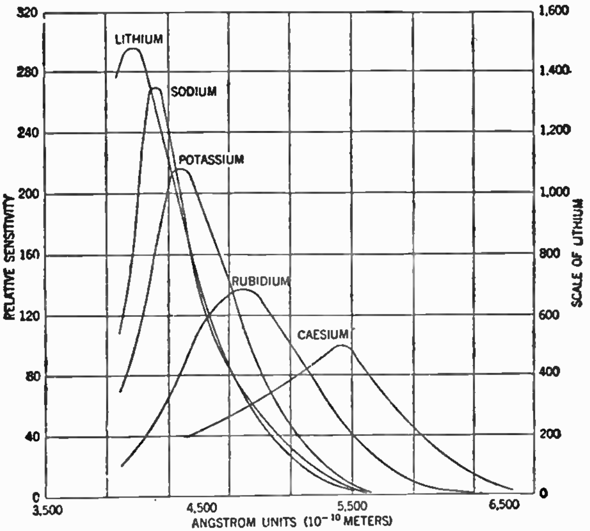


FIG. 3.—Curves showing color sensitivity of various elements.

Therefore, if the intensity of the light is increased, only the number of electrons emitted increases, but their velocity stays the same. The only factor that influences their velocity is the frequency, color or wave length of the light. The higher the light frequency or the nearer the light is toward the ultra-violet end of the spectrum the higher is the speed of the emitted electrons.

It is obvious that when the light source is interrupted the flow of electrons and also the anode current stops.

The sensitivity of phototubes to different light color varies with the type of materials used, but the hydrides and oxides of the metals previously mentioned, have a higher factor of sensitivity than the pure metals themselves, hence are most commonly used.

Various Types of Phototubes.—There are at present three general types of photoelectric tubes utilizing light to produce an electric current, known as the *photo-emissive; photo-conductive;* and *photo-voltaic.*

Phototubes of the Emissive Type.—The photo-emissive tube is essentially a two electrode tube consisting of a semi-cylindrical cathode and a central anode sealed in a glass envelope. The cathode consists of a base metal such as silver with a light sensitive surface, usually caesium oxide, and is the larger element of the two.

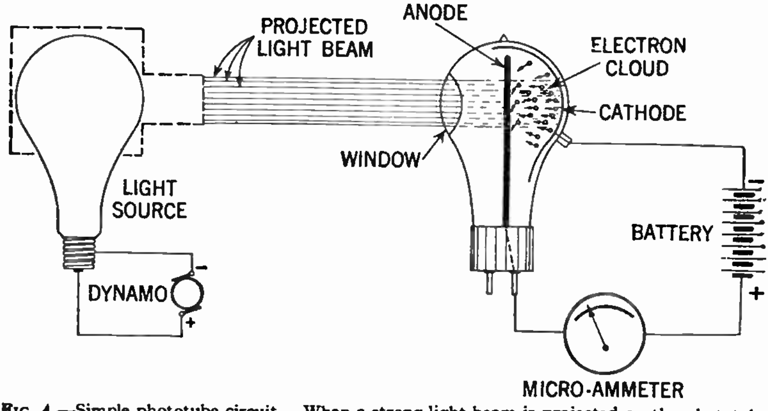


Fig. 4.—Simple phototube circuit. When a strong light beam is projected on the phototube window. the electron emission will be indicated on a sensitive meter

The anode consists of a straight wire electrode mounted along the axis of the cathode. The action of light upon the cathode results in the emission of electrons from the light sensitive surface, and the electrons which are released by this action are drawn to the anode by virtue of the voltage which is applied between the cathode and the anode. See fig. 4.

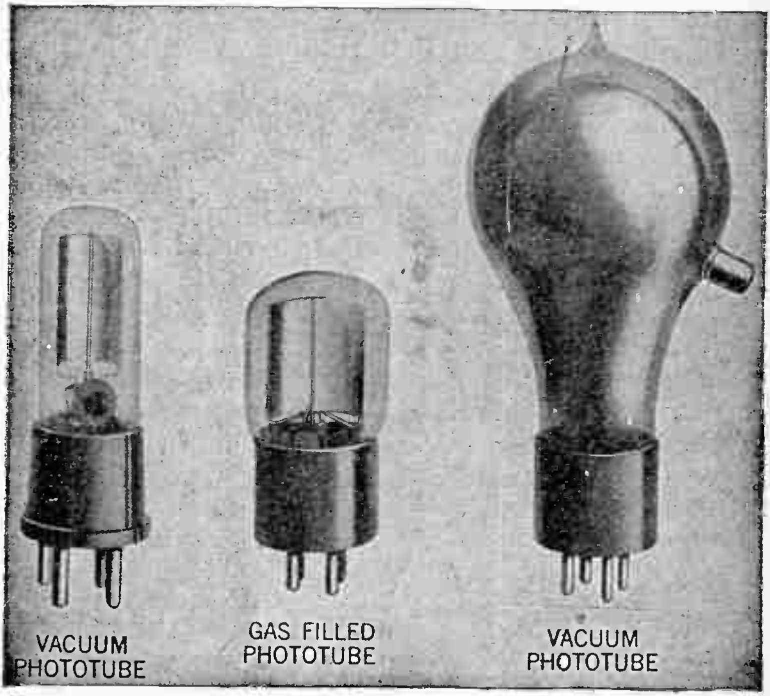


FIG. 5.—Typical phototubes.

These phototubes are made in two different types, namely, vacuum and gas-filled.

The two types are identical as to structure but differ in that the high vacuum of the vacuum type is replaced with an inert gas of a very low pressure in the gas-filled type. The chief advantage of the vacuum type of phototube is the light-current linear response characteristic; however, the total current consists of only the primary electrons emitted from the light sensitive surface of the cathode.

On account of its *light-current linear response*, the vacuum phototubes are used in measurement and instrument and

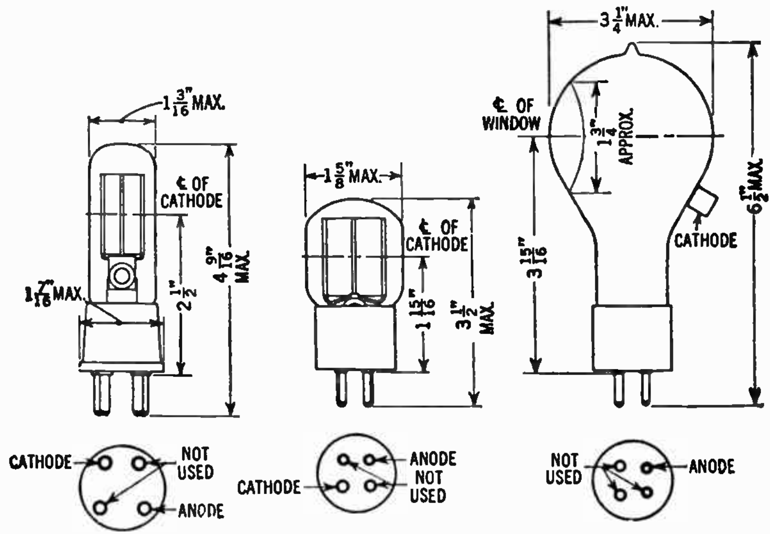


FIG. 6.—External dimension of phototubes shown in fig. 5.

research work where the greatest constancy of characteristics is desired.

In the gas-filled type, greater effective response is obtained due to gas amplification and secondary emission. When the applied voltage is above 25 or 30 volts, the electrons traveling from cathode to anode have sufficient velocity to knock out electrons from gas atoms with which they collide, thus splitting up the atoms into positive ions and free electrons. The electrons are, of course, attracted to the anode and the positive ions to the cathode, which they may strike sufficiently hard to knock out several "secondary" electrons. Thus these two factors produce an additional current which at higher voltages may be several times the value of the primary electron current.

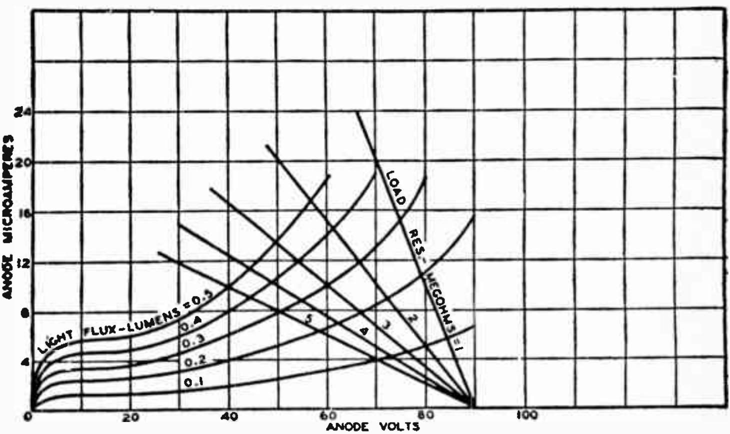


FIG. 7.—Average gaseous type anode characteristics.

The *gas ratio* of a phototube, that is, the ratio of its response at the operating voltage to its reponse at the voltage where gas amplification begins, for a given illumination, is a measure of the gas and secondary emission amplification. The gas ratio is often taken as the ratio of its reponse at 90 volts to that at 25 volts with a constant illumination. Care must be taken with gas-filled tubes not to exceed a certain maximum voltage (the value of which depends on the type of tube and the illumination on the tube) or a glow discharge will result which will ruin the sensitive surface. The limits are shown in the accompanying curve of lumens plotted against anode voltage. Anode voltages to the left of this curve are safe values.

Photo Conductive Tubes.—The photo conductive tube is a tube which is developed on the characteristics of ohmic resistance changes in certain materials when subjected to the action of light rays.

Selenium, a material discovered by Berzelius in 1817 possesses this peculiar property in that when this substance is illuminated its resistance decreases, permitting the current to increase.

The selenium cell is usually constructed as follows: The selenium surface in the cell is formed entirely in vacuum by a similar process as that of forming the vaporizing metal film in radio tubes. The dry inert gas is admitted during the annealing process. By forming the selenium surface in vacuum, certain defects, such as instability and low efficiency have been largely overcome.

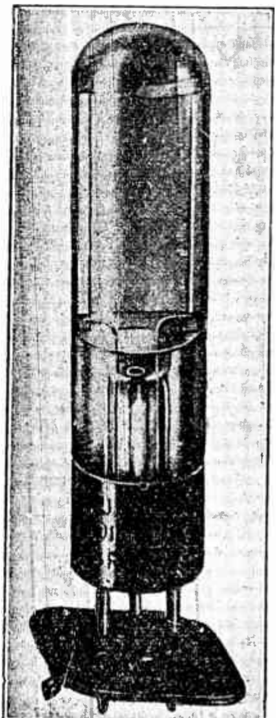


FIG. 8.—The "Burgess" selenium type light sensitive cell.

Several types of selenium tubes of very favorable characteristics are at present in use such as the FJ-31 selenium tube (General Electric Co.), the Burgess Radiovisor Bridge (Burgess Battery Co.), etc. This latest tube is manufactured to operate from 12 to 800 volt with currents from 1 to 250 milliamperes.

Photo Voltaic Cells.—In this type the passage of electrons from one surface to another is accelerated by light rays, generating a voltage. This is termed the photo-voltaic effect, and this property is exhibited by certain materials, notably copper oxide, and the cell is often called *the copper oxide photo-voltaic cell.*

One of the advantages of this cell is that since it generates a voltage independently, in most cases an amplifier is not necessary. The cell is able to operate a relay coil directly, but if, however, an amplifier is used, the number of stages required are less than is the case with the photo-emissive type.

GENERAL COMPARISON OF THE THREE TYPES OF LIGHT RESPONSIVE TUBES

Photo-Emissive Tubes.—As a comparison between the three classes of photo-sensitive tubes it can generally be said that photo-emissive tubes have: 1. A high responsitivity towards the red end of the spectrum and is therefore suited for operation with the incandescent lamp. 2. High speed—they are practically instantaneous in operation. 3. Relatively high impedance resulting in a high voltage output.

The limitations are: 1. Current generated is low;—maximum output is only about 50 micro-amperes (millionths of an ampere); and they cannot therefore at present operate a relay coil without an amplifier.

Photo Conductive Tubes.—The advantages of these types are:

1. They can be operated at low voltage.

2. Some types generate a relatively high current. In some cases the current is sufficiently large to operate a sensitive relay without amplification.

3. They can be made very sensitive towards the infra-red band of the spectral region.

Their limitations are:

1. They are sluggish, *i.e.* have a great time lag.

2. Some types are unstable.

3. They have a rather high temperature coefficient.

Photo-Voltaic Tubes.—1. They have the advantage to be able to operate independently without outside source of power and is therefore adaptable in portable use where a normal voltage source is not available.

2. They generate a comparatively high current and can therefore operate a relay coil without an amplifier provided a sufficient change in illumination intensity is available.

3. Several cells can be connected in series or parallel.

4. Its spectral response is similar to that of the human eye.

The limitations of these types are:

1. In respect to operation the time lag is considerable.

2. The output is not readily adaptable for amplification by the usual vacuum tube method.

3. The relays required are rather expensive as they must be designed for a low torque, and therefore has a low contact pressure.

Because of the fact that phototubes are used extensively in various industrial applications and in photometry with the incandescent lamp, whose light is largely towards the red end of the spectrum, the research laboratories have directed their energies towards making the tube of maximum sensitiveness towards the red and infra-red side of the spectrum.

In industrial control applications the gas filled phototube is quite extensively used due to its greater sensitivity, whereas as already described the vacuum tube is frequently used in connection with measurement of intensity of light, etc., because of greater linearity.

COMPARISON OF PHOTO-ELECTRIC TUBES IN VARIOUS SPECTRAL REGIONS

Response in the Infra-Red or Heat Wave Region.—The range of sensitivity of various photo-electric devices extends from 2,000 Angstrom in the ultra-violet region to approximately 20,000 Angstrom in the infra-red or heat wave region. In practice, one need not expect any useful response beyond 12,000 Angstroms in cesium-oxide phototubes. It seems doubtful at present if more than a mere trace of photo-electric effect will ever be experimentally realized for the infra-red region beyond, say, 30,000 Angstroms. Quite possibly dependence will have to be placed on thermal devices such as thermocouples and bolometers for the heat waves.

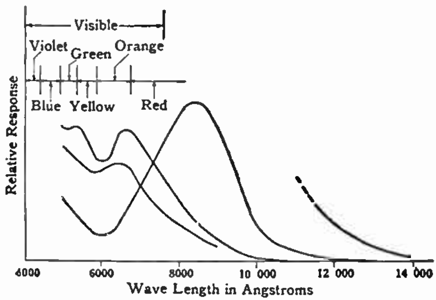


FIG. 9.—Spectral characteristics for various caesium-oxide phototubes, showing their penetration into the infra-red region.

Spectral curves for some experimental cesium-oxide phototubes are given in fig. 9. In the region from 7,000 to 14,000 Angstroms such tubes can be conveniently used to measure or to be actuated by infra-red light. A cesium-oxide tube, together with a visibly opaque, infra-red transmitting filter, such as Corning glass No. 254, Jena glass No. RG-9 or Wratten No. 87, comprises a unit sensitive only to the region just defined. As tungsten lamps radiate maximum energy in the same region, an efficient system for an invisible burglar alarm is readily suggested.

Both selenium and copper-oxide photocells can be made to have near infra-red response, although generally the selenium cell is more red sensitive as seen in fig. 10, where curves for typical copper-oxide, selenium cells and the human eye are shown together.

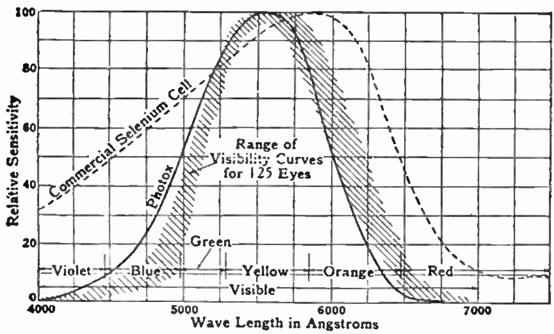


FIG. 10.—Spectral characteristics for selenium and copper oxide cells as compared to the range of sensitivity to that of the human eye.

Response in the Region of Human Visibility.—In the visible spectrum it becomes convenient to evaluate light intensities in terms of visibility. Hence it is highly desirable to employ a light-sensitive device whose spectral response closely resembles that of the eye; copper-oxide photocells can be made with natural response amazingly close to the average eye. In general copper-oxide cells tend to be somewhat shy in red response, while selenium cells have excess sensitivity in both red and violet.

However, by the use of a suitable filter, at the expense of sensitivity, the selenium cell can always be made equivalent to the eye. Also it is becoming apparent that the selenium curve can be shifted by admixture of other elements into the selenium. In any event, for the visible spectrum, the photocell affords the long sought light measuring analogue to the temperature measuring thermocouple.

In devices such as color matchers or color analyzers in which it is necessary to obtain comparable responses in all parts of the visible spectrum, one should have a light sensitive unit at least as responsive to violet as it is to other colors. In fact, since the tungsten lamps, which serve as light sources, are notoriously weak in violet radiation compared to red, it is highly desirable to use a light-sensitive unit more sensitive to violet and blue than to red.

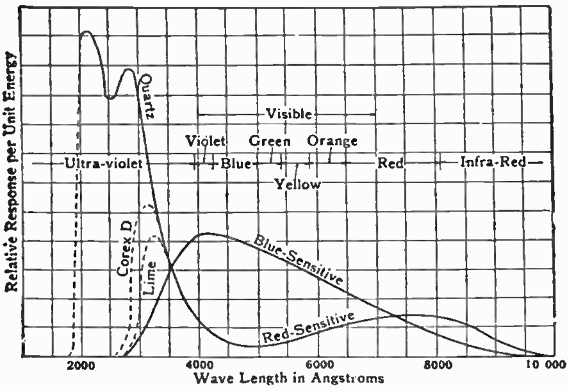


FIG. 11.—Spectral characteristics for two types of caesium-oxide phototubes, illustrating the effect of the envelope on the response.

The normal cesium-oxide tube is relatively weak for blue light, as fig. 11 shows. Fortunately it is possible to modify the manufacturing schedule so as to obtain a blue-sensitive tube that is almost ideal for the application. Superfluous infra-red response can be conveniently removed by means of an infra-red absorbing filter such as Corning Aklo glass.

Response in the Ultra-Violet Region.—It is probably a general impression that cesium-oxide cathodes have a sharp maximum of response in the near ultra-violet. This peak, however, is only apparent as is shown in fig. 11. The sharp cut-off on the short waves is caused by the absorption of the glass envelope. Putting the cathode in a Corex D envelope, which is more transparent to ultra-violet, the curve is seen to shift.

If the cathode is mounted in a quartz blank, it appears that the normal or red-sensitive cesium-oxide cathode is super-sensitive to weave lengths at least as short as those transmitted through quartz. Such a tube is doubtless the most sensitive device known for measuring ultra-violet light between 2,000 and 3,000 Angstroms.

When it is desired to measure a limited portion of the ultra-violet spectrum, one is encountered with the embarrassment of choosing proper filters to exclude all radiations not of interest and to transmit these radiations in which interest is centered. For example, if radiations of the erythema region (2,800 to 3,200 Angstroms) are to be measured, a first approximation can be had by using a cesium-oxide cathode in Corex D in addition to a filter such as Corning Red Purple Corex 986. A second approximation results from the addition of a liquid filter consisting of a nickel-sulphate solution.

Ultra-violet response is limited by the combination to the region 2,600 to 3,700 Angstroms, but unfortunately both the Corex 986 and the nickel-sulphate are transparent to infra-red light between 8,000 and 9,000 Angstroms,-light to which the cesium-oxide surface is notably sensitive.

One method of obviating this difficulty is illustrated in fig. 12. The continuous curves give the spectral response for a cesium-oxide surface in Corex D, and lime-glass envelopes respectively. The dashed curve represents the difference between the other two curves. Thus if a cesium-oxide surface in a Corex D envelope is exposed alternately through Corex D and lime-glass filters to general radiation, the variable component of the tube response will be a measure of the intensity in the erythema region. By suitable choice of glass for the envelope and filters, any spectral region can be similarly isolated and measured. The filters can, in practice, be made as alternate sectors of a disc rotated with proper frequency in front of the tube.

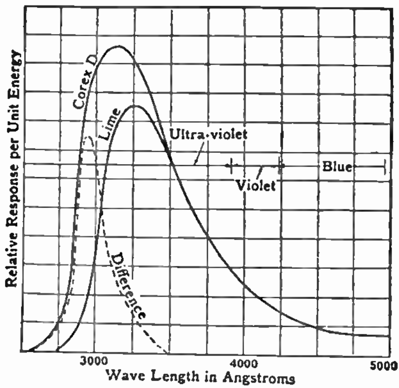


FIG. 12.—Spectral characteristics for a caesium-oxide phototube.

An inherent difficulty of application of this principle, particularly when the energy of the region to be measured is small compared to the total energy of the incident light, is the same as that always encountered in any attempt to detect a small difference between two large quantities. For example, it may be difficult to prevent saturation in the input circuit of an associated amplifier; or in obviating saturation, instability may be introduced. However, the method is feasible and should often prove useful.

Doubtless a better method for measuring isolated regions in the ultra-violet is provided through the use of special ultra-violet phototubes. These tubes consist of pure sputtered films of various metals enclosed in envelopes of Corex glass or quartz. Although their current sensitivity is relatively low, they have the distinct advantage of having their total response confined to quite narrow spectral regions of the ultra-violet, being entirely insensitive to any other light. The long-wave limit is defined by the threshold frequency of the particular metal involved while the short-wave limit is fixed by the absorption characteristics of the envelope.

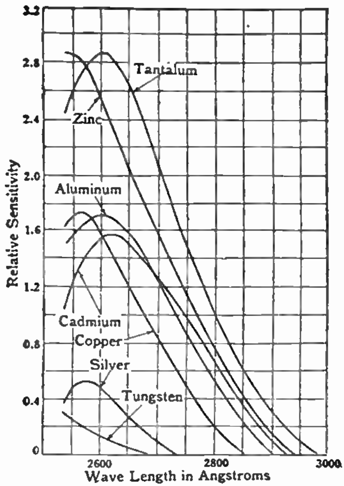


Fig. 13.—Spectral characteristics illustrating the changes in the threshold frequency in the ultra-violet for several metallic cathodes.

Typical spectral curves for such tubes are given in fig. 13. It is apparent that practically any desired region can be isolated by suitable choice of metal and envelope.

The selenium type of photocell exhibits a certain amount of direct response to ultra-violet light, and any type of cell can be made responsive to ultra-violet by use of contiguous fluorescent screens and suitable combinations of filters. Even Roentgen radiations can be conveniently measured by such a combination of fluorescent screen and photocell.

The Weston Photronic Photoelectric Cell.—This cell was first introduced in Weston illumination intensity meter in 1930, and has found a wide variety of practical industrial applications.

It consists essentially of a thin metal disc on which there is a film of light-sensitive material. The metal disc forms the positive terminal and a metal collector ring in contact with the light sensitive surface forms the negative terminal.

The cell is contained in a case having a window of glass or quartz depending upon whether the cell is to be used only in the visible or infra-red regions of the spectrum or in the ultra-violet.

It is very compact as there is no separate anode and collector plates or evacuated space as in the usual form of photoelectric cells. A typical photronic photoelectric cell is shown in fig. 14.

The action of the light impinging upon the sensitive surface is entirely electronic, and according to Weston engineers, the tests made indicate that no chemical or physical change takes place during its operation, therefore the life of the cell seems to be unlimited, if operating rules are observed.

The current output varies as usual with the illumination on the cell and also with the external resistance connected to it as shown in chart 15. The output is linear for low resistances;

however, this is not true for higher external circuit resistances, due to the fact that the cell resistances decreases with increasing illumination and current output.

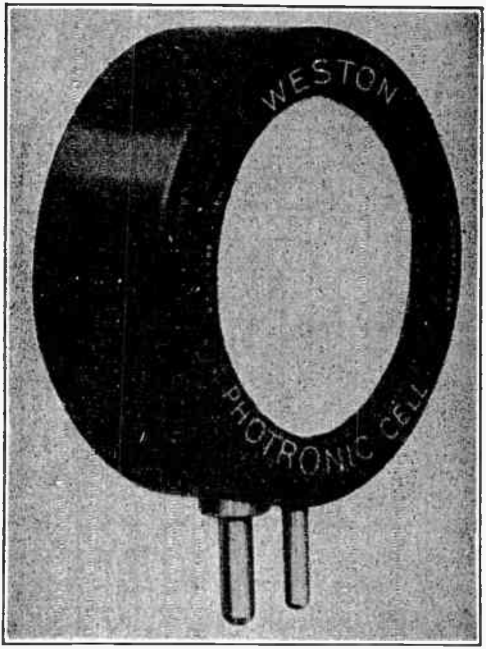


Fig. 14.—A typical "Photronic" photo-electric cell. (Courtesy of Weston Electric Company).

The current output is approximately 1.4 microamperes per foot candle of illumination, or 120 microamperes per lumen. The area of the sensitive surface is 1.8 sq. ins.

An interesting and useful property of this cell is that when connected to low external resistance circuit, it is not necessary to distribute the illumination uniformly over the exposed disc, as the current output per lumen is almost independent of the area of the disc exposed.

For example a lumen of luminous flux concentrated on say a circle of ¾ inch in diameter, will result in approximately the same microampere output as if a lumen were uniformly distributed over the entire area. This may be explained by the fact that the resistance of the unexposed portion is very high compared to that of the exposed portion, so that the shunting effect becomes negligible.

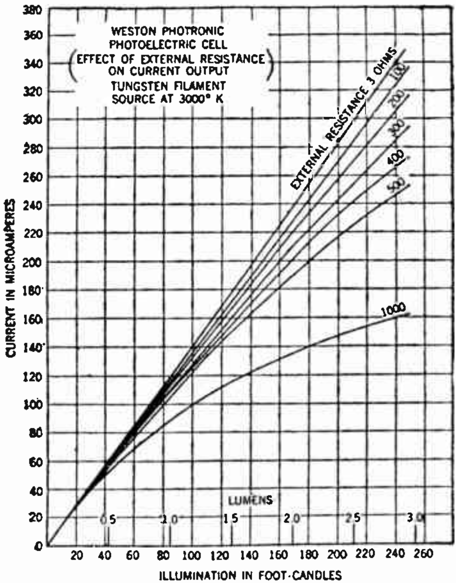


FIG. 15.—Effect of external resistance on current output.

Series and Parallel Operation.—The cells may be connected in series or parallel and the effect when so grouped is approximately the same as for the voltaic type cells, remembering, of course, that the resistance is not constant, but is rather a function of both the current output and the intensity of illumination. However, since the cell resistance for low light intensity is relatively large, there is no practical gain in current output by connecting the cells in series, since each cell adds resistance in approximately the same proportion as it adds e.m.f. When connected in parallel, the combined internal resistance diminishes, resulting in greater current output.

The suitable number of cells to be used in parallel operation for any particular requirement depends upon the intensity of illumination and sensitivity and resistance of the indicating instrument used, and is usually best determined by experiments.

The internal resistance of the cell is not constant, but varies with the illumination of radiant flux, and also upon the leakage current through it. It is of the order of 2,000 to 6,000 ohms decreasing with an increase in illumination and current output. See chart 16.

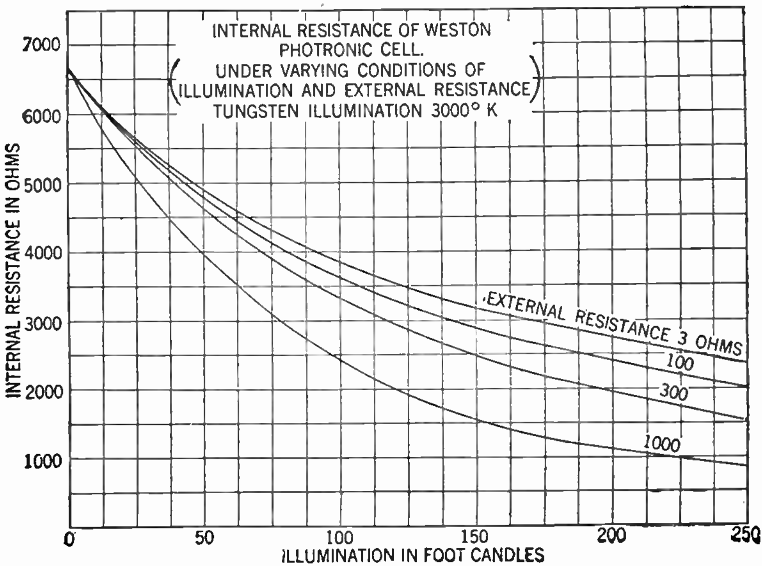


FIG. 16.—Effect of external resistance on internal resistance of the cell.

The frequency response of the cell diminishes with increasing frequencies due largely to the shunting effect of the internal capacitence of the cell, which is about 0.5 microfarad. If the response at 60 cycles is assumed at 100%, that at 120 cycles will be about 58% and at 240 cycles about 30% and finally at 1000 cycles approximately 6.4% and so on as the frequency is increased.

Therefore, this type of cell is not suitable for use in, for example, talking pictures where audio frequencies are employed, or in television work, where similarly high frequencies are encountered.

The speed of response is very rapid, in fact it may be considered as instantaneous. It has been found by tests that the response is sufficiently rapid to record the passage of a rifle bullet through a beam of light incident upon the cell.

When it is desired to amplify the current output, it is recommended to "chop" the illuminating source by a suitable sector disc or by other means, at a frequency of say 60 impulses a second, and then amplify the alternating current derived from the pulsating current output by an audio frequency amplifier.

CHAPTER 41

Phototube Amplifiers

Methods of Current Amplification.—Since the current generated in most photocells is very low and is usually measured in microamperes, it is evident that for practical operation a way must be found to increase this feeble current, for practical relay operation.

Therefore in order to increase the power output of the photocell a method of amplification very similar to that associated with radio circuits is employed.

The amplifier tubes may be of the high vacuum or of the gaseous type. When the photocell is connected to an amplifier circuit the current can be measured in milliamperes instead of in micro-amperes, as previously, i.e. the current is now one thousand times larger than before.

Two types of photo circuits are shown in figs. 1 and 2. Fig. 1 shows a simple circuit in which the current is measured in microamperes and fig. 2 shows an amplifier circuit where the current is measured with a milli-ampmeter.

The amplification can be arranged as required in various ways so as to give the necessary size of current variation for proper functioning of accessory apparatus.

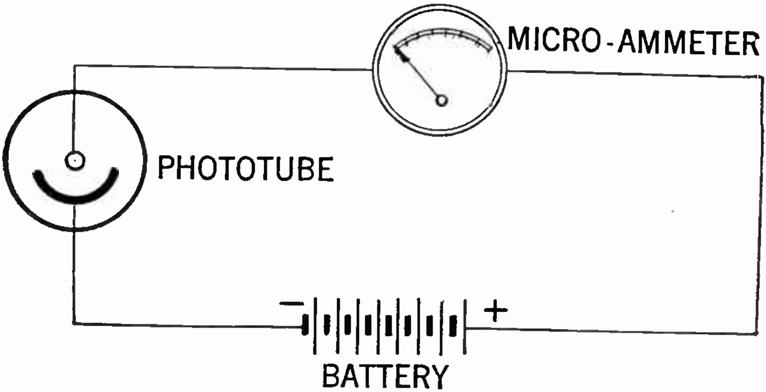


FIG. 1.—Photo-electric cell circuit. When the photocell is connected as shown, the current is too small for practical use.

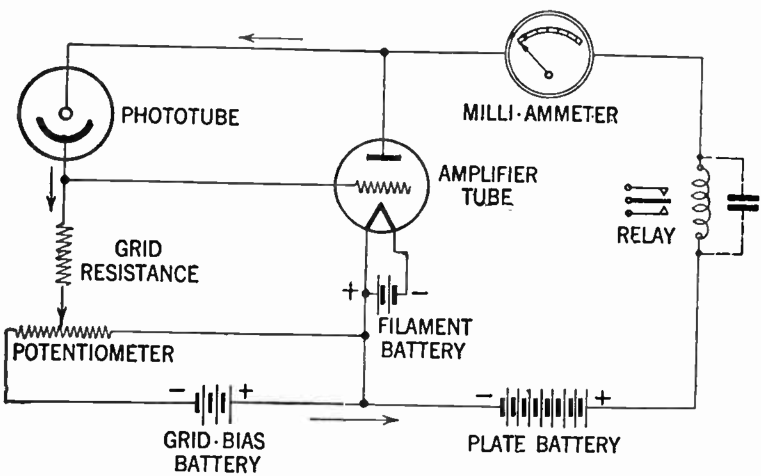


FIG. 2.—Simple battery operated one stage amplifier circuit for use with a photo-electric cell. When the photo-electric cell is connected in this manner the current will operate a sensitive relay.

For example there are single stage amplifiers of type as shown in fig. 2, multi-stage amplifiers, amplifiers designed for direct current operation, and amplifiers for A.C. operation.

The amplifier tubes may be connected to the photocell in such a way so as to increase or decrease the relay or output current when the amount of light on the phototube is varied. Sometimes a circuit connected to increase the output current of the amplifier tube when the light rays on the phototube increases, is called a *forward circuit*, and a circuit connected to decrease the current output of the amplifier tube when the illumination of the phototube increases is called a *reverse circuit*. See figs. 3 and 4.

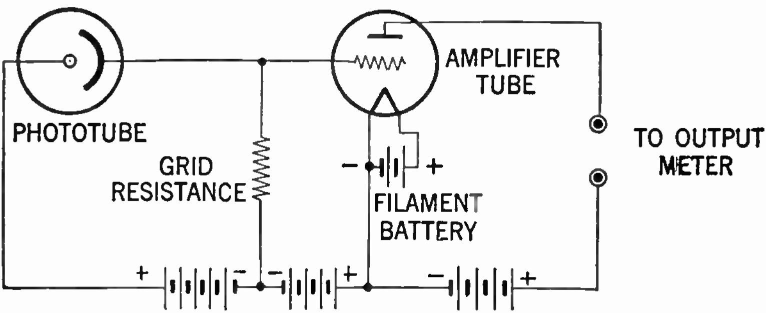


FIG. 3.—Typical battery operated amplifier. *Forward* circuit for phototube operation.

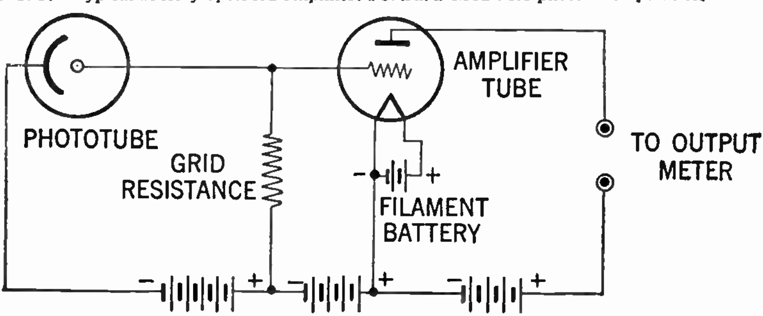


FIG. 4.—Typical battery operated amplifier. *Reverse* circuit for phototube operation.

As seen from the diagrams there is a striking similarity between the two circuits. The forward circuit is more commonly used than the reverse circuit, which is frequently used when the voltage supplied to photocell equipment and the light source is unstable or variable.

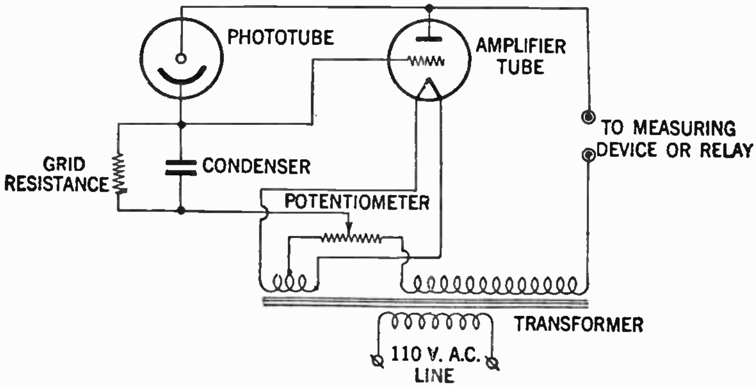


FIG. 5.—Typical A. C. operated amplifier. *Forward* circuit for phototube operation.

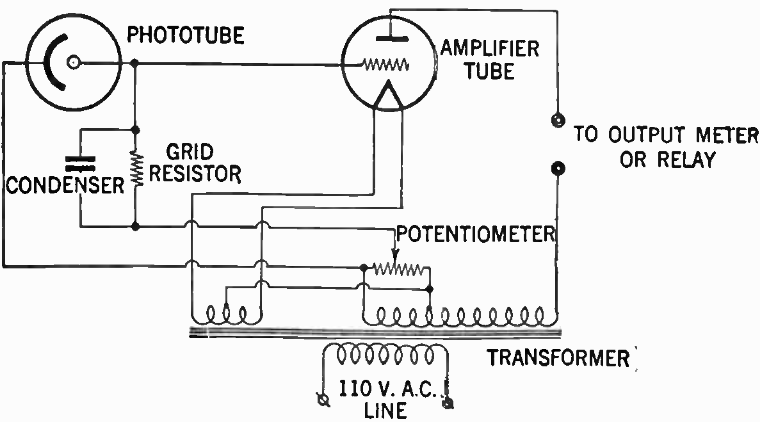


FIG. 6.—Typical A. C. operated amplifier. *Reverse* circuit for phototube operation.

Similarly a forward and reverse circuit may also be operated from an alternating current amplifier. See figs. 5 and 6.

The Function of Grid Resistors in Amplifier Circuits.—When comparing the phototube amplifier circuits it may be noted that the grid resistance is common to all circuits. Because of the fact that even when amplified the phototube current is very small, and in order to procure a voltage drop of a size to give the needed change in grid voltage, the grid resistor is necessary, and must be of very high value, usually from 10 to 200 megohms.

It is evident that by increasing the grid resistance we also increase the sensitiveness of the amplifier, but at the same time the amplifier tends to be unstable. Therefore it is considered good practice to compromise between stability and sensitivity, and the grid resistor must obviously be of a size to suit other values of the circuit.

Type of Current for Phototube Amplifiers.—*1. Use of Direct Current.* Where very great sensitiveness is required a direct current amplifier is preferred. In this type the output current of the amplifier per unit of illumination on the phototube is direct proportional to the product of sensitivity of the grid resistance and the phototube.

Instead of operating from "A" and "B" batteries it is often preferable to secure the voltage direct from, for example, a 110 V. direct-current source.

One of the disadvantages in this case is that in order to obtain the filament voltage it is necessary to place a certain amount of resistance in the circuit, in which a considerable amount of heat is dissipated, therefore this type is uneconomical.

One other disadvantage is that only a limited potential is available to the amplifier plate circuit.

2. *Use of Alternating Current.*—Because both the phototube and the amplifier tube are half-wave rectifiers, it is possible to operate the amplifier directly on alternating current, and on account of its great flexibility alternating current is most commonly employed in photolube amplifiers for industrial purposes. Direct current is preferred as previously noted where great sensitiveness is desired, for example in measuring laboratories, etc.

Multi-Stage Amplifiers for Phototubes.—In general there are three types of multi-stage amplifiers in use with phototubes (although the circuits may be modified to suit individual requirements) classified as: 1. *The transformer-coupled.* 2. *The condenser-coupled.* 3. *The resistance-coupled amplifier.*

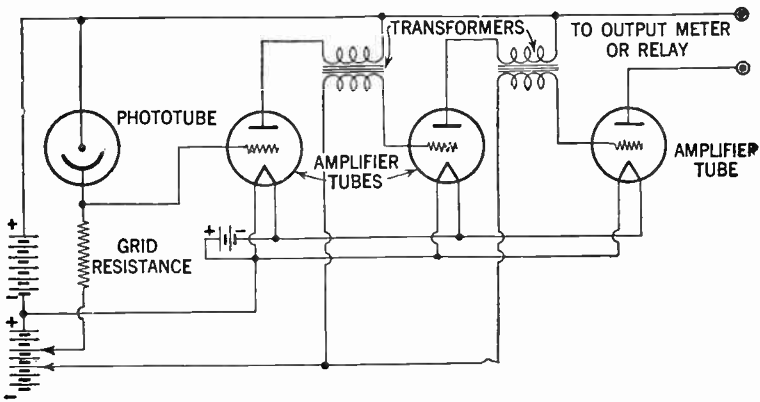


FIG. 7.—Transformer coupled multi-stage amplifier for use with photo-electric tube.

Transformer Coupled Multi-Stage Amplifier.—A typical transformer-coupled multi-stage amplifier used with phototubes is shown in fig. 7.

The effect of the transformers is to prevent the plate voltage of one stage from influencing the grid voltage of the successive stages. The amplification factor in this type may be from 20 to 200 per stage, depending on type of tubes used.

Condenser-Coupled Multi-Stage Amplifier.—A condenser-coupled amplifier is shown in fig. 8.

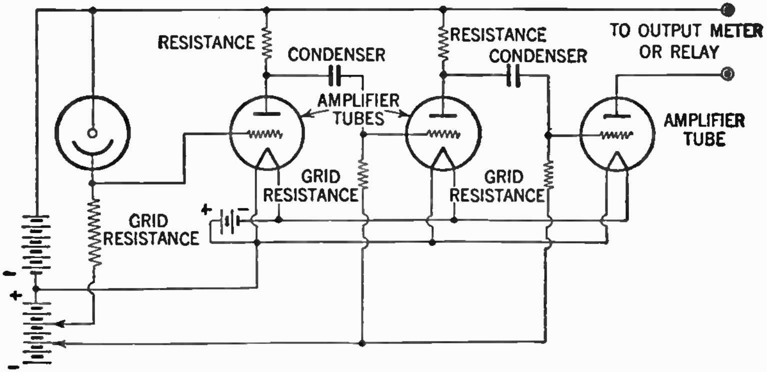


FIG. 8.—Condenser-coupled multistage amplifier for use with photo-electric tube.

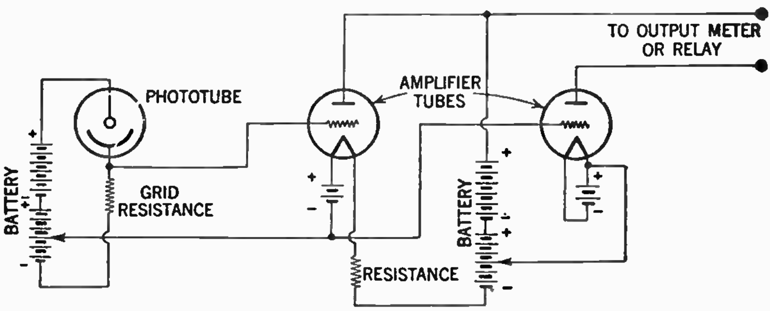


FIG. 9.—Resistance-coupled multistage amplifier for use with photo-electric tube.

Instead of transformers used in the preceding amplifier circuit, between the plate and grid, a condenser is used in this circuit.

This type of connection is commonly employed where it is necessary to amplify very low frequencies.

Resistance Coupled Multi-Stage Amplifier.—The type of circuit shown in fig. 9 is often used when it is needed to obtain amplification of ripless D.C. current.

The number of stages, however, are limited on account of amplification of certain variation in first-stage tube characteristics.

Alternating Current Amplifier for a Vacuum-Type Phototube.—A typical A.C. multi-stage amplifier for measuring or relay operation is shown in fig. 10 using R.C.A. tubes Nos. 38 and 43 as amplifier tubes and type No. 25Z5 as rectifier tube.

When the vacuum type phototube is connected as shown in solid lines the output current of the 43 is greatest for maximum illumination of the phototube, and with the phototube connected as shown in dotted lines, the output current is greatest for minimum illumination.

In order that best results may be obtained from this circuit, it should be adjusted so that the grid potential of No. 43 stays between zero volts and cut-off bias for all values of illumination on the phototube.

For the connection shown in solid lines, the adjustment can be made as follows: Set P_3 at the positive end of R_3 and P_1 and P_2 at the positive end of R_4. Then move P_1 towards the negative end of R_4 until the IR drop across R_2 due to plate current of the 38 brings the 43 to zero grid bias. As the movement of P_1 is started no effect is produced on the output meter reading. When the movement begins to effect the meter reading, the 43 is approximately at zero bias and P_1 has the correct setting.

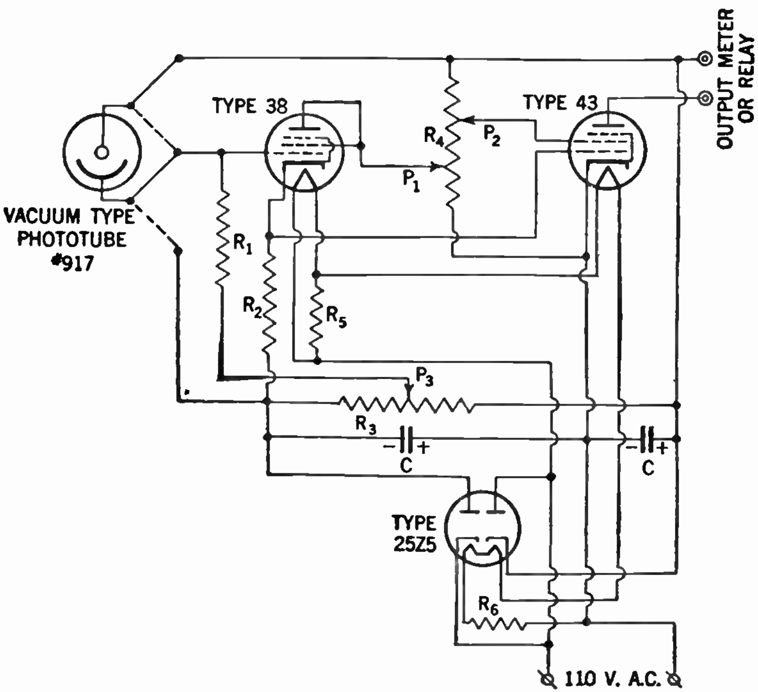


FIG. 10.—Typical amplifier circuit for use with vacuum-type phototube.

$C = 8\ \mu f$;
Output meter or relay (0-25 MA);
$R_1 = 100$ megohms;
$R_2 = 0.5$ megohm;
$R_3 = 0.1$ to 2.0 megohm;
$R_4 = 0.1$ megohm;
$R_5 = 50$ ohms (1 watt);
$R_6 = 190$ ohms (20 watts).

Then adjust the screen voltage of the 43 by means of P_2 to give the desired maximum value of output current. Next set the illumination of the phototube at zero and move P_3 toward the negative of R_3 until the output current has the desired minimum value.

For the connection shown in dotted lines, a similar procedure may be followed. First, with the illumination of the phototube at zero bring the 43 to zero grid bias and adjust the output current to have the desired maximum value by the same steps as described above. Then with the illumination of the phototube at the maximum value which is to be encountered in practice, adjust P_3 to give the desired minimum value of output current.

CHAPTER 42

Phototube Relays

Since as already described the current change accomplished in photoelectric cells is very small, it is necessary to employ an amplifier in order to receive a current of sufficient strength to operate a relay.

When selecting a relay for operation in a photoelectric circuit, it is of course necessary to be informed about the characteristics of the circuit, speed of operation, etc.

It is also important that the relay employed is able to carry the load to be operated across its contacts without damage.

A relay generally is defined as a form of electro-magnet; when a current is passed through the wire surrounding the iron core, this latter becomes magnetized and will close or open a contact placed close to the core.

If the relay is designed to close a circuit, it is often referred to as a "circuit closing relay" or when designed to merely open the circuit as a "circuit opening relay."

With respect to its function a relay may be considered as a form of electrical multiplier in that a weak current in one of the circuits controls a strong current in the other.

The type of relays most commonly used in photoelectric circuits for commercial purposes are usually referred to as the communication type or simply "telephone relays." This type will operate at approximately 5 milliamperes, and the maximum current the spring contacts will carry is about 250 milliampere, i.e. the current flowing in the circuit it is desired to control, should not exceed ¼ of an ampere.

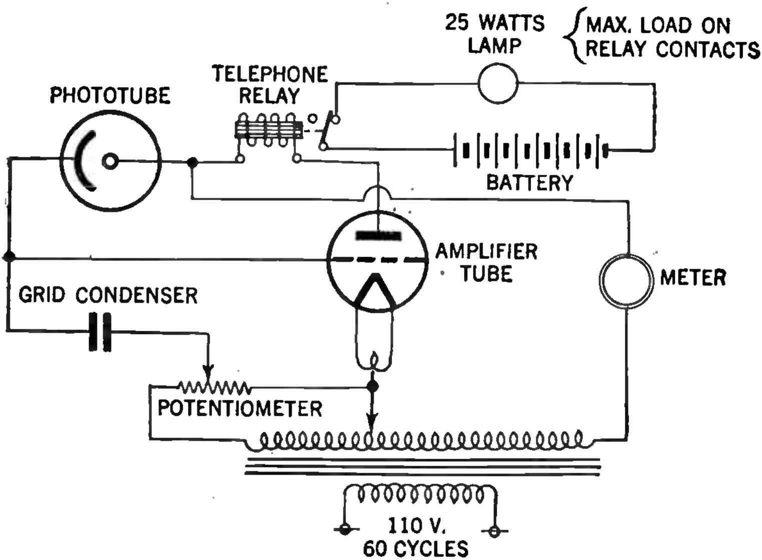


FIG. 1.—Circuit illustrating approximate maximum current to be carried over contacts of a communication type of relay.

In many cases this amount of current is insufficient and the telephone relay is used to energize a larger relay carrying 10 to 15 ampere. The limitation of a telephone type relay and method of connection when an additional relay is used, is shown in figs. 1 and 2.

There is at present a great multiplicity of special purpose relays developed suitable for photoelectric circuits, some of which have very desirable characteristics. Sometimes a combination of a photocell and amplifier is referred to as a light relay, or photomatic light relay. In this type the amount of light on the cell can be varied by inserting plates of various apertures. Other types are known as controlled rectifier relays, photoroller relays, etc.

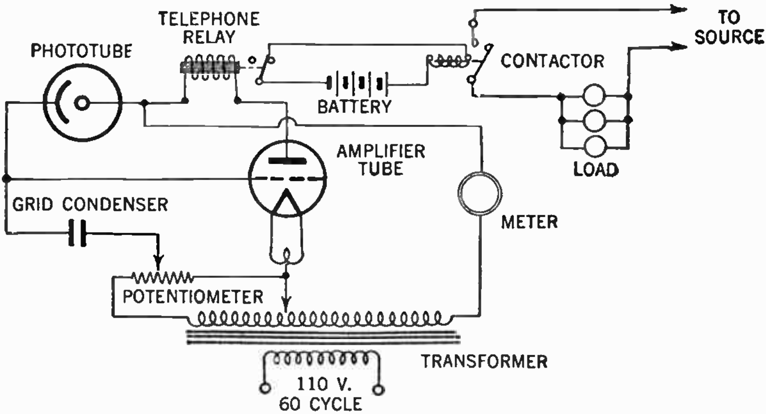
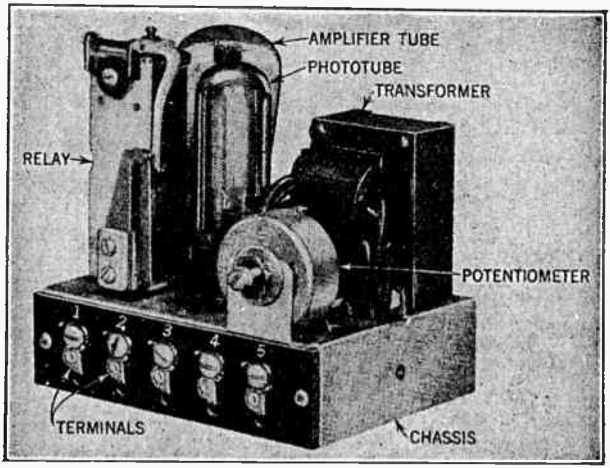


FIG. 2.—Circuit showing typical connection when it is necessary to operate a larger load than is possible when using only a communication type relay.

A relay of the type described in fig. 1 is capable of operating on a few milliamperes output of the amplifier, however, it cannot control any large amount of power directly, nor even the operating coil circuits of medium size contactors or solenoids.

A High-Speed Light Relay.—Photographic illustration of a typical and compact photoelectric relay unit is shown in fig. 3 and its circuit diagram in fig. 4.

This relay is able to carry approximately one ampere across its contact tips at 115 volts (non-inductive). It operates with a minimum illumination of 5 foot candles on the phototube and upon a 50% change in light which lasts for not less than 0.066 second when operated from a 60 cycle source, and will operate up to 400 times per minute.



FIGS. 3 and 4.—An A. C. operated photo-electric relay and connection diagram. A relay of this type may be used in automatic weighing processes; in machines for grading ball bearings; for the automatic inspection of vent holes in battery caps, and in many other applications.

The operation of this relay is as follows:

When terminal *A* of the transformer secondary is positive, both the triode amplifier tube and phototube anodes are negative, hence no current flows in either circuit inasmuch as electron tubes are inherently rectifiers.

However, if C_1 be considered to have zero charge the grid of the amplifier tube will be positive when terminal *A* is positive and grid current, limited by grid resistor will flow to charge grid capacitor C_1 in the sense indicated on the diagram. Upon reversal of the a.c. voltage, the amplifier tube and photo-electric tube anodes become positive, but the amplifier tube grid is negative by an amount equal to the charge of the capacitor plus the voltage from terminal *A* to the slider of the potentiometer and, therefore, no current flows in the amplifier tube anode circuit.

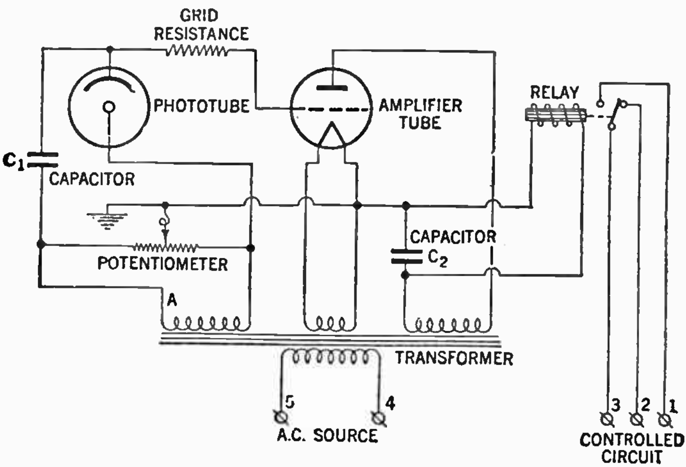


FIG. 4

If there be light on the photo-electric tube, current passes through it to the capacitor in the direction which tends to discharge the capacitor and charge it in the opposite sense. As the voltage across the capacitor decreases and finally reverses, the amplifier tube grid is made less and less negative with respect to the cathode and finally reaches a potential which permits current flow in the anode circuit.

The current of the amplifier tube at first flows largely into the smoothing capacitor C_2 inasmuch as the inductive effect of the magnetic circuit of the sensitive relay tends to maintain zero magnetic flux linkages in the relay coil at the beginning of current flow in the anode circuit. Shortly after anode current of the amplifier tube starts to flow the anode voltage of this tube again reverses and anode current stops.

However, current flows in the local circuit composed of the capacitor C_2, and the coil of the sensitive relay until the energy stored in that circuit is dissipated in the coil resistance. C_2 is made sufficiently large that it is enabled to maintain continuous current through the coil of the relay between pulses of the amplifier tube anode current before the average value of the current in the relay coil reaches the value necessary to operate the relay.

Hence, the relay has but small tendency to chatter at the critical average current value for pick-up. This complete series of events is repeated each cycle as long as there is light on the photo-electric tube.

With no light on the photo-electric tube, the action during the half-cycle when terminal *A* is positive is the same as before. However, in this case, when the a.c. voltage reverses, practically no current flows in the photo-electric tube, and therefore capacitor C_1, is not discharged but maintains its negative charge and keeps the grid negative throughout the positive half-cycle, thereby prohibiting flow of current in the amplifier tube anode circuit.

Adjustment of the circuit is accomplished by means of the potentiometer, the position of which determines how far capacitor C_1 must be discharged by the photo-electric tube current to permit current to flow in the anode circuit of the amplifier tube.

The average value of anode current of the amplifier tube is therefore determined by 2 factors: (1) The value of light flux impinging upon the photo-electric tube (the magnitude of photo-electric tube current is a function of the magnitude of the light flux); and (2) the potentiometer adjustment.

The Thyratron Electronic Relay.—In a number of applications the type of relay previously described works perfectly satisfactory, but frequently applications are encountered in which the speed of response as well as the amount of current required is too great and hence make the described methods unsatisfactory.

In such cases it has been found advantageous to substitute the relay or relays for a grid controlled glow discharge tube, which is also known as the Thyratron tube or the *Thyratron electronic relay.*

These tubes are extensively used in a wide variety of electronic circuits where the grid is used for various control purposes. They may thus be used in a modified form of rectifier circuit to provide power to perform relay operations as well as to secure control of a switching circuit for a definite number of alternating current cycles.

These tubes resemble the conventional three electrode vacuum tubes in construction inasmuch as they contain an anode, a cathode, and a grid, spaced relatively to one another and sealed in an air tight glass or metal container. However, the resemblance ceases here as these tubes are filled with mercury-vapor at a suitably low pressure, and the conduction of current from the cathode to the anode is through a glow or arc-discharge occurring in the gas or vapor. In the conduction of current through a gas or vapor, the electrons ionize the neutral atoms and thus produce positive ions. These positive ions neutralize the negative space charge caused by the electrons, and thereby permit the passage of large currents with a correspondingly low potential drop across the tube.

The function of the grid is to control the breakdown of the tube, the breakdown being the point at which current is allowed to pass between the anode and cathode. The discharge occurs when the grid is given the proper potential and, after breakdown occurs, the current is conducted between the anode and cathode in the form of a glow or arc-discharge, which is limited mainly by the circuit load conditions.

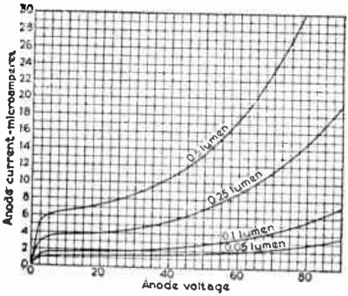
Once the discharge is started, the tube voltage drop reaches a low and essentially constant value throughout the period of conduction, and the grid is no longer effective in controlling the discharge. Hence, the tube possesses a lock-in characteristic when used with direct current sources.

This is especially desirable in certain applications where the grid is used to block the discharge until some disturbance of very short duration imposes a voltage surge upon the grid which allows the tube to break down. The tube thus affords the highest speed lock-in relay known. The anode potential must then be interrupted to stop the discharge.

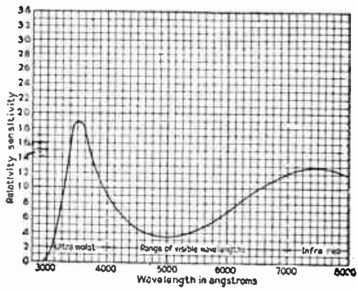
The tubes are generally used with alternating current sources where the discharge is periodically extinguished, and the grid control is restored by the reversal of the anode-cathode voltage. Thus grid control is never lost for more than one-half cycle, provided that the frequency is not more than 150 cycles per second.

On alternating current the anode voltage passes through zero during each cycle, thereby giving the grid an opportunity to regain control so that the starting potential on the next positive half cycle can be varied. By thus controlling the point on the alternating current wave at which current starts to flow, the average rectified output of the tube may be varied from essentially zero to a maximum value. This control may be effected by either changing the magnitude of the grid potential or its phase with respect to the anode to cathode potential.

Phototube PJ-23 -- Description and Rating



Anode Voltage vs Anode Current for Phototube PJ-23

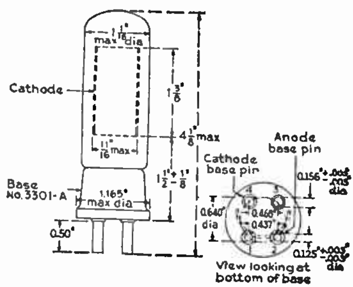


Color Sensitivity Characteristic, Constant Energy for Phototube PJ-23

The PJ-23 is a gas-filled phototube designed for general use. The active surface is caesium deposited on oxidized silver. Argon gas is used to produce the ionization, which augments the primary electron emission. This tube is useful in all cases where it is necessary to obtain a greater output than is possible with the vacuum type of phototube.

TECHNICAL INFORMATION

Number of Electrodes	2
Maximum Anode Voltage, d-c or peak a-c	90
Maximum Anode Current, microamp	20
Average Sensitivity at Anode Voltage of 90, microamp per lumen	50
Interelectrode Capacitance, μμf	4
Gas Ratio (Ratio of Anode Current at 90 volts to Anode Current at 25 volts) maximum	10
Window Area, square inches	0.9
Maximum Operating Temperature, ambient, deg C	65



Pliotron Tube FP-195 - - Description and Rating

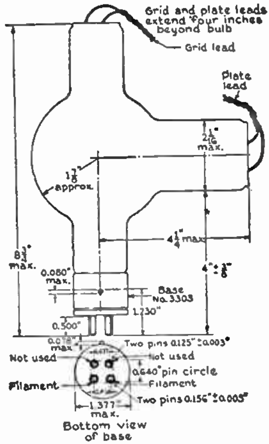
The Pliotron FP-195, an improved FP-1 (852), is a three-electrode, high-vacuum tube, designed primarily for use as an oscillator or radio-frequency power amplifier in high-frequency circuits and may be used to replace the FP-1 or 852 types.

The filament, grid, and plate are supported on separate stems with the leads brought out through separate seals, thus assuring high insulation and low interelectrode capacitance.

A 50 per cent larger anode than the FP-1 allows a much increased safety factor in withstanding sudden overloads. To eliminate reverse emission when alternating voltage is used, the anode is made of carbon. Also, it is specially processed and exhausted at extremely high temperature so as to assure freedom from gas.

Another important feature of the FP-195 is the location of the getter in the cathode arm. Former designs have utilized the assembly getter in the anode arm with the assembly attached to the anode support so that at high frequencies both the getter and assembly act as part of the anode. The getter being placed in the cathode arm eliminates the possibility of stray electrons collecting on the getter and causing sufficient heating to gas the tube or puncture the bulb.

These new features are especially important when the tube is used to generate ultrahigh frequencies.



Outline Pliotron Tube FP-195

MAXIMUM RATINGS AND TYPICAL OPERATING CONDITIONS

Class C, R-f Power Amplifier and Oscillator (Key down conditions without modulation)*

	Typical Operation (Approximate)			Maximum Ratings
Voltage	Volts			
Plate (D-c)	2000	2500	3000	3000
Plate (A-c rms)	-	-	-	3000
Grid (D-c)	-200	-350	-500	-
Filament (A-c)	10	10	10	-
Current	Amperes			
Plate (D-c)	0.150	0.132	0.116	0.150
Grid (D-c)	0.020	0.015	0.015	0.040
R-f Grid	-	-	-	10
Power	Watts			
Plate Input	300	330	350	350
Plate Dissipation	110	110	110	125
Output	190	220	240	-

*Modulation (essentially negative) may be used if the positive peak of the audio-frequency envelope does not exceed 115 per cent of the carrier conditions.

TECHNICAL INFORMATION

GENERAL DESIGN

Number of Electrodes	3
Filament Voltage, Volts	10
Filament Current, Amperes	3.25
Average Characteristic Values Calculated at E_b = 2000, I_b = .050, E_f = 10 volts D-c.	
Grid Voltage, Volts	-100
Amplification Factor	12
Grid-plate Transconductance, Mmhos	1200
Approximate Direct Interelectrode Capacitances	
Plate to Grid, μμf	2.8
Grid to Filament, μμf	2.2
Plate to Filament, μμf	1.2
Over-all Dimensions, Inches	
Maximum Length	8-3/4
Maximum Radius	4-1/4
Type of Cooling	Air

Ignitron Tube FG-235-A - - Description and Rating

Ignitron FG-235-A is a mercury-pool type controlled-rectifier tube designed particularly for high-current, intermittent operation, such as is required in welder-control service. As the tube is water-cooled, it is capable of passing these high instantaneous currents with a relatively high duty factor. The FG-235-A may also be operated continuously as a controlled rectifier at reduced current. Control is maintained by a third electrode or ignitor which initiates the arc at the desired point of each conducting cycle.

TECHNICAL INFORMATION

GENERAL DESIGN

Tube Voltage Drop at 300 amperes	
Maximum	16
Minimum	8

MAXIMUM RATINGS

Welder Control Service

Max Peak Anode Voltage, Volts ⊙	Maximum Anode Current, Amp Peak ⊙	Average ⊙	Max Conducting Time per Spot per Tube, Sec ⊙ /
900	750	135	1.50 ø
900	1000	135	1.40
900	3000	95	0.64
900	4000	75	0.25
700	750	135	1.50 ø
700	1250	135	1.33
700	3000	100	0.75
700	4500	70	0.25
360	750	135	1.50 ø
360	1750	135	1.25
360	3000	110	0.97
360	6000	50	0.25

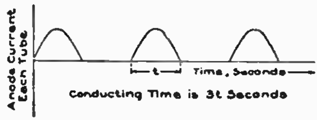
Rectifier Service	
Maximum Peak Voltage, volts	700
Maximum Peak Anode Current, amp	600
Maximum Average Anode Current, amp	100
Maximum Time for Averaging Anode Current, seconds	120
Instantaneous Ignition Current, amperes	
Maximum Required	40
Maximum Allowed	100
Average Ignition Current, amperes	
Maximum Required	0.5
Maximum Allowed	1.0
Maximum Time for Averaging Ignition Current, seconds	10
Instantaneous Ignition Potential, volts	
Maximum Required, Ignitor Positive	250
Maximum Allowed, Ignitor Positive	900
Maximum Allowed, Ignitor Negative	5

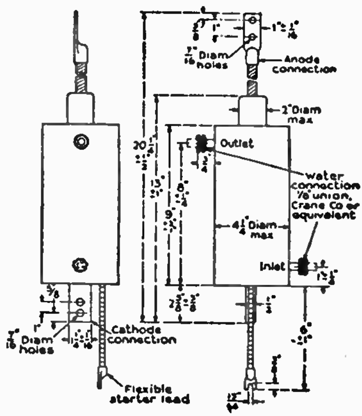
Maximum Outlet Water Temperature C	40
Minimum Flow, gallons per minute	1.5

⊙ At any one voltage, straight line interpolation may be used to arrive at other detailed ratings.

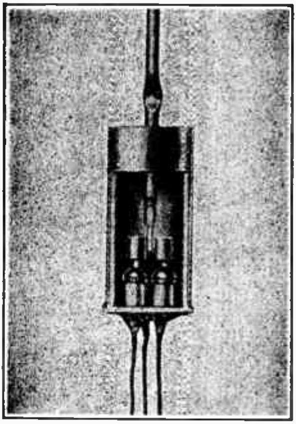
ø At peak currents below 750 amperes, the "Conducting Time per Spot" is limited only by the average current rating and the averaging time of the tube.

/ Minimum Off Time Between Spots -- Any period during which a tube has passed the rated "Maximum Conducting Time per Spot" must be followed by sufficient time off, to cause short-time average current to fall below 150 per cent of the rated "Average Anode Current". The time for taking this short-time average is the period during which conduction has taken place, plus the following off period.

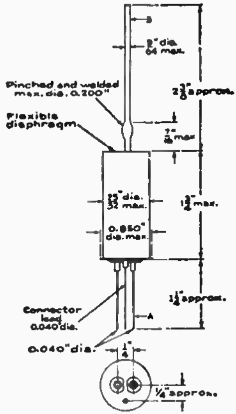




Metal Vacuum Contact Tube FA-6 -- Description and Rating



Cut Away View of Vacuum-
Contact Tube, Type FA-6



Outline Vacuum Tube FA-6

The FA-6 is a vacuum contact tube designed for use as a general-purpose switch, Contacts have a much longer life in vacuum than in air and less pressure is required to close them. Only a few thousandths of an inch movement is required to interrupt the rated current. This small movement and the light construction of the moving parts account for the very small amount of power necessary to operate the device and for the high speed of operation which may be attained.

TECHNICAL INFORMATION

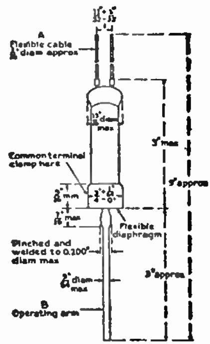
Circuits	Single-pole Double-throw
Maximum Voltage, d-c	500
Maximum Voltage, a-c	440
Continuous Current, amp	10
Interrupting Rating, Non-inductive	
At 250 v, a-c and 125 v, d-c, amp	10
At 440 v, a-c and 250 v, d-c, amp	7
At 500 volts, d-c, amp	4

Force Required to Move Operating Contact from One Stationary Contact to the Other (Initial Tension Neutralized)	
Maximum, grams	70
Average, grams	40
Travel of Arm 2-3/8 in. from Diaphragm	
Maximum, inch	0.070
Average, inch	0.045
Initial Tension at 2-3/8 in. from Diaphragm	
Maximum, grams	30
Minimum	Floating
Maximum Safe Contact Pressure, Measured 2-3/8 in. from Diaphragm, grams	250

A, leads }
B, operating arm } May be cut off as desired

Vacuum Contact Tube FA-15 - - Description and Rating

Vacuum Contact Tube FA-15



Outline Vacuum Contact Tube FA-15

The FA-15 is a vacuum contact tube for use as a general-purpose switch. This device operates by means of an operating arm which extends through a flexible diaphragm. Glass construction at the contact end permits visibility of the contacts and comparatively high insulation voltage; enclosed construction allows the tube to be mounted in wet or crowded places, or to be immersed in oil. The absence of air in the contact chamber prevents the formation of gaseous arcs and resultant corrosion of the parts. Consequently the contacts last longer than in air; and because they are always clean, less pressure is required to close them. Only a few thousandths of an inch movement is required to interrupt the rated current. This small movement and the light construction of the moving parts account for the very small amount of power necessary to operate the device and for the high speed of operation which may be attained.

TECHNICAL INFORMATION

Circuits	Single-pole Double-throw
Maximum Voltage, a-c or d-c	3000
Continuous Current, amperes	8
∅Interrupting Rating, amperes	
At 250 volts a-c and 125 volts d-c	8
At 600 volts a-c and 250 volts d-c	6
∅Interrupting Rating, amperes, Cont.	
At 500 volts d-c	4
At 1500 volts a-c or d-c	0.5
Force required to move operating contact from one stationary contact to the other	
Max including initial tension, grams/	75
Max, initial tension neutralized, g	50
Avg, initial tension neutralized, g	30
Maximum safe contact pressure measured at 2 3/8 in. from diaphragm, grams	250
Travel of arm, 2 3/8 in. from diaphragm	
Maximum, inch	0.035
Average, inch	0.026
A, Leads B, Operating arm	May be cut off as desired

∅On inductive loads the surge voltage must be limited to 3000 volts or to the maximum safe voltage for the circuit. This may be done by means of capacity or discharge resistance across the load.

/The normal position of the contacts may be either open or closed and must be adjusted externally by the user.

Thyratron Tube FG-154 - - Description and Rating

The FG-154 is a hot-cathode gas-filled, double-grid Thyratron tube particularly useful in applications where constancy of characteristic is necessary even with large variations in ambient temperature. This tube may be used where the available grid power is small.

TECHNICAL INFORMATION

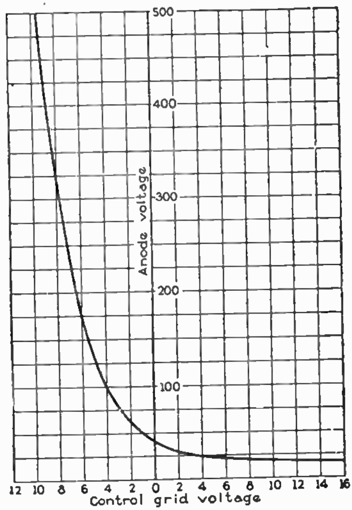
GENERAL DESIGN

Number of Electrodes	4
Cathode, coated-filament type	
Voltage, volts	5.0
Current, amperes approx	7.0
Heating Time, sec typical	10.0
Tube Voltage Drop, volts	
Maximum	24
Minimum	10

Approximate Starting Characteristic, volts

Anode Voltage	Shield Grid Voltage	Control Grid Voltage
60	0	0
100	0	-3.5

Deionization Time, microseconds approx	1000
Ionization Time, microseconds	10



Anode Voltage vs Control-grid Voltage for Thyratron Tube FG-154

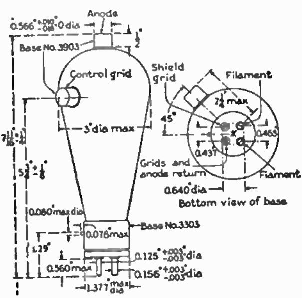
MAXIMUM RATINGS

Maximum Peak Anode Voltage	
Inverse	500
Forward	500
Maximum Negative Control Grid Voltage	300
Maximum Negative Shield Grid Voltage/	0
Maximum Anode Current, amp	
Instantaneousø	10.0
Average θ	2.5
Surge, for design only	80
Maximum Control Grid Current, amp	
Instantaneous	1.0
Average θ	.25
Maximum Shield Grid Current, amp	
Instantaneous	1.0
Average θ	.25
Temperature Limits, ambient C	-20 to + 50

øWhen the operating frequency is less than 25 cycles, the maximum instantaneous current rating is reduced to twice the average current rating.

θ Maximum time of averaging current is 15 seconds.

/ It is recommended that the shield grid be connected to the mid-point of the filament through a resistance not greater than 500 ohms.



Outline Thyratron Tube FG-154

Thyratron Tube FG-172 -- Description and Rating

The FG-172 is a hot-cathode, mercury-vapor, double-grid Thyratron tube of the "all-metal" type for use in control circuits where it is desired to actuate the grid from a high-impedance source. This tube should be used where the available grid power is very small. Because of its long deionization time, this tube is not recommended for inverter operation.

TECHNICAL INFORMATION

Number of Electrodes 4

Cathode
- Volts 5.0
- Amperes (approx) 10.0
- Type Indirectly Heated
- Typical Heating Time (minutes) 5.0

Maximum Peak Anode Voltage
- Inverse 1000
- Forward 1000

Maximum Anode Current (amperes)
- Instantaneous* 40
- Average 6.4
- Surge (for design only) 200

Maximum Time of Averaging Anode Current (seconds) 15

Maximum Shield Grid Current (amperes)
- Instantaneous 2.0
- Average 0.50

Maximum Control Grid Current (amperes)
- Instantaneous 1.0
- Average 0.25

Tube Voltage Drop
- Maximum 24
- Minimum 6

Approximate Starting Characteristic

Anode Voltage	Shield Grid Voltage	Control Grid Voltage
100	0	+1.0
1000	0	-10.0
125	0	0

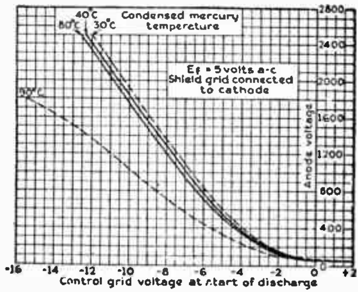
Over-all Dimensions (inches)
- Maximum Length 10-3/4
- Minimum Length 10-3/8
- Maximum Diameter 3-5/8
- Maximum Radius 1-1/8

Temperature Limits - Condensed Mercury (C) 40°-80°

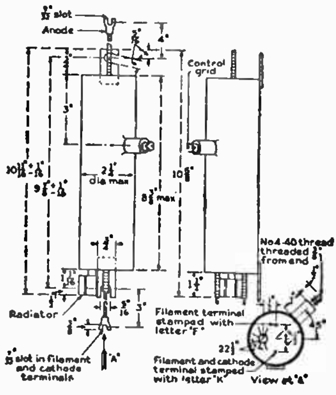
Deionization Time (microsec, approx) 1000

Ionization Time (microsec, approx) 10

*When the operating frequency is less than 25 cycles, the maximum instantaneous-current rating is reduced to twice the average current rating.



Curves of Anode Voltage vs Control-grid Voltage at Start of Discharge for Various Condensed Mercury Temperatures for Thyratron Tube FG-172



Thyratron Tube FG-57 - - Description and Rating

The FG-57 is a Thyratron tube for use in control circuits where it is desired to actuate the tube with a change in negative grid voltage. The tube is suitable, therefore, for relay uses where current flow is desired in the absence of grid excitation. This Thyratron is not satisfactory for inverter operation due to its long deionization time.

TECHNICAL INFORMATION

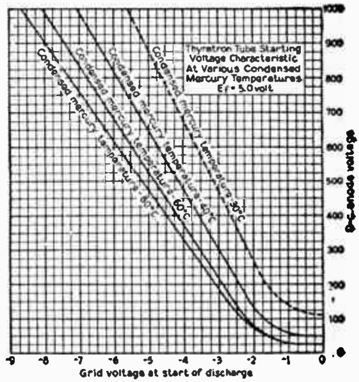
Number of Electrodes	3
Cathode	
Volts	5.0
Amperes, approx	4.5
Type	Indirectly Heated
Typical Heating Time, minutes	5
Maximum Peak Anode Voltage	
Inverse	1000
Forward	1000
Maximum Anode Current, amperes	
Instantaneous∅	15
Average	2.5
Surge, for design only	90
Maximum Time of Averaging Anode Current, seconds	15
Maximum Grid Current, amperes	
Instantaneous∅	1.0
Average	.25
Tube Voltage Drop, volts	
Maximum	24
Minimum	10

Approximate Starting Characteristics

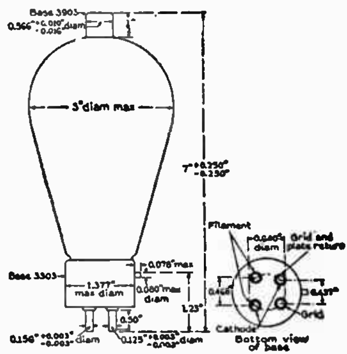
Anode Voltage	Grid Voltage
100	-1.50
1000	-7.0
70	0

Temperature Limits, Cond Mercury C	40 - 80
Deionization Time, microsec, approx	1000
Ionization Time, microsec	10

∅When the operating frequency is less than 25 cycles, the maximum instantaneous current rating is reduced to twice the average current rating.



FG-57 Thyratron Tube Starting Voltage Characteristic at Various Condensed Mercury Temperatures



Outline Thyratron FG-57

The Thyratron Tube Used as Timer in Low-Speed Welding Application.—When a resistor-condenser combination is used as a means of measuring short time intervals in electrical circuits, several important difficulties are encountered, one of the most outstanding being that for large power transfer the size of the condenser would be uneconomically large. However, if the condenser be used in the grid circuit of a thyratron, a small condenser can be arranged to charge or discharge during a relatively long interval and therefore exert control over an external load after a predetermined time delay.

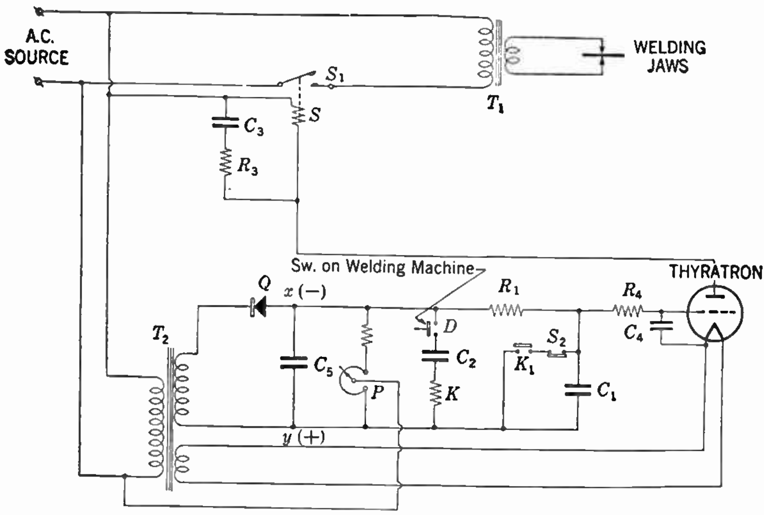


Fig. 5.—Chematic diagram of a low speed welding circuit, with thyratron timer.

Thus, in relatively low-speed spot welding where a contactor provides satisfactory control of the welding current, thyratron timer circuits are being used to determine the duration of the closure of the main contactor. Time intervals adjustable from ⅛ to 10 seconds or more can be satisfactorily measured out.

The elementary diagram of such a circuit is given in fig. 5. Here the thyratron performs the double function of a timing device and a rectifier, so that a robust d.c. contactor capable of high speed operation can be used on an a.c. supply.

The welding contactor S_1 has its coil S energized by half way rectified a.c. current suitably smoothed by parallel condenser C_3, a resistor R_3 being included to prevent excessive condenser charging currents being used by the thyratron.

In the grid circuit a small rectifier Q, holds the conductors x and y at the potentials indicated, smoothing being effected by condenser $C5$. Prior to the weld being made, the condenser C_1, is charged up to the potential existing across lines x-y. The thyratron is therefore held non-conducting owing to the relatively high negative potential between x and the adjustable potentiometer connection P, which is tied to the cathode.

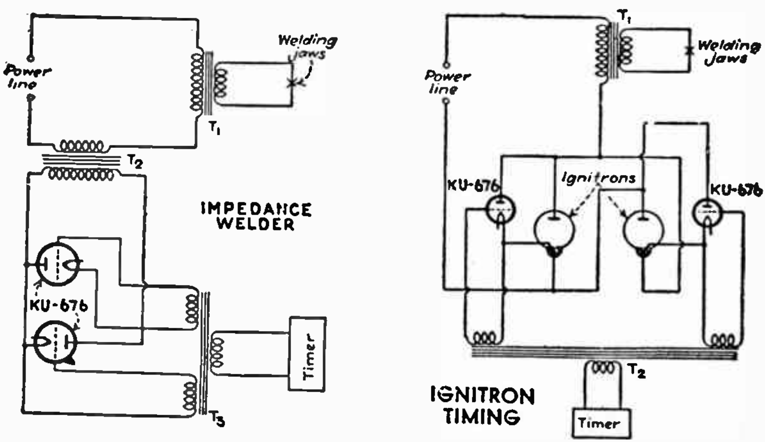
R_4 is the grid-current limiting resistor, having a sufficiently high value to prevent grid current interfering with the timing circuit. C_4 is the usual surge-suppressing condenser.

Assume now that the electrodes are brought down on the work, the switch D, on the welding machine closes. Condenser C_2 immediately charges up and momentarily energizes a small relay coil K. Contacts K_1 of the relay are therefore closed, short-circuiting C_1. The grid potential is now that of the line y, and is therefore positive with respect to the cathode by the drop across P-y. The thyratron arc therefore strikes, energizing the contactor S. At the instant the main contacts S_1 close thereby starting the welding period proper, an interlock S_2 on the contactor opens, and the condenser C_1 commences to charge up through the resistance R_1. The grid now falls in potential; a time is reached dependent on the setting of P, when it becomes slightly negative with respect to the cathode, and the arc is extinguished. The contactor coil S, is de-energized and therefore the welding period is terminated.

The duration of each spot weld is determined by the rheostat P, the value of R_1 or C_1, and, of course, on the voltage across x-y. The latter is about 150 volts, so that changes in the control ratio of the thyratron due to temperature variations, etc., do not affect the accuracy of the timing.

Two features of the circuit are that timing period (i.e. the condenser charging period) commences only when the main contacts close, and hence variations in welding heat due to the variable times of closure of the contactor are eliminated; this is of some consequence on a short weld of, say, 8 cycles.

Secondly, a single weld of definite duration is made irrespective of the time of closure of the welding machine switch D.



FIGS. 6 and 7.—Illustrates the connection of 2 thyratron tubes in welding applications.

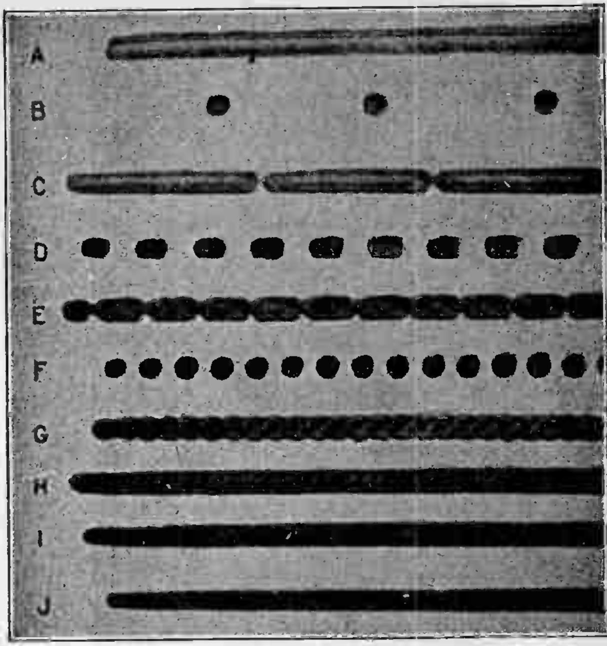


FIG. 8.—Resistance welds made at approximately 7 feet per minute by line welder controlled by a control panel using grid controlled vapor discharge tubes.

A. 21 spots per inch

B. Long off period, short on period

C. Short off period, long on period

D. Intermediate speed and ratio

E. Intermediate speed and ratio

F. 1⅔ spots per inch

G. 3 spots per inch

H. 4½ spots per inch

I. 6 spots per inch

J. 14 spots per inch

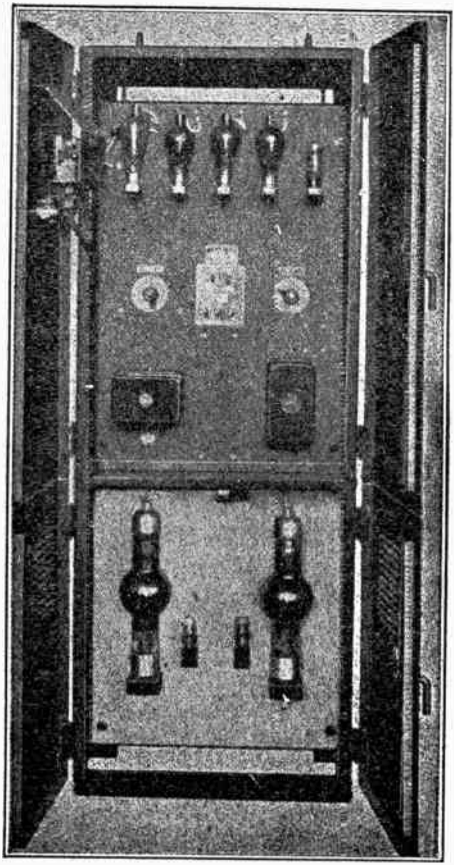


FIG. 9.—Front view of control panel for electrone tube, spot and line welder (Courtesy General Electric Co.)

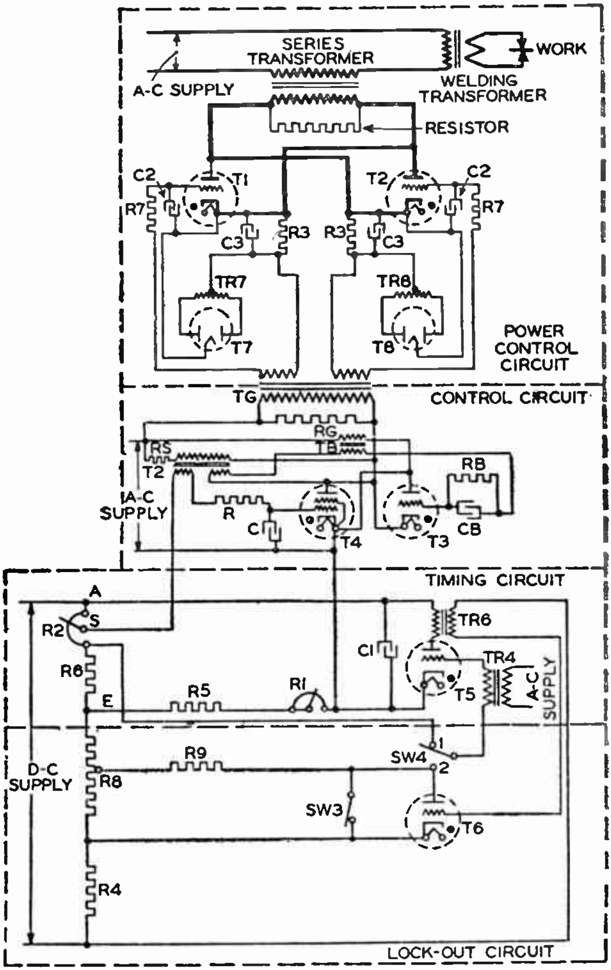


FIG. 10.—Schematic circuit diagram of electrone tube welder control panel shown on opposite page.

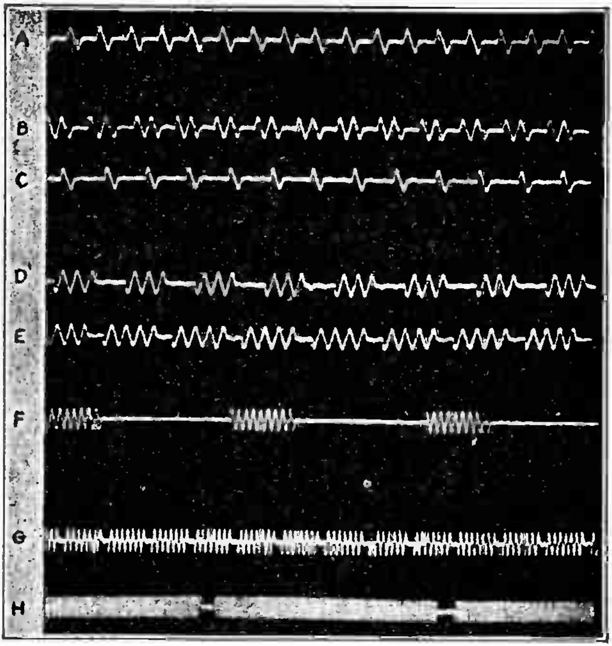


FIG. 11.—Oscillograms showing range of control with electrone tube control for resistance welding machines.

A. 1 cycle on, 1 cycle off
B. 2 cycles on, 1 cycle off
C. 1 cycle on, 2 cycles off
D. 3 cycles on, 2 cycles off
E. 4 cycles on, 1 cycle off
F. 9 cycles on, 19 cycles off
G. 7 cycles on, 1 cycle off
H. 97 cycles on, 7 cycles off

CHAPTER 43

Application of Electronic Devices

Instrument and Relays for Use with Weston Photronic Cell.— When using measuring instruments, galvanometers, or relays in connection with the photronic cell described on page 742 the effect of the resistance of the meter must be considered. In most measurements, it is desirable to have an approximately linear response, that is, when the current produced is directly proportional to the light intensity. To obtain this, it is necessary to use an instrument of relatively low resistance, the value of which in turn depends upon the maximum intensity of the illumination to be measured. For example, if the maximum illumination is say 250 foot-candles, a resistance of 200 ohms or less, will be satisfactory. On the other hand, if the maximum illumination is 5 foot-candles, then an instrument resistance of at least 1000 ohms is necessary to give the linear response required for practical purposes.

Relays usually require high torque to enable them to establish reliable contact, and for this reason their resistances in general are considerably higher than in simple indicating instruments, and as a consequence, the action of a relay may depart considerably from a strictly linear relation, depending upon its resistance.

This of course is not serious but must be considered in the design of the equipment. In fact, an instrument having a definite full scale range in light value, advantage is often taken of the non-linear characteristics of the cell with high external resistance, to increase the sensitivity for relatively low light values within the scale ranges. That is, the change in deflection per unit change in light value is greater in the lower part of the scale than in the upper part.

When using high resistances however, consideration must be given to temperature errors which may occur as a result.

Smoke Density Control.—Photoelectric equipment of this nature has been developed to control smoke densities, and to permit consistent adherence to the smoke abatement laws, it also eliminates the fuel waste which is reflected by excessive smoke conditions.

Apparatus of this type work generally as follows: A beam of light is focused through the smoke stack and on to the photoelectric cell. The cell generates electricity in proportion to the amount of light which reaches it. As the smoke passes through the light beam it reduces the intensity of light on the cell, the corresponding loss in the current generated permits a relay located in the boiler room to operate an alarm or suitable colored signal light and warn the fireman of the excessive smoking conditions in the stack. With the knowledge of the amount of smoke in the stack, combined with the data furnished by the boiler control instruments, it enables the operator to adjust the draughts and fuel supply to maintain maximum efficiency in the operation of the boilers at all times.

Continued records of smoke densities in addition to an alarm or light indication, are provided for in a number of systems for smoke control.

Among a great variety of standard smoke control recorders manufactured, the Weston Electrical Instrument Corporation have developed a simple and compact smoke alarm unit shown in fig. 1.

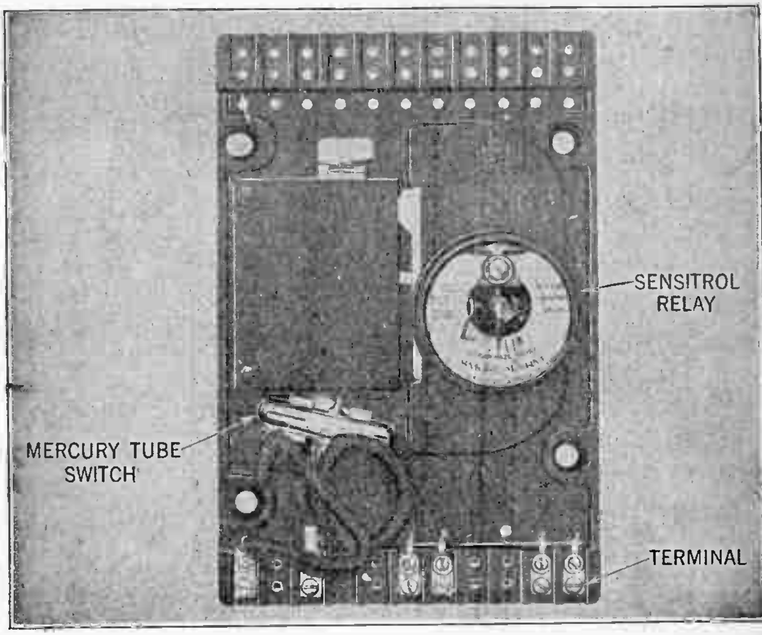
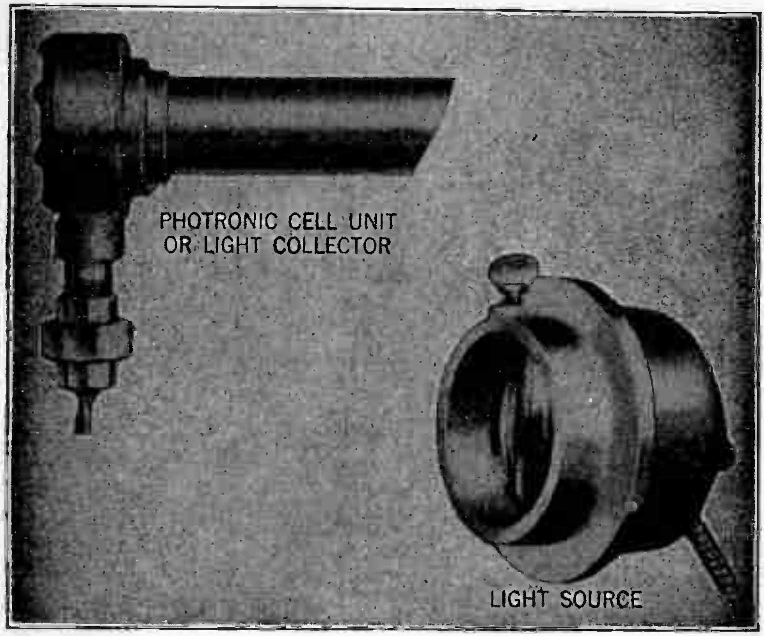


FIG. 1.—Weston Electrical Instrument Corporation's smoke alarm relay unit.

The complete smoke alarm consists of three parts: (1) A light source. (2) A light collector which contains a Weston photronic cell. (3) A relay panel. See fig. 1 to 3. The relay unit may be located at a considerable distance from the photronic cell, the resistance of the leads connecting the relay unit with the cell however, should not exceed 100 ohms.

Fig. 4 illustrates the connections between the various units.

For installation of the light source a suitable round hole is cut in smoke stack diametrically opposite the light collector, which is mounted outside of the stack.



Figs. 2 and 3.—Light collector (cell unit) and light source.

The light source consists of a 6 to 8 volt concentrated filament automobile headlight bulb of 21 to 31 candle power depending on the diameter of the stack. A small 110/6 volt transformer unit and associated rheostat enables the operator to adjust the lamp voltage occasionally to compensate for the accumulation of soot on the lamp and cell windows so that infrequent cleaning periods are necessary.

The relay unit depicted consists of a panel on which are mounted a Weston sensitrol relay, a small a.c. motor and a mercury tube switch.

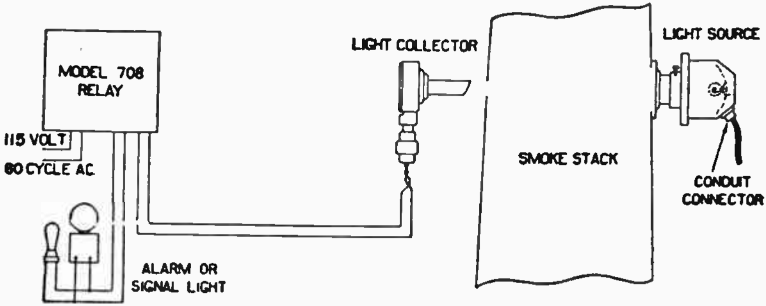


FIG. 4.—Diagram illustrating typical connection of equipment shown in figs. 1 to 3.

Note that the relay is calibrated directly in smoke units, For example: No. 2 on the dial is located at the point of haze or increasing smoke density. The relay may be set or calibrated to operate at this or any other desirable value of density, in which the cycle of operation is as follows: When smoke reduces the intensity of the light beam in the stack, the relay actuates the contact of the a.c. motor which racks the mercury tube completing the circuit to the alarm, notifying the operator about the abnormal condition. The alarm sounds for about 30 seconds, and will continue to sound at this time interval until the operator corrects stack conditions.

The contacts on the relay are automatically reset when smoke ceases to interfere with the light beam.

If a continued record of smoke density is desired, a voltage recorder may be connected with the mercury tube giving a graphic account of the time elements of improper combustion.

Illumination Control.—Photoelectric equipment for control of interior or exterior illumination, depending on changes in the intensity of natural light, has to-day almost completely replaced time switches and kindred apparatus.

Application of equipment of this nature range from the illumination of twilight-zone lighting to control of electric signs such as office and show-windows, schools, flood lighting installations, navigation lights, airway and airport lighting, etc.

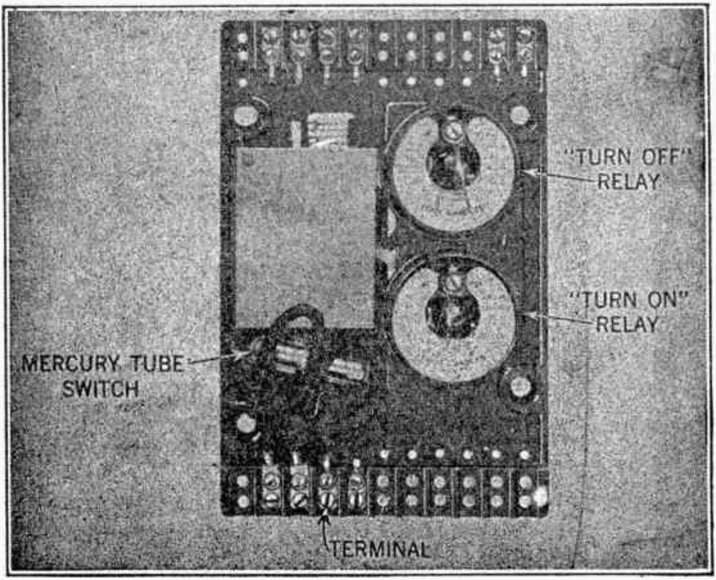


Fig. 5.—Illumination control unit, cover removed.

There is a great variety of standardized units in use for the various illumination controls. A compact and efficient control unit is designed by the Weston Engineers and is depicted in fig. 5.

The light control equipment consists of the light collector and the cabinet on which the instruments are located and interconnected as shown.

The illumination control relays turns lights on and off in accordance with the natural light intensity, so that a predetermined level of illumination may be maintained. The unit consist of a small panel on which are mounted two Weston sensitrol relays; one for turning on the lights and the other for turning them off.

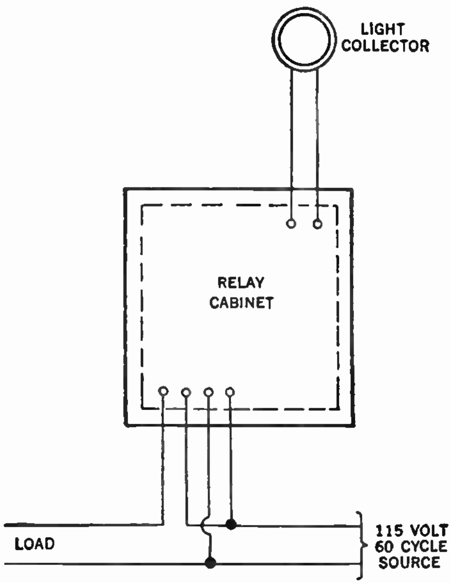


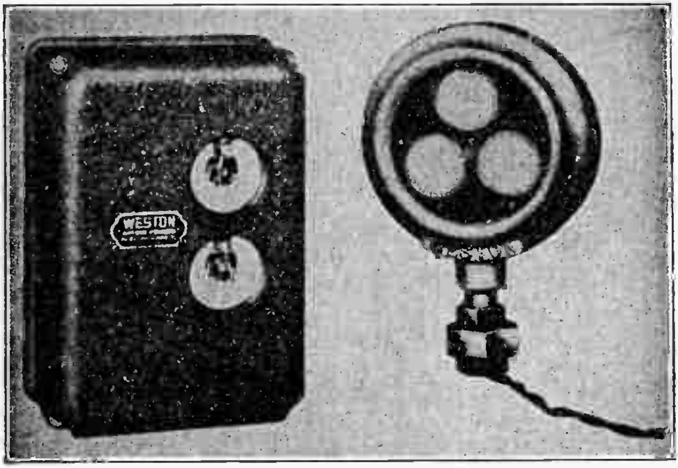
Fig. 6.—Wiring diagram of illumination control unit.

Each relay may be independently adjusted and the value at which it operates may be selected from a calibrated scale.

The design of the relay contact circuits are such as to give a relatively high contact pressure eliminating chattering. The energy for their operation is obtained from either one of the three interconnected photo-electric cells, shown in fig. 8.

The performance of the unit is dependent upon the positive action of the relays, and in order to fully understand the performance of the "turn on" relay, the operation is as follows:

The relay is a single contact device for closing a primary circuit. The energy delivered to the relay from one of the photoelectric cells is sufficient for their operation and therefore no batteries or auxiliary apparatus are necessary.



FIGS. 7 and 8.—Illumination control unit (cover attached) and photo-electric light collectors.

In order to make or break a circuit it is necessary to have two contacts, one moveable and the other stationary. The stationary contact in the relay consists of a small permanent magnet, and the moveable contact consists of a magnetic "rider" which is attached to the instrument pointer. Light impigning upon the photoelectric cell generates electric energy in sufficient amount to keep the contacts open.

When the light diminishes, the energy is decreased proportionally until the relay pointer swings the moveable contact into the magnetic field of the permanent magnets stationary contacts. It is then drawn firmly against it, producing a very firm contact pressure and prevents chattering.

The "turn off" relay operates exactly on the same principle, but the action takes place when the natural light intensity is increasing, not diminishing.

When daylight diminishes to a predetermined level, the contacts of the "turn on" relay closes and completes the circuit to a small induction motor, which in turn drives a small cam. This cam rocks a mercury tube switch, completing the lighting circuit. At the same time it locks out and resets the "turn on" relay.

The motor now stops, leaving the light on and releasing the "turn off" relay from its locked out position so that when the light intensity rises to the desired operating value, the lights will be turned off.

This same procedure occurs when the "turn off" relay makes contact. The entire operation is completed in approximately one minute. This operating interval is advantageous as it permits the stabilization of light conditions, thus preventing continuous operation due to shadows falling upon the photoelectric cell.

The above description is common to the illumination control relay units for both interior or exterior operation.

For interior illumination control the relay scales are usually calibrated from 10 to 20 foot-candles "turn on" and 20 to 30 "turn off," although any desired range is supplied. For street lighting or outdoor control the relay is calibrated from 0 to 2 foot-candles, permitting a low operating value of 0.5 foot-candle.

For outdoor mounting the relay unit is encased in a weather-proof housing. The photoelectric cells are also enclosed in a weather-proof light collector.

The installation is simple. It is only necessary to mount the relay panel on a wall or post, set the photoelectric cell and run leads from the relay panel to the connection on the existing switch box. The small induction motor requires approximately two watts for a period of one minute; the energy being obtained from the most convenient 110 volt, 60 cycle source. As no energy is consumed except during the cycles of operation, operating cost is practically negligible.

Sensitive High Speed A.C. Photo-Electric Relay.—In applications which require great sensitivity and speed of response a relay of the type shown in fig. 9 may be applied, especially if the device to be operated be a small solenoid or other small magnetic device which may be operated directly from the grid controlled vapor discharge tube in place of the contactor shown, thus saving the time required to operate the magnetic relaying contactor.

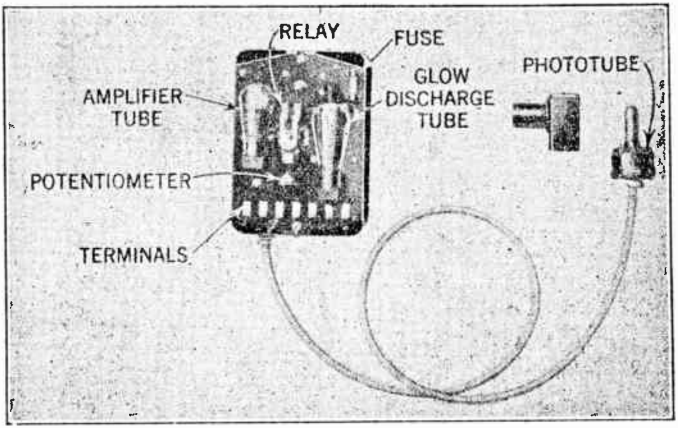


FIG. 9.—A sensitive, high speed A. C. photo-electric relay operating a grid controlled vapor discharge tube.

That is, the relay of fig. 9 employs the photoelectric tube amplifier circuit of fig. 10 to operate a grid controlled vapor discharge tube. Hence, since an arc discharge of a grid controlled vapor discharge tube will establish itself within a few microseconds after its grid receives the tripping impulse, power is applied to the relaying contactor or operating solenoid in minimum time (for an a.c. circuit).

Relays of this type are used in tooth paste tube machines to align properly the end crimp with the printing on the tube, in steel mills to respond to radiant energy from hot bodies, and in slow speed package wrapping machines to insure correct register of the printed matter upon the wrapper to the package.

The circuit of relay, shown in fig. 10 operates as follows:

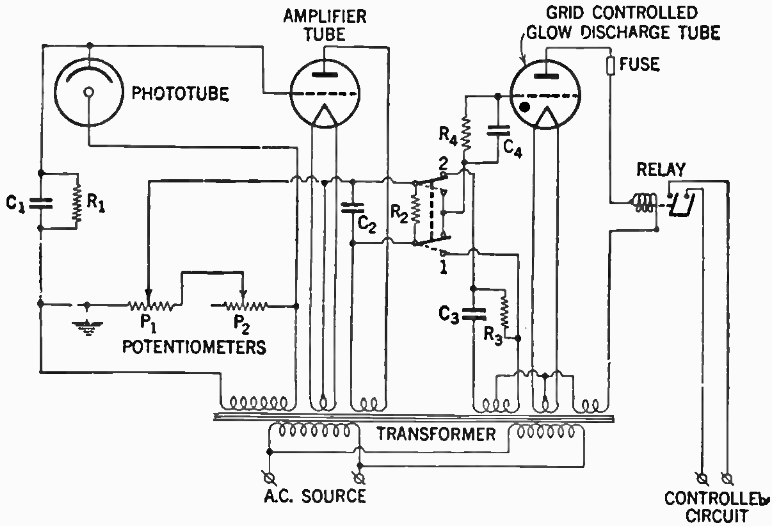


Fig. 10.—Wiring diagram of relay shown in fig. 9.

As before, an increase in light on the photo-electric tube causes an increased average plate current flow through the amplifier tube, but due to the a.c. circuit and to the time constant of the local circuit of C_2 and R_2 (over one-half cycle at 60 cycles) anode current flows through the amplifier tube in quarter-cycle pulses (while the anode voltage of the grid controlled vapor discharge tube is negative) to charge C_2 and so produce a bias voltage in the grid circuit of this latter tube. Inasmuch as different applications demand that an adjustment be provided so that this tube in one case may be made to conduct upon light increase, and in another may be made to conduct upon light decrease, a change-over switch is provided between the photo-electric tube-amplifier circuit and the circuit of the grid controlled vapor discharge tube to allow the polarity of the tripping voltage introduced into the circuit of the latter tube by the amplifier to be reversed.

With the change-over switch in position 1 and zero current being passed by the amplifier tube, the voltage conditions in the circuit of the grid controlled vapor discharge tube are as shown in fig. 11A i.e., an a.c. grid bias voltage 180° out of phase with the anode voltage is used to charge C_4 through the grid cathode circuit of the grid controlled vapor discharge tube.

The time constant of the local circuit of C_4 and R_4 is less than ⅛ cycle at 60 cycles per second, yet is sufficient to carry the grid negative enough before the anode becomes positive so that incidental shifts of anode voltage phase caused by current flow through the contactor coil are insufficient to cause the tube to fire erratically. With the relations of fig. 11A the anode current is zero.

If the amplifier tube is caused to pass more and more current, the conditions of fig. 11B finally obtain; i.e., due to the a.c. bias voltage superimposed on the difference in voltages existing on C_4 and C_2, the grid of the grid controlled vapor discharge tube is more positive than the critical grid voltage at the beginning of the half-cycle during which the anode of this tube is positive. Hence, full current is passed by the tube.

However, if the change-over switch be thrown to position 2 and there be zero anode current in the amplifier tube, the conditions of fig. 11C obtain; i.e., an a.c. voltage is introduced into the grid circuit of the grid controlled vapor discharge tube from the mid-tap of the bias winding and the junction of C_3 and R_3, which leads the anode voltage of this latter tube by

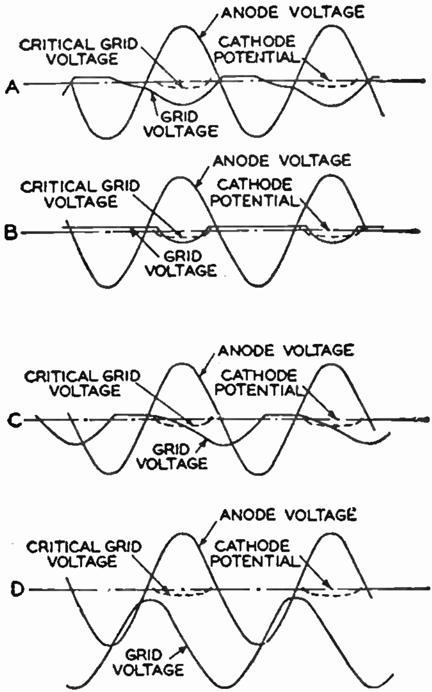


FIG. 11.—Voltage relations of grid controlled vapor discharge tube of the relay shown in fig. 9.

slightly less than 90°. This voltage charges C_4 in a quarter-cycle pulse and holds the grid positive at the beginning of the half-cycle during which the anode is positive. Hence, full current is passed by the grid controlled vapor discharge tube.

If, under the latter conditions the amplifier tube is caused to pass more and more current, the conditions of fig. 11D finally obtain; i.e., the increasing voltage across C_2 shifts the axis of the 90° leading a.c. grid voltage in the negative direction until the critical grid voltage is no longer exceeded, and the grid controlled vapor discharge tube ceases to conduct.

Particular notice should be taken of the care used in the above circuit to provide grid voltages for the vapor discharge tube of the correct phase and ample magnitude such that the tube cannot but pass full or zero anode current—a necessary condition to prevent erratic operation of the device controlled by the tube.

This relay will operate with a minimum illumination on the photo-electric tube of one foot candle and upon a 40% change in illumination at this value, or upon a 10% change in illumination at 10 foot candles, provided these changes last 0.05 second or longer (assuming a 60 cycle source of power). Hence the relay will operate up to 600 times per minute, assuming that the device operated by the grid controlled vapor discharge tube will follow at that speed.

A Simple Two-Stage A.C. Operated Photo-Amplifier Relay Circuit*.—Fig. 12 shows a simple two-stage photo-amplifier relay circuit operating directly on the a.c. line. The simplicity of the circuit is illustrated by the fact that the complete list of circuit parts includes only one voltage divider resistor, one plate load resistor and three condensers. The circuit shown in fig. 12 consists of a high impedance phototube feeding through a voltage amplifier or buffer stage into a power-output stage.

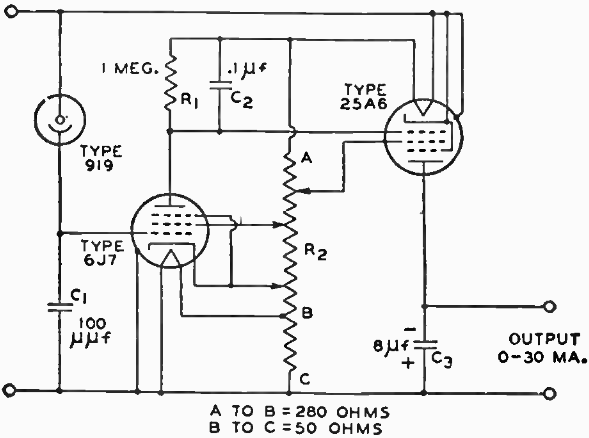


FIG. 12.—A simple two-stage A. C. operated photo-amplifier relay.

The filament voltage of the buffer stage has been lowered to reduce the temperature of and, hence, the electron emission from the grid of the buffer tube.

The plate current of the buffer stage is kept at a minimum in order to reduce the electron bombardment of the gas molecules within the tube and hence, the gas current to the grid.

The bias to the grid of the buffer stage is obtained by means of the rectifying action of the grid itself. This method of obtaining the grid bias keeps the effective bias and, hence, the plate current of the tube constant, regardless of large fluctuations in contact potential between the grid and the cathode.

The impedance of the condenser C_1 acts as a load impedance for the phototube. Condenser C_1 is charged up to a definite negative potential on one-half of the a.c. cycle and is allowed to discharge through the phototube on the other half of the cycle. The amount that it is discharged by the phototube determines the working potential on the grid of the buffer stage. The size of C_1 can be set to any desired value to determine the desired sensitivity range of the relay.

Quick-Acting A.C. Operated Photo-Amplifier Relay.—Figs. 13, 14 and 15 show three variations of an a.c. operated photo

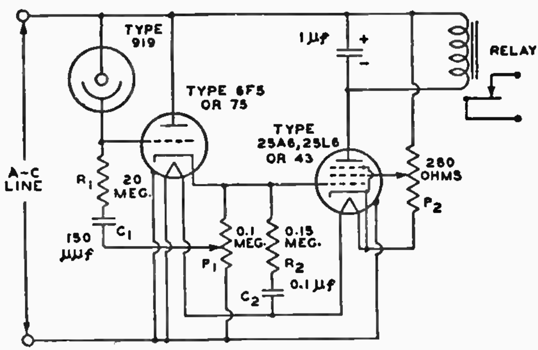


FIG. 13.—A quick-acting A. C. operated photo amplifier relay, functioning in a positive direction on the received light.

relay that will respond to a pulse of light having a duration as short as one-sixtieth of a second, or 1/120th of a second if the pulse is properly phased with the power supply voltage.

The operation of these circuits is essentially as follows: On the negative half of the power supply cycle with no light on the photocell, the cathode of the 6F5 goes negative with respect to the grid, passes current to the grid, and thus during a period of several cycles charges C_1 to a value equal to the peak value of the a.c. voltage applied between the grid and cathode. This voltage added to the instantaneous a.c. voltage applied between the grid and cathode is sufficient to reduce the plate current of the output tube to zero.

When light is received by the phototube, the phototube current has two effects, first, an instantaneous drop appears across the phototube load R_1, and second, the phototube current into condenser C_1 opposes the current fed into C_1 from the grid of the amplifier.

This action causes the potential across C_1 to balance at some negative value between zero and a value equal to the peak of the a.c. voltage between grid and cathode. The potential across C_2 is fixed in like manner by a balance between the charging grid current and the discharging buffer-tube current.

In figs. 13 and 14 an instantaneous flash of light occurring on the positive half of the cycle will cause an instantaneous drop across R_1, an instantaneous change in the plant current of the buffer stage, and an instantaneous change in grid voltage of the output tube. In fig. 15 due to the current taken by the buffer stage, there is a rapid loss of potential across C_2. This loss is slowly restored through R_3 over a period of several cycles. Thus the pulse of output current will have sufficient duration to operate a sluggish mechanical relay, even though the pulse of light be of extremely short duration.

The circuit in fig. 14 is identical to the circuit shown in fig. 13 except that the heater voltages are supplied by suitable transformers. The use of a transformer supply for the heaters eliminates the degeneration or loss of gain that is inherent

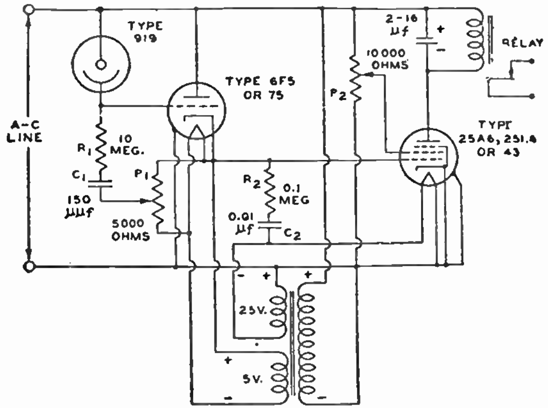


FIG. 14.—A quick-acting non-degenerative A. C. operated photo-amplifier relay, functioning in a positive direction on the received light.

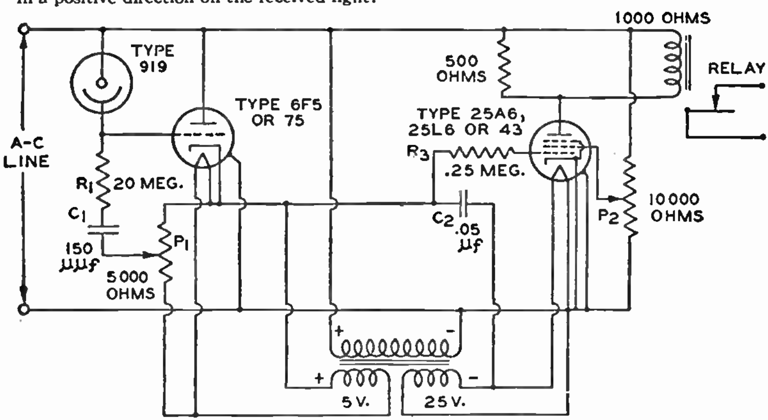


FIG. 15.—A quick-acting slow-releasing A. C. operated amplifier relay, functioning in a positive direction of the received light.

in the circuit shown in fig. 12 due to the fact that the d.c. potential between the lower side of C_1 and the cathode of the buffer tube does not remain constant. In this circuit care should be taken to keep the instantaneous transformer polarities as shown.

These simple photo relays find their application for use in moderately high speed sorters, counters, register controls, shooting galleries, etc.

A Sensitive Light-Intensity Indicator.—Fig. 16 shows a sensitive photo-amplifier circuit that can be used for accurately matching the intensities of amounts of light. With this circuit, it is easily possible to indicate light differences or changes which

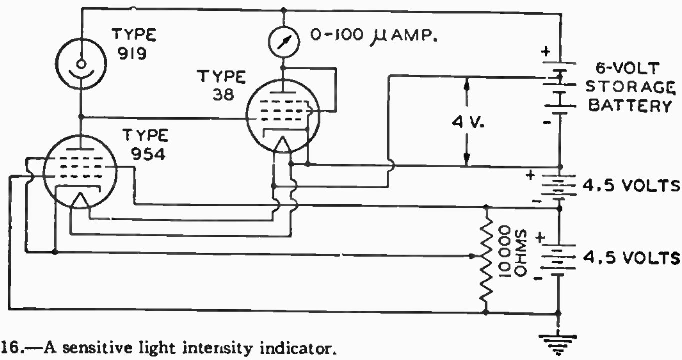


FIG. 16.—A sensitive light intensity indicator.

may amount to small parts of one per cent. In this circuit arrangement, the high-impedance 954 pentode acts as a load impedance for the 919 high-impedance vacuum tube phototube. It can be seen by reference to fig. 17 that the potential of the common connection between the 919 and the 954 is determined by the intersection of the 954 and 919 characteristics. It is also evident that a small change of light on the phototube will result in an output of several volts. This output voltage is applied to the grid of a 38 output tube, the plate current of which is indicated on a 100 microampere meter. Because the phototube with the 954 load has an extremely high output impedance, it is necessary to operate the 38 so that its grid input impedance is extremely high. To reduce the grid emission to a minimum, the voltage to the heaters of the 38 and 954 is reduced to 4 volts. The possibility of emission from the heaters to the grid is eliminated by operating the heaters at a potential positive with respect to the plate of the 954 and the grid of the 38.

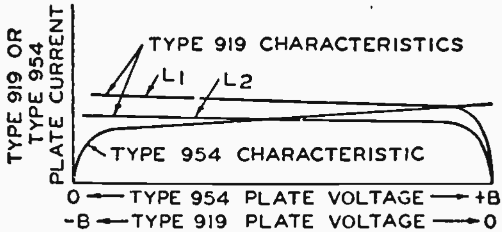


FIG. 17.—Plate characteristics of a vacuum type phototube with a pentode as a plate load.

Gas current to the grid of the 38 is kept at a minimum by keeping the potentials within the 38 low so as to minimize the ionization of any gas that may be in the tube. Because all of the high impedance external connections are made to electrodes brought out from the tops of the tubes, external leakages are reduced to a minimum. External leakage can be greatly reduced by carefully cleaning the tubes and coating them with a non-hygroscopic wax. This can be done by dipping the tubes in hot ceresin wax and holding them under the surface of the wax until the greater part of the moisture on the glass is boiled off. Care should be taken not to scorch the wax. Ceresin wax has long been used by research men for reducing the effects of moisture leakages in high impedance d.c. circuits.

This circuit finds application where it is desirable to indicate very small percentage variations of an amount of light. For instance, it can be used to indicate the absorption of light by a fluid and, consequently, to indicate or control the concentration of certain chemicals in suspension or solution. The use of monochromatic light can be used to advantage when it is desired to isolate a particular constituent. This circuit also finds application in color matchers and in indicating small changes of small amounts of light. For instance when measuring small changes of small amounts of light, it has been demonstrated that a change of light intensity on the order of two-millionths of a lumen is sufficient to swing the output meter over its full scale.

A Variable-Range, Variable-Sensitivity Light-Variation Indicator.—It is sometimes desirable to make the sensitivity of the light intensity meter indicator less for small percentage changes of light. The sensitivity can be reduced to any desired degree by varying the plate characteristics of the 954 between those of a pentode and those of a triode. This variation is produced in the arrangement shown in fig. 18 by properly adjusting P_2 and P_3 to control the relative potentials on the control grid and the screen grid.

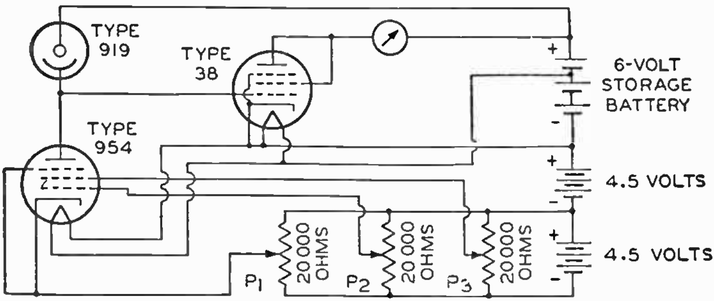


FIG. 18.—A light intensity indicator having a variable range and variable sensitivity.

When the No. 2 grid of the 954 is positive with respect to the cathode, the 954 has a high impedance pentode characteristic. Changing the No. 1 grid bias changes the height of the characteristic as shown in fig. 19 by the curves No. 1 and No. 2. As the potential of the No. 2 grid is made more negative, the characteristic of the 954 changes to that shown by curve No. 3. With zero bias on the No. 1, and the No. 2 grids, the characteristic curve is as shown by curve No. 4.

When a negative bias is placed on the No. 2 grid, the shape of the characteristic is unchanged, but it is shifted along the voltage axis as shown by curve No. 5. If the No. 1 grid is biased properly, the slope of the characteristic is increased. Curve No. 6 shows the effect of positive bias on the No. 1 grid (bias on the No. 2 grid for this curve is zero). Placing a negative bias on the No. 2 grid shifts this characteristic along the axis as shown by curve No. 7.

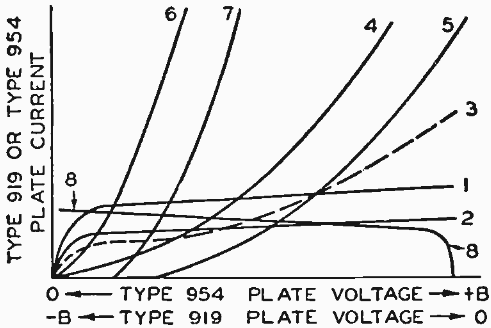


Fig. 19.—Plate characteristics of a vacuum-type phototube with a pentode having a controlled plate impedance as the phototube load.

From this analysis it can be seen that the 954 phototube load can be adjusted to give practically any desired positive impedance load at any desired current and at any desired voltage across the tube. This means that the full scale reading of the output meter can be made to cover a fraction of a per cent light variation, a 100 per cent light variation, or any desired amount of variation between these two extremes. A photo amplifier such as this finds application as a densitometer for use in connection with the analysis of photographically recorded spectra, and for use in connection with a suitable monochrometer or light filter as a means of measuring the absorption lines or the concentration of certain chemicals in solution. These are but two of a large number of possible applications for this type of circuit.

Photo-Electric Exposure Control.—Fig. 20 shows a circuit that will act to operate a relay or a solenoid when the phototube has received a certain predetermined amount of light after switch S_2 has been closed. This action is independent of the time over which the light has been received, providing the time is greater than about ½ a second. In practice the phototube can be arranged to receive the light reflected from or transmitted through a part or the whole of the plate, film, or paper in the camera.

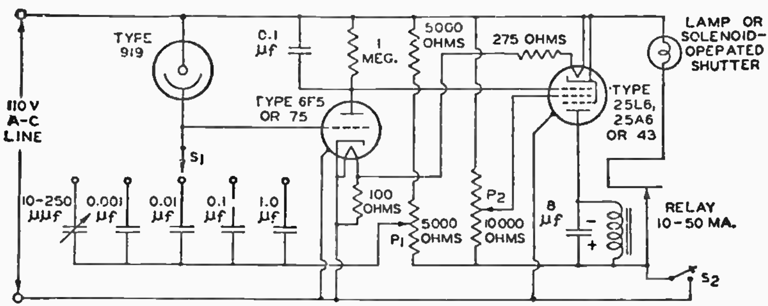


FIG. 20.—A light-quantity metering and control circuit.

When switch S_2 is open the plate and screen voltages to the output tube are zero, and the output relay is de-energized. One side of the a.c. line is applied through one of the timing condensers to the grid, while the cathode is connected to the other side. Due to the rectifying action between the grid and cathode of the buffer the condenser assumes a charge, the direct potential of which reaches a value approaching the peak of the a.c. line voltage. On closing switch S_2 the d.c. voltage or the major portion of this voltage is removed from between the grid and cathode of the buffer stage, thus allowing the above mentioned d.c. potential on the grid to cut off the plate current.

This in turn allows the voltage drop across the plate load of the buffer stage to drop to zero. As this drop across the buffer stage plate load is both signal and bias for the output stage, and as the plate and screen voltages of the output tube are applied by closing switch S_2, the plate current of the output tube will rise to operate the output relay or solenoid.

This in turn lights the exposure lamp or opens the camera shutter. After the charge across the timing condenser is dissipated through the phototube to a low enough value so that the grid of the buffer stage permits the buffer stage to conduct plate current, a voltage will be developed across the buffer stage plate load resistor of sufficient value to cut off the plate current of the output tube. This action releases the relay or solenoid, and thereby turns off the exposure lamp or closes the camera shutter.

Theory.—The current passed by a vacuum tube phototube is directly proportional to the intensity of the light received by the phototube, and is practically independent of the voltage across the tube. The quantity of light received is intensity times time, and is in general a measure of the proper exposure. The quantity of electricity passed by the photocell is proportional to its current times time, hence, the quantity of electricity passed is a measure of the quantity of light received.

As it takes a definite quantity of electricity to discharge a condenser from one potential to another, the size of the condenser and the voltage through which it has to be discharged can be used as a measure of the desired exposure. It should be noted that judgment of the operator is still necessary to determine the setting of P_1 which compensates for the percentage of light and dark areas in the picture.

This particular circuit finds its application in all types of copy work, and in all types of picture work where time exposures are used. For instance the exposure of zinc plates in newspaper work; the exposure in making microphotographs; in portrait work; in photostat work, in printing, etc. can all be controlled by this device.

A Sensitive Light-Balance Indicator.—Where it is desired to indicate accurately the balance between two amounts of light, the circuit shown in fig. 21 is of value. This circuit is capable of indicating a light unbalance of less than ¼ of 1 per cent when the light on the phototubes is as low as 0.0001 lumens; the accuracy of balance is somewhat better with larger amounts of light. All of this is done by using the unregulated a.c. power lines for the power supply.

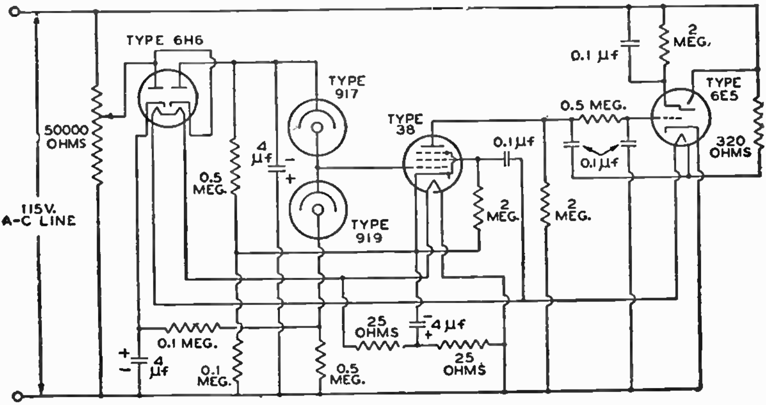


FIG. 21.—A sensitive light-balance indicator.

The circuit uses a 6E5 electron-ray tube as the balance indicator, a 38 as an a.c. operated buffer stage and electrometer, and a 6H6 as a rectifier to supply direct current to the 917 and 919 phototubes.

One phototube acts as the high impedance load for the other, so that relatively high voltage outputs are available, even for very small percentage variations of light.

The high impedance output of the phototube bridge circuit is fed directly to the grid of the 38. Because the cathode of the 919, the anode of the 917 and the grid of the 38 come out of the tops of the tubes, the connecting wires touch nothing but tube caps and the tubes can be coated with a suitable non-hygroscopic wax such as white ceresin wax to reduce to a minimum all external leakages. Low leakage is essential when measuring small amounts of light.

The type 38 acts on the alternating voltage supplied to its plate and screen in such a manner that the average direct potential built up on its plate is negative, and is of such magnitude that it can be used as bias and signal to the grid of the 6E5 indicator tube. As a means of increasing the input resistance of the 38, the heater is operated at reduced voltage, the screen at about 10 volts, and the plate at about 18 volts. To avoid the effects of emission from the heater to the grid, the heater is operated at a potential at all times positive with respect to the control grid.

In actual use a system of mirrors or reflecting surfaces are arranged to take the light from a common source and pass it through or reflect it from the surface of the sample under test.

A calibrated shutter, a pair of rotatable calibrated polarized discs, or a calibrated runway for the light source, can be used to determine accurately the change in balance intensity as various samples are placed between the light source and one of the phototubes.

With a suitable light source having the proper wave-lengths, this device can be used for color matching, turbidity measurements, reflectance measurements, and the absorption analysis of solutions.

It is generally known that all substances in solution have certain spectral absorption lines, and that the measurement of the amount of light of a particular wave-length that is absorbed by a solution, is an indication of the concentration of a particular constituent in the solution.

With a source of monochromatic light of the desired wavelength, the above circuit has been successfully used for accurately determining the sugar concentration in beverages, also the concentration of various syrups and flavorings. This arrangement has also been used commercially for determining the vitamin concentrations of vitamin bearing oils.

Phototube Circuit for Matching Measurements.—Matching measurement of photometric qualities such as brightness, color and turbidity, can also be made with high precision by means of circuit fig. 22. In this circuit one vacuum type phototube receives light from the test lamp or test material under observation. The other identical phototube receives light from the standard lamp or standard material.

A small inequality in light falling on the two phototubes causes a comparatively large voltage to be applied to the grid of the amplifier tube. By this means a very slight mis-match between the standard and the unknown can therefore be detected on a meter connected in the plate circuit of the amplifier tube.

Similarly this meter can also be used to obtain quantitative measurements. For example, if the brightness of a lamp is to be measured, the distance from the unknown lamp (or the standard lamp) to its corresponding phototube is varied, until the plate circuit meter indicates equal illumination on the two phototubes.

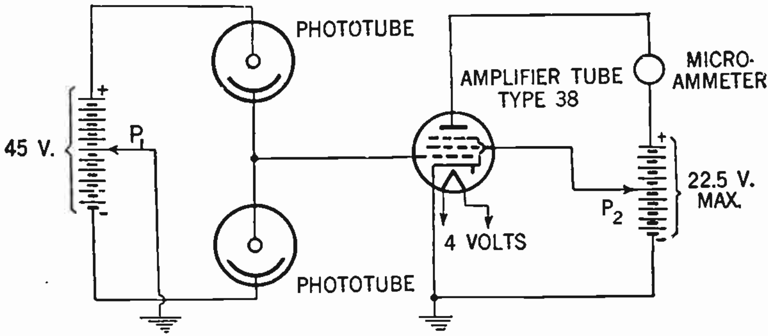


FIG. 22.—Sensitive circuit for matching measurement. Note: P_1 should be set so that with no light on the phototubes, the output-meter reading is approximately mid-scale. Contact P_2 should be set so that the maximum possible output current is limited to 100 microamperes.

The brightness on the unknown lamp can be computed from the inverse square law (see page 14). When other qualities are to be measured, the aperature of a shutter, which controls the amount of light falling on one phototube, is varied until the plate-circuit meter indicates that equal amount of light are falling on both phototubes.

This shutter obviously can be calibrated so that the value under measurement can be read directly from the setting of the shutter aperature.

The theory of this circuit may be considerably simplified if it is considered that one phototube acts as the load of the other as shown in fig. 23. In this figure, one of the phototubes is repreented by the phototube current-voltage characteristics, and on this curve is drawn a reversed phototube current-voltage characteristic as a load line representing the other phototube.

The intersection of the characteristics gives the distribution of voltage across the two phototubes because the two phototubes being in series, must pass the same current.

This intersection is shifted widely by a small change in the light on one phototube. This change is shown by the dotted curves which is the characteristics for one tube under slightly decreased illumination.

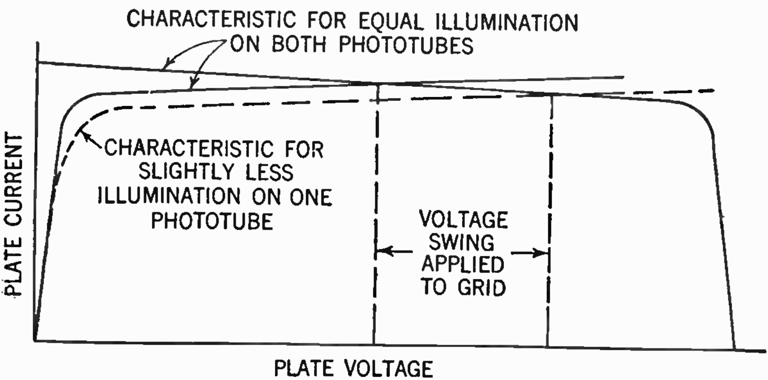


FIG. 23.—Phototube characteristics when connected as shown in fig. 22.

The wide shift means a large voltage swing on the grid of the amplifier tube and consequently, high sensitivity.

Phototube Circuit for Measuring Low Values of Light.—Small amounts of lights can also be made with a high degree o accuracy by means of circuit shown in fig. 24.

In this circuit the triode section of the type 85 tube starts tc oscillate with L_1 and C_1 as the tank circuit. The oscillations wil soon terminate because the grid builds up a negative charge or C_2 and blocks the tube. Oscillations begin again when the grid draws enough positive charge through the vacuum type phototube to unblock the tube.

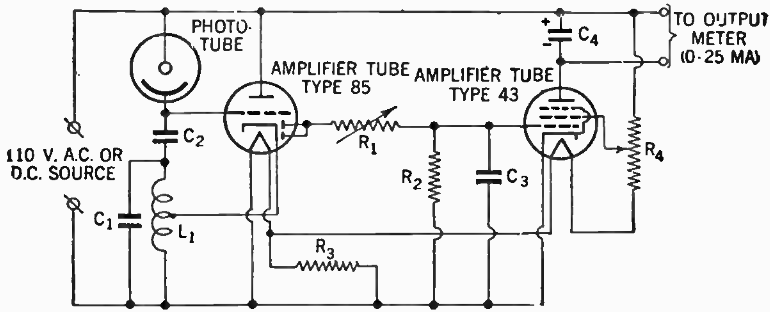


FIG. 24.—Circuit for measurement of small amount of light.

C_1=20 to 150 $\mu\mu f$	R_1=0 to 100,000 ohms (sensitivity control)
C_2=50 $\mu\mu f$	R_2=0.5 megohm
C_3=0.5 μf	R_3=50 ohms (1 watt)
C_4=4 μf	R_4=275 ohms (25 watts)
L_1=1 to 10 M H (Mid-tapped)	

The same cycle, oscillation followed by cut-off is repeated. The duration of the cut-off period depends on the rate of flow of charge through the phototube, which, in turn, depends on the illumination of the tube.

The output of the 85 triode is, therefore, a series of trains of oscillations and the time trains depends upon the illumination of the phototube.

The diode section of the 85 rectifies these trains of oscillations and feeds a charge into condenser C_3 for each train. The charge on the condenser C_3 leaks off slowly through the high resistance of R_2 so that the net d.c. voltage across C_3 depends on the number of trains per second, which is a measure of illumination of the phototube. This voltage is applied to the grid of the 43 and is amplified to give a meter reading in the plate circuit of the 43. The meter is calibrated in terms of illumination on the phototube.

The high sensitivity of this circuit for the measurement of small amounts of light is due to the fact that it is the duration of the cut-off period which is used to measure the illumination.

Since grid current is small when the tube is cut off, the measurement of small current through the phototube is not disturbed by grid current and as a consequence extremely small amount of light incident on the phototube can be readily measured. The circuit can be adopted to the measurement of different ranges of light intensity by changes in R_1, R_2, C_1 and C_2.

Operating power can be obtained directly from a 110 volt line a.c. or d.c. Operation on a.c. gives somewhat less sensitivity than operation on direct current.

Circuit for Measurement of Illumination Ratios.—Ratios of illumination can be measured by means of the a.c. operated circuit shown in fig. 25. Condenser C_1 is charged during one half-cycle through one phototube. On the next half-cycle the condenser is charged in the opposite direction through the other phototube.

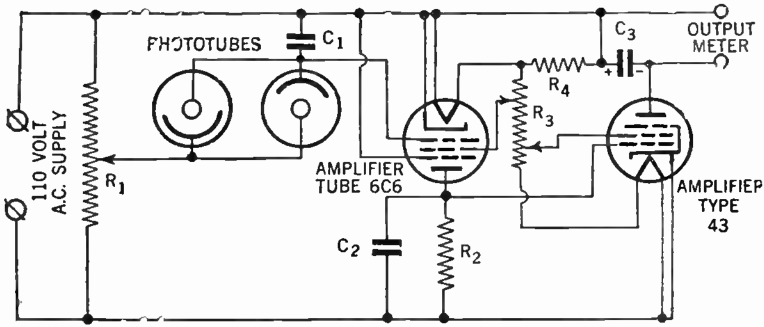


FIG. 25.—Circuit for measurement of light intensity ratios.

C_1 = 0.0001 μf
C_2 = 0.25 μf
C_3 = 4 μf
R_1 = 5000 to 500,000 ohms (sensitive control)
R_2 = 0.5 megohm
R_3 = 275 ohms (25 watts)
R_4 = 50 ohms (1 watt)

If now the vacuum type phototubes are equally illuminated they feed equal charges into the condenser and the net d.c. voltage across the condenser is zero.

When, however, the phototubes are *unequally* illuminated there is set up across the condenser, a d.c. voltage whose magnitude is a function of the ratio of illuminations. This condenser voltage amplified by the 6C6 and the 43 is read on the output meter which can be calibrated to show directly the intensity of one source as a multiple or a fraction of that of the other.

Sound on Film Circuit.—A typical first stage circuit for a sound-head amplifier is shown in fig. 26. Load resistance values for this service depend on gain and fidelity requirements. Higher values of load resistance give higher gains but with some increase in distortion.

An illustration of a typical relay circuit is given in fig. 27. In this circuit high sensitivity is obtained by the use of a large load resistance.

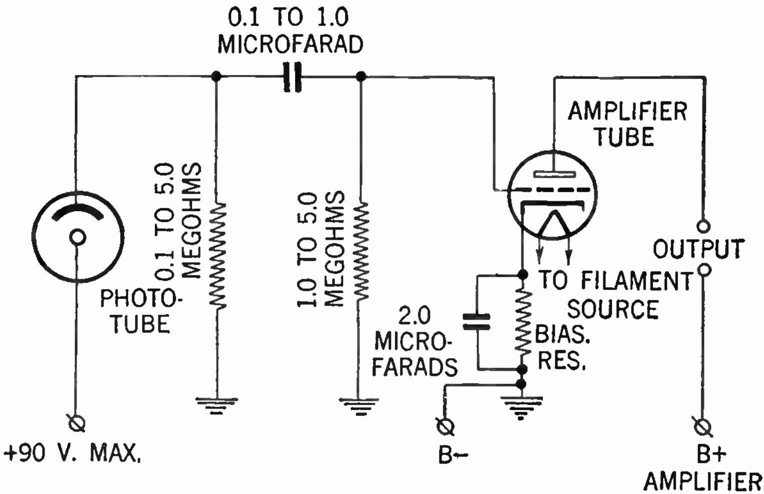


Fig. 26.—Typical circuit employing a gaseous type phototube for sound frequency reproduction.

It should be noted that most amplifier tubes are rated for operation with a grid circuit resistance of less than 1 or 2 megohms. When a higher resistance phototube load is used in the grid circuit of the amplifier tube, it will be necessary to take precautions to prevent the grid of the amplifier tube from building up a high positive potential and thus causing the tube's plate current to become excessive.

Such precautions are: reduction of the plate and screen supply voltages much below the rated values, reduction of the heater or filament voltage, and use of a large resistance in the plate supply lead to limit plate current.

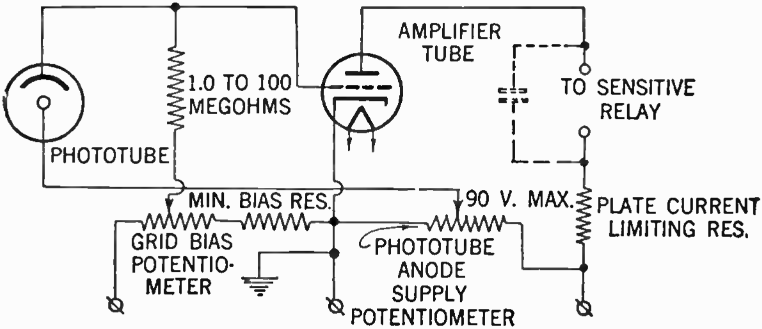


FIG. 27.—Typical relay circuit employing gaseous type phototube.

High-voltage Circuit Providing Overvoltage Protection of Gaseous Type Phototube.—In some relay applications, it may be desirable to gain increased sensitivity by the use of a very large supply voltage.

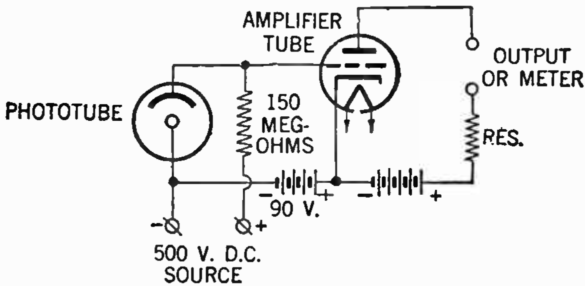


FIG. 28.—Typical high-voltage circuit providing over-voltage protection for phototube.

This can be accomplished by the use of a circuit similar to that shown in fig. 28 in which the voltage across the phototube cannot rise above 90 volts. In this circuit, the amplifier tube must be protected against excessive plate current by following the precautions previously mentioned. These precautions are essential because the resistance of the phototube is very high and is connected in the grid circuit of the amplifier tube.

Ultra-High Speed D.C. Operated Photo-electric Relay.—In many modern processes it is required to employ a photo-electric relay which will respond to a light impulse lasting but a few microseconds. For example, many wrappers for packaged articles first have printing applied in a rotary press, then are removed to a machine which cuts the wrapper in register with the printing and applies it to the package.

Here it is necessary for accurate high speed work, for photo-electric control apparatus to provide the synchronizing tie between the cutting knife and the printed matter on the web, because factors such as slip of the web in the machine and variations in stretch of the web preclude successful operation otherwise. Because it is essential that the photo-electric apparatus work on some small part of the printed design which may give but small photo-electric contrast with its background (or on some small mark printed specifically for the purpose) and at the high web speeds possible in modern machines, an extremely sensitive and fast photo-electric device is required.

The type of relay shown in figs. 29 and 30 has been found to be adapted to meet the exacting requirements of this type of service. Its virtues may best be understood, perhaps, from the following description of the operation of its circuit, shown in somewhat simplified form in fig. 31.

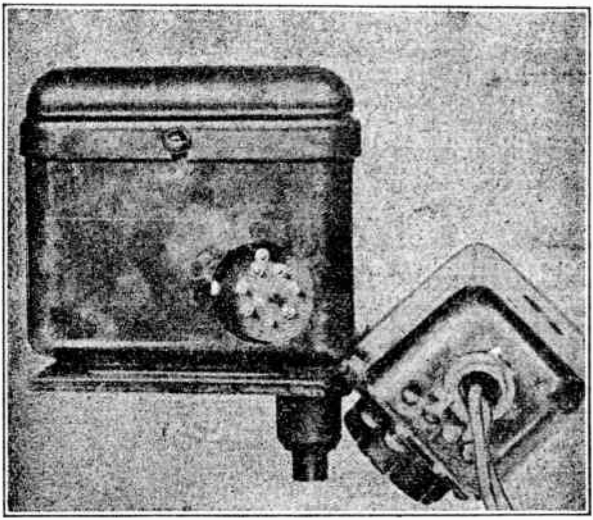


FIG. 29.—Scanning head of ultra high speed D. C. operated photo-electric relay. (Courtesy General Electric Co.).

In order that the tubes may operate at any instant and be as free as possible from the transient voltage disturbances common on industrial power distribution lines, power is usually taken from the a.c. power source used for incandescent lighting, modified in voltage by an electrostatically shielded transformer, rectified and carefully filtered by a full wave rectifier tube and π-filter. The practically pure d.c. voltage thus derived is applied across voltage dividers from which are tapped the voltages required by the various tubes.

Because of the high impedance of the photo-electric tube, and the extreme speed at which this circuit must work, the photo-electric tube and amplifier are placed as close together as possible in a shielded enclosure known as the "scanning head," see fig. 29.

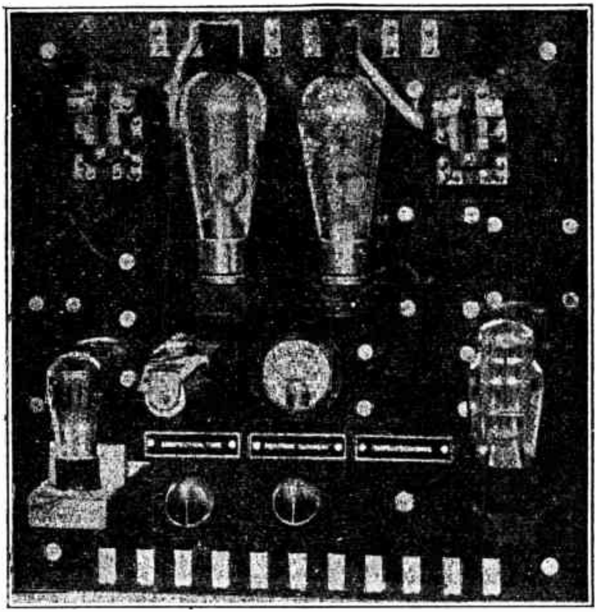


FIG. 30.—Control panel of ultra high speed D. C. operated photo-electric relay. (Courtesy General Electric Co.)

Usually the light source is mounted on the scanning head by a bracket, thus providing a unit which operates from change of reflected light which is relatively free of troubles due to moisture, dirt, electro-static interference, or variations in focus. Sometimes, dependent upon the installation and upon the web material, the light source is mounted on the opposite side of the web from the photo-electric tube housing, thus providing a unit which operates upon transmitted light, which may allow a larger value of light flux to fall upon the photo-electric tube.

Due to the relatively high level of power output from the scanning head, however, the grid controlled vapor discharge tubes, control contactors, and rectifier may be mounted in a separate enclosure several feet from the scanning head in such a manner as to allow easy access, and in a position free from vibration.

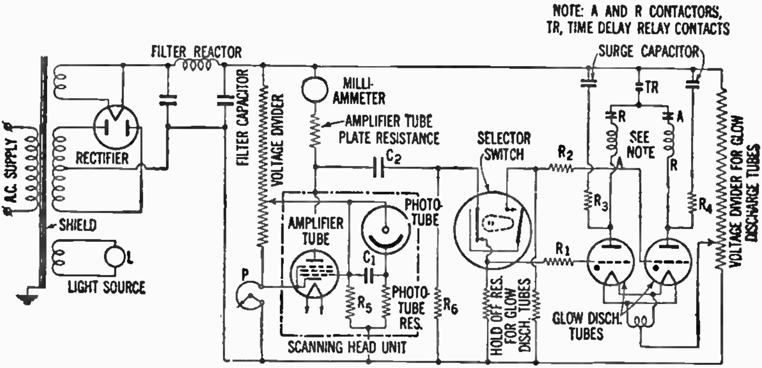


FIG. 31.—Ultra-sensitive high speed D. C. register control using photo-electric tube and grid controlled vapor discharge tubes.

Particular notice should be taken of the method of circuit coupling. Referring to fig. 31 the photo-electric tube-amplifier circuit operates as follows: When there is no change of light on the photo-electric tube, capacitor C_1 assumes the potential existing across the photo-electric tube resistor, there is zero current flow in R_5 and the amplifier tube grid is at ground potential, negative with respect to its cathode. However, upon change of light on the photo-electric tube, since the response of the tube is instantaneous, a new potential value exists across the photo-electric tube resistor.

The voltage across C_1 must finally equal the new voltage across the resistor but, since a capacitor cannot change its charge instantly, the difference between the old and the new voltage existing across the resistor must initially appear across R_5, changing the grid potential of the amplifier tube by that amount. The grid potential will be carried in a more positive or more negative direction, depending upon whether the capacitor is charged or discharged. Hence, due to the "capacity coupling" effect, the amplifier will respond to rapid changes of light, but not to slow changes.

The pentode is used for the amplifier tube because its plate current is independent, roughly speaking, of the plate voltage value, if that value be kept above a certain minimum. Hence high values of plate resistance may be used and great amplification secured.

The grid controlled vapor discharge tubes are normally biased negatively through hold-off resistors of moderately high value. Their grid circuits are carried through a selector switch and capacity coupled through $R6$ and $C2$ to the amplifier. Hence, if TR be closed, A and R, be de-energized, one grid controlled vapor discharge tube or the other, according to the position of the selector switch, will be in condition to be rendered conducting by its grid being carried positive by a voltage of correct polarity appearing across $R6$ (a circuit of low impedance). The tube, once fired, will remain conducting until TR is opened, even though the potential across $R6$ may have become zero meanwhile, or the selector switch contact opened, carrying the grid negative. A and R are the operating coils of contactors which operate to produce the required correction; while TR opens, then recloses after the desired correction period has passed, rendering the tube non-conducting again and putting it in condition to operate on the next proper impulse.

Relays of the type of fig. 30 will operate on a minimum light change of 0.02 lumen occurring at an average rate of between 2 and 200 lumens per second.

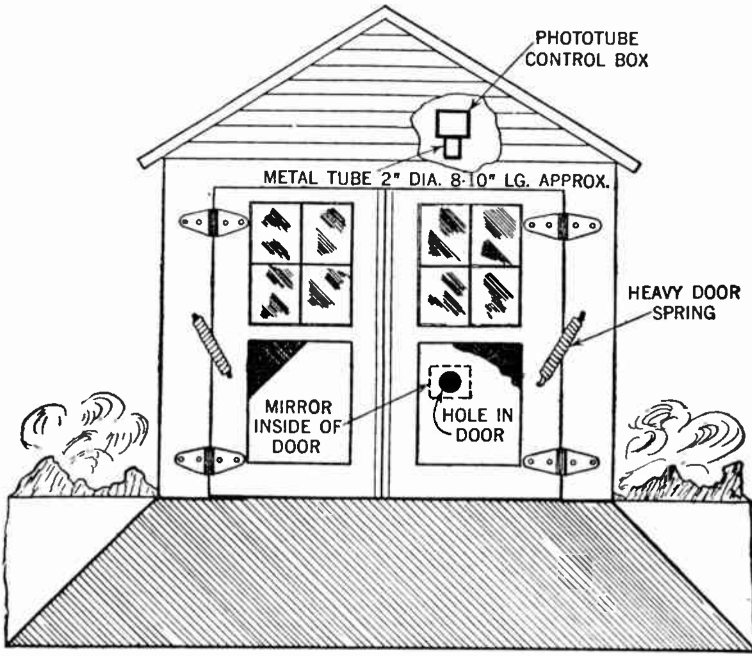


Fig. 32.—Front elevation showing relative approximate location of light admittance opening and relay box.

Automatic Opening of Garage Doors.—A practical, inexpensive and reliable device for automatically opening of garage doors by means of directing the headlight beam on a photo-electric tube is shown in figs. 32, 33 and 34.

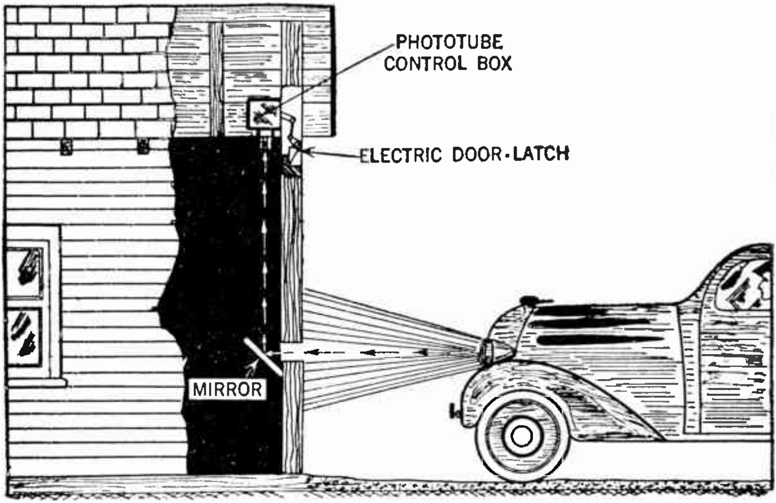


FIG. 33.—View showing arrangement and position of car for automatic opening of garage doors.

Due to the absence of mechanical door actuating or trigger devices the equipment shown is very simple to install and maintain. It consists of two units—an electrically operated door-opener or release associated with the relay cabinet, and a mirror which reflects the light beam to the photo-electric cell.

A circular hole in the door admits the light beam, which is reflected to the light sensitive tube by the mirror which is installed at a 45° angle on the inside of door as depicted.

The door opener (of similar type as is used in apartment house doors) is energized from a bell ringing transformer, which in turn receives current through relay contacts *H*, as shown in diagram fig. 34.

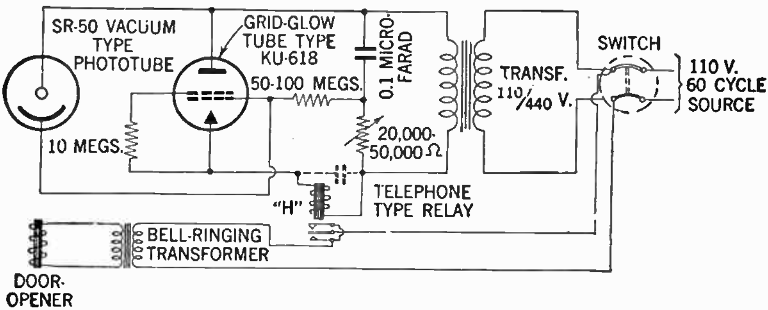


FIG. 34.—Diagram of connections for apparatus suitable to operate garage doors. (Circuit values are approximate only and may be adjusted if required).

When a current impulse is sent through the coil of the door opener it releases the latch, and the doors are opened by action of heavy coil, door springs. The springs should be mounted in such a way so as to exert their full force against the doors, as they are released, and are installed on the outside of doors as shown.

This device is suitable for opening of small and medium sized swing doors only and not for heavy duty doors of roller or folding type. A typical circuit capable of handling currents required for motor operated heavy-duty garage doors, is shown on page 958

When there is no light falling on the photo-electric tube, the grid-glow tube passes no current. As soon as light falls on the phototube a breakdown of ionization of the gas within the grid-glow tube occurs and current passes between the anode and cathode.

Hence this current passes through the relay winding *H* which relay closes its contacts and energizes the bell ringing transformer which operates the coil of the door-opener mechanism.

The relay *H* may be of the D.C. communication or similar type. With some types of relays it may be desirable to shunt the coil winding with a small condenser of 0.1 m.f. or larger to prevent chattering.

The circuit is operated from a regular 60 cycle 110 volt source. The transformer should have a ratio of 110/440 volts, and as the load is very light less than 1 watt, a regular transformer of type used in radio receiving set may be used as long as the voltage ratio is satisfactory.

Electronic Remote Control Device for Radio Receiver.—A radio receiver remote control box by means of which a radio can be controlled from any point in the house, has recently been developed by the R.C.A. engineers.

Referring to figs. 35 and 36 the heart of the device consists of a gas discharge tube which is ionized by radio impulses, being created by the simple process of pushing a button of a small box located at the point where the control is desired. This box contains a miniature radio transmitter, the signal of which is sent over the light circuit wires to the receiver. (I.e. with this type of remote control the radio receiver proper is controlled by means of radio waves, which are set in motion by the pushing of a selected button of the control box.)

How the Control Box Operates.—The control box shown schematically as in fig. 35 contains a number of push buttons and an oscillator. The box is plugged into a convenient wall outlet of the house lighting circuit. When pressing a button of the control box a radio impulse is generated by the oscillator and instantaneously transmitted over the house lighting circuit to the remotely located receiver, which is put into operation.

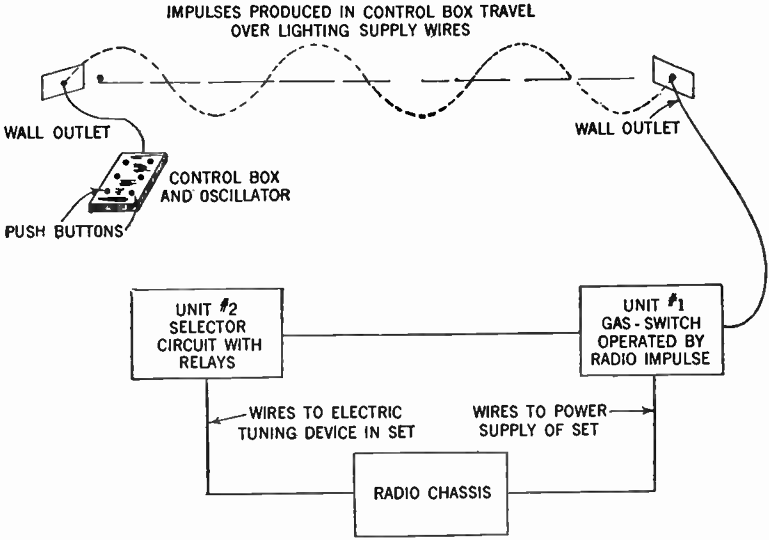


Fig. 35.—Elementary diagram of connection between the principal units used in radio receiver remote control.

If the station so received is not the one desired another button is operated which automatically is atuned to this preferred frequency. If the loud speaker is too high or too low a third button is operated for this adjustment, etc.

The Gas Discharge Tube Is the Heart of the Device.—The fundamental principle of this control scheme is the application of the gas tube switch the circuit of which is shown in fig. 36. This tube designated as the WE-313A is connected on one side with a potentiometer formed by condensers C_2 and C_3.

By varying C_3 the voltage between the electrodes *A* and *B*, can be adjusted to any desired level. The system operates as follows: It is generally well known that any gas filled tube has a specific breakdown value, which is that voltage at which the tube conducts, and starts a current flow between the electrodes of the tube.

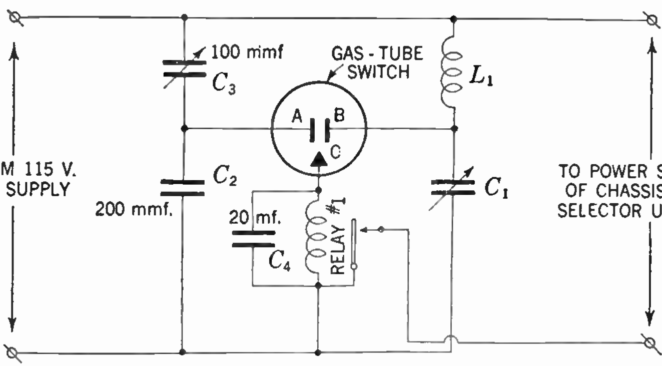


FIG. 36.—Diagram of connection for gas discharge tube, and associated apparatus located in unit No. 1 fig. 35.

The break down value for this particular tube is approximately 70 volts. Now if C_3 be adjusted until only 60 volts exist between points *A* and *B*, no ionization will take place between those points despite the fact that only 10 volts more are required before the tube will start to conduct, and consequently there will be no current flow through the tube.

With this in mind consider condenser C_1 and the inductive coil L_1. This condenser and coil are the units of a timed circuit, in this case a circuit tuned to 300 K.C.

The oscillator contained in the previously described control box shown in fig. 35 radiates a radio impulse of 300 K.C. into the power line. Since now L_1 and C_1 are coupled with this line a radio potential will form across L_1. This additional voltage added to the existing 60 volts already across the gap will start the ionization between electrodes A and B, and a current will flow instantaneously. However, this flow is also taking place across B and C, and when relay No. 1 closes the circuit, the set as well as the selector unit No. 2 are connected with the power line.

Additional tubes and relays installed in the No. 2 selector unit respond to other signals originating in the oscillator and operate a small electric motor of the type already built into modern electric tuned receivers.

It is by these means that a large number of different radio transmitting stations, together with the off and on switch and the volume control, may be operated. Also since the impulses require only the house lighting circuit as a tie-in between the control box and the radio set with its auxiliaries, it is evident that the radio may be controlled from any place in the house where a wall outlet can be found.

Evidently the above described control units may be assembled together with the set proper, and thus simplify the assembly as a whole.

Capacity Operated Relay Circuits.—It is a well known fact that if the grid from any ordinary vacuum tube be entirely disconnected from the outside circuit and the tube be connected as shown in fig. 36, and the base pins be insulated to prevent leakage, the tube will be sensitive to capacity effects, a body, or metal objects placed in proximity of the tube. This phenomenon has been utilized in various ways such as in burglar alarms, show window displays, door openers, counters, signaling systems, etc.

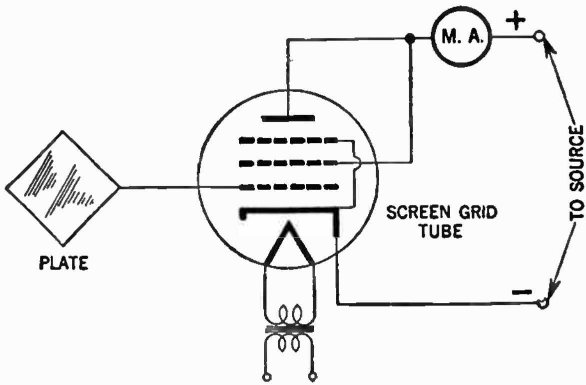


FIG. 36.—Simple circuit for capacity indications.

Self-Balancing Capacity-Operated Relay.—When it is desired to operate a relay only on a change of capacity occurring within a period of several seconds, the antenna to ground capacity may drift considerably over long periods of time, due to temperature and humidity changes. A circuit which will automatically rebalance itself after a short period of time to compensate for the slow variations of the antenna to ground capacity within a certain range is shown in fig. 38.

In this circuit operating on the a.c. line, the sensitive element consists of a pentode oscillator, the feed-back of which is determined by the difference in the ratio between the inductance of the two parts of the oscillator coil L_1 and L_2 and the ratio between C_1 and the antenna-to-ground capacity. Because the cathode of the oscillator is at an *r-f* potential, and because the control grid of the output is by-passed for high frequencies

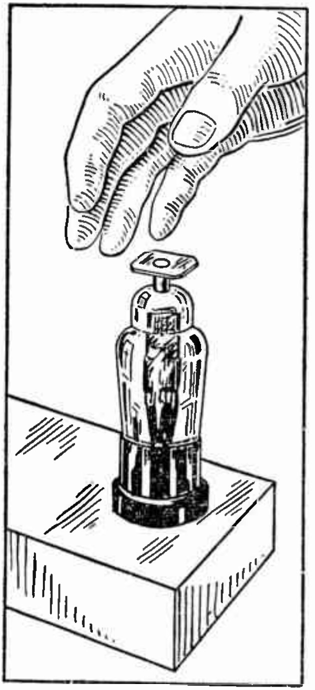


FIG. 37.—If a sensitive current indicator be connected as shown in fig. 36, the meter will show the current change due to the capacity effect, if a hand be placed in proximity to the antenna.

through suitable by-pass condensers to the cathode of the oscillator, a negative d.c. voltage equal to the peak *r-f* voltage on the cathode of the 6*J*7 is built up across the grid-leak and condenser of the 25*L*6 due to the rectifying action of the grid. The 6*J*7 oscillator oscillates at high frequency on one-half of the a.c.

cycle and builds up the above mentioned negative charge on the grid of the output tube.

During this time, the output tube has negative plate and screen voltages and so is non-conducting. On the other half of the a.c. cycle, the 6*J*7 oscillator has negative plate and screen voltages and so ceases oscillating. The negative charge built up on the grid of the output tube does not leak off during this interval and, hence, is effective in controlling the plate current of the output tube during its positive plate-voltage interval.

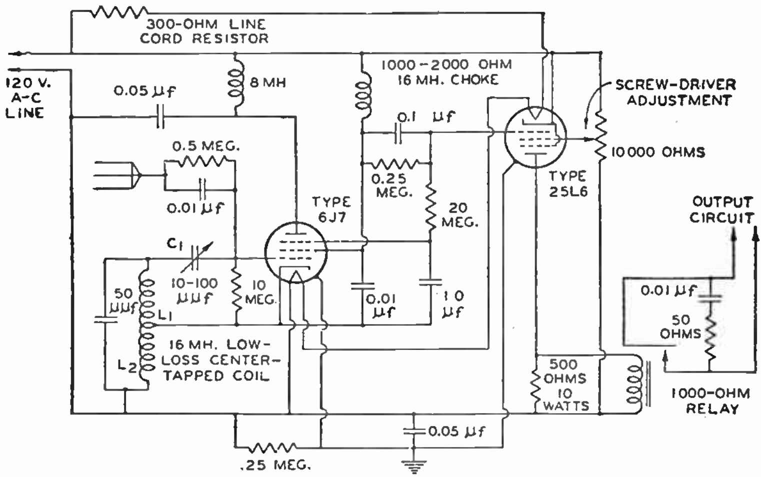


FIG. 38.—Self-balancing capacity-operated relay.

The sensitivity of the unit is an inverse function of the quality of the oscillator coil; that is, the lower the losses in the oscillating circuit, the greater will be the sensitivity. Theoretically, as the oscillator plate impedance approaches infinity and the losses in the antenna and the tuned circuit approach zero, the sensitivity approaches infinity. Sensitivity gained in this manner is much more stable than that gained by regeneration.

The sensitivity of this circuit to small changes in capacity can be increased regeneratively by increasing the resistance of the choke coil feeding the screen of the 6*J*7. When this resistance is more than about 15,000 ohms, the circuit will become unstable, *i.e.*, the relay will relax.

The increase in sensitivity is caused by the fact that as the intensity of oscillation of the 6*J*7 increases, its plate and screen currents decrease. This causes the screen voltage and hence, the mutual conductance of the 6*J*7 to increase; the increase, in turn, helps to increase the intensity of oscillation. Chattering of the relay can be effectively eliminated by the damping resistor placed across the relay coil. If desired, the resistor can be replaced by an electrolytic condenser large enough to keep the relay from chattering. (8 microfarads for most relays.)

The intensity of oscillation is automatically controlled by feeding a negative potential to the No. 3 grid of the 6*J*7. This potential makes the grid negative with respect to the cathode, reduces the mutual conductance of the tube, and reduces the plate impedance of the tube which is effectively shunted across the lower part of the tuned circuit. Both of these actions tend to reduce the amplitude of oscillation for a given feed-back or to make the oscillator require a greater feed-back for a given intensity of oscillation.

As the negative potential applied to the No. 3 grid of the 6*J*7 is derived through a time-delay circuit from the grid of the output tube, this grid, as explained above, assumes a direct potential equal to the peak high-frequency voltage appearing across the lower half of the oscillator coil, L_2. Thus, the intensity of oscillation is maintained substantially constant for wide variations in antenna-to-ground capacity (feed-back).

The above is true for slow capacity variations; however, sudden variations cause the intensity of oscillation to vary rapidly before the corrective voltage can be applied through the condenser-resistor time-delay circuit to the No. 3 grid of the 6J7. Hence, short time capacity variations are effective in operating the relay while long-time variations within limits are automatically compensated for.

The "Petescope"* and Principle of Operation.—In all of the hitherto employed photo cell applications the apparatus have been actuated by either an increase or a decrease in the photo-electric current caused by the actuating light effect. They have, therefore, been responsive to a quantatitive charge.

The magnitude of this change is in general closely related to the ratio between the extent of the controlling light effect and the total light flux received by the photo-electric cell.

Obviously for reliable practical results the percentage change in relay current which is due directly to the actuating effect must be substantially greater than that due to all other possible variables.

In commercial applications, it is apparent, from the above, that unless the actuating effect represent a sizeable fraction of the total light, which in the general cases means, unless the actuating effect occupies a substantial portion of the field of view embraced by the photo cell, the system will require a closely adjusted and sensitive relay and commensurate maintenance.

*The "Petescope." A new principle in photo-electric application, by Alan S. Fitzgerald. *Franklin Inst. Journal*, September, 1936.

The apparatus has been named the "Petescope" in reference to its outstanding quality of actually seeing moving objects. It requires no light source or other external appurtenance, the motion of the object being the primary actuating agent.

It is a feature of a very large majority of photo-electric applications that the object to which they are required to be responsive is, incidentally, a moving object.

In the photo-electric system represented by the "petescope" a degree of sensitivity, far surpassing the hitherto obtained in systems based on purely quantitative action, is achieved by making the system specifically responsive to the motion of the object.

This system is actuated not by the amount of light falling upon the light sensitive element, but instead, in accordance with the first divided function or rate of change in illumination. The apparatus is entirely unresponsive to any steady value of illumination, whether of high or low intensity.

In addition a double optical system is used in conjunction with a pair of photocells connected in a balanced bridge arrangement. As a result of this feature the apparatus can only be actuated by effects tending to unbalance the bridge arrangement, and accordingly the system is entirely unresponsive to fluctuation in the general level of illumination of the field of view.

It responds only to pulsations in the light affecting the two optical systems which have the effect of causing an alternating unbalancing of the bridge. The response is proportional to the rate of change, or the frequency of the unbalancing effect.

The field of view is, therefore, exhibited to the photo-electric elements through special screens or gratings by means of which continuous movement of any object within the field of view causes a fluctuating or alternating component in the photo-electric currents.

Where there are no moving objects no alternating component is present. The movement of the objects creates an alternating component. This represents a qualitative change in conditions which, even though it be of minute amplitude, may be detected with much greater effective sensitivity than merely a quantitative change.

The presence or absence of a characteristic effect can obviously be more readily detected than a difference between the magnitudes of two effects of like nature. Thus a much greater degree of amplification can effectively be employed and exceptional sensitivity to small or distant object is achieved.

Fig. 39 shows the essential elements of the system in a diagrammatical form. A pair of objective lenses L_1 and L_2 embrace an optical field which includes a movable object which is distinguishable by color or shade from its background; such, as for example, an airplane.

Light falling upon the objective lenses is directed through two approximately parallel beams onto the two phototubes P_1 and P_2 shown in the diagram, a pair of condensing lenses C_1 and C_2 serve to concentrate the light onto the photocells. The two objective lenses tend to set up duplicate images of the optical field at their respective focal planes. Approximately at these focal planes are mounted two specially divided screens S_1 and S_2 through which all the lights reaching the photocells have to pass.

The two screens are divided into a number of small portions alternately transparent and opaque. The divisions may be regular or irregular and may be of various shapes or patterns, but both screens are exactly identical in patterns and are of opposite characteristics. That is to say, if any portion of the screen S_1 is opaque the corresponding section of S_2 is transparent; and vice versa.

In other words the two screens have exactly the characteristics of a photographic negative and a transparent positive thereon. The screens may conveniently be found in this manner.

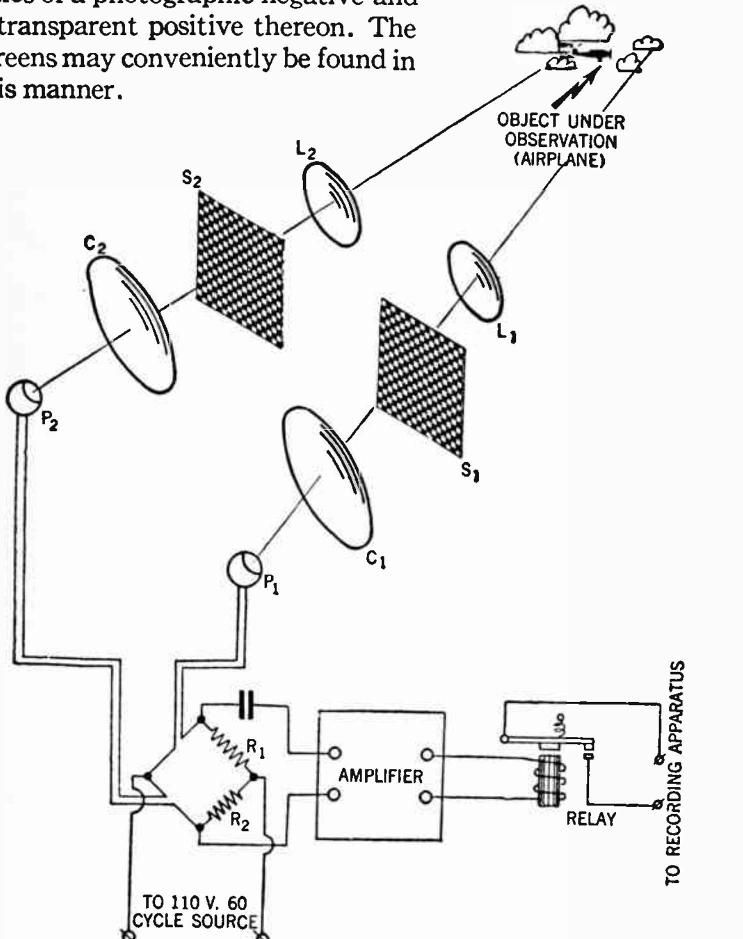


Fig. 39.—The Petescope and arrangement when an object moving both in the horizontal and the vertical plane is under observation.

In fig. 39 these screens are shown divided regularly, according to a checker-board pattern.

The rectangular divisions are identical in shape and dimensions, but it will be seen that each square which is transparent in S_1, is opaque in S_2. Likewise, each square which is opaque in one is transparent in the other.

It will be apparent that, according to this arrangement, duplicate images of the field will be cast on the screens. A ray of light emanating from any given point in the field will be projected to duplicate focal points on the screens.

It is important to note that if the position of the point in the image falls on an opaque section on S_1, the position of the same point on the image formed on S_2 will lay on a transparent section. Thus the ray of light from the said point will pass through the screen S_2 and will impinge on the photo-sensitive element P_2 whereas the duplicate ray falling on S_1 will be stopped thereby and will not reach P_1.

It follows therefore that a ray of light emitted by any given point in the field will be transmitted in duplicate as far as screens S_1 and S_2 but therefore only one of the duplicate beams of light will be further transmitted to the photo-sensitive device, the other one being stopped by the screens.

Thus, light from any given point may reach one or the other of the photo-sensitive elements, but not under any circumstances both of them at the same time. Therefore, if an object in the field be mobile, and if it be of such distance from the lenses and of such dimensions that the image thereof, on screens S_1 and S_2 is of the same order of magnitude as the divisions of the screens, or smaller, the image of the object, as the latter moves across the field, will alternately appear on opaque and on transparent divisions on the screens.

When it appears on a transparent portion of S_1 it will stimulate P_1, but will be on an opaque section of S_2 and will not affect P_2. Likewise, after it has moved a short distance, it will come onto an opaque area on S_1 and into a transparent portion of S_2 when it will affect the photo-sensitive element of P_2 but not P_1.

Thus, movement of the object will give rise to alternating stimulation on the photo cells P_1 and P_2.

The frequency of these alternations will depend on the velocity of the movement, the distance of the object from the lenses, and upon the dimensions of the divisions on the screens S_1 and S_2.

If on the other hand there be no measurement of any kind occurring in the field, no matter what degree of differing color or shade may be distributed, according to any kind of pattern, in the background and other objects comprising the field, the light reaching the photo-sensitive elements P_1 and P_2 respectively will be substantially equivalent and of steady value. Variations in the intensity of the general illumination of the field will cause like variation in the stimulus of P_1 and P_2.

The photocells P_1 and P_2 together with two resistors R_1 and R_2 are therefore connected so as to form a balanced bridge circuit as shown in fig. 39.

The amplifier is connected through a coupling condenser, across normally equi-potential points of the bridge.

Thus, only a difference between the amount of light received by the two photocells P_1 and P_2 will unbalance the bridge, and because of the condenser coupling, only a varying out-of-balance voltage will affect the amplifier.

The amplifier, therefore, will not respond to changes in intensity of daylight because this tends to affect both photocells simultaneously. This feature is of importance because under weather conditions involving cloud effects of the cumulus and similar forms, the passage of cloud patches, of the type which have clearly defined margins, across the place of the sun, may cause the ambient light intensity to undergo a change of several hundred per cent, in a few seconds, representing an appreciable rate of change quite enough to affect, in a substantial degree, a single condenser coupled photocell and sensitive amplifier.

A still more important external condition that must not be overlooked is the possible use of apparatus of this type under artificial illuminations.

The 120 cycle flicker, present in all 60 cycle light sources, while it is not important to the eye, would affect a single condenser connected to the photo-cell and amplifier an extent many times greater than the minimum threeshold value of response possible in modern amplifiers.

Both of the above disturbing elements are obviated by the use of bridge connections.

Special Applications:—In fig. 39, S_1 and S_2 are shown divided in checker-board pattern. This is an appropriate arrangement for applications associated with aircraft or any purpose in which the movement of the object may take place in any direction.

If, however, the application is such that, due to the essential nature of the case the motion of the object take place, entirely, or principally in one plane only, any other component of the motion being of no significance, it is not necessary to utilize screens S_1 and S_2 divided as previously shown. For example in a system primarily intended to be actuated by objects moving across the field of view in a horizontal plane, screens divided vertically only as shown in fig. 40 may be used.

It is obvious that only the horizontal component of the motion in such an application will be of significance.

The effect of the screen of this form will be that the apparatus will be responsive only to the horizontal component of motion since only movement in this direction will set up an alternating component in the photo-electric currents. Similarly the axis of screen divisions may be circulated according to any direction if it is desired to provide a system for responding selectivity to a given directional component of motion.

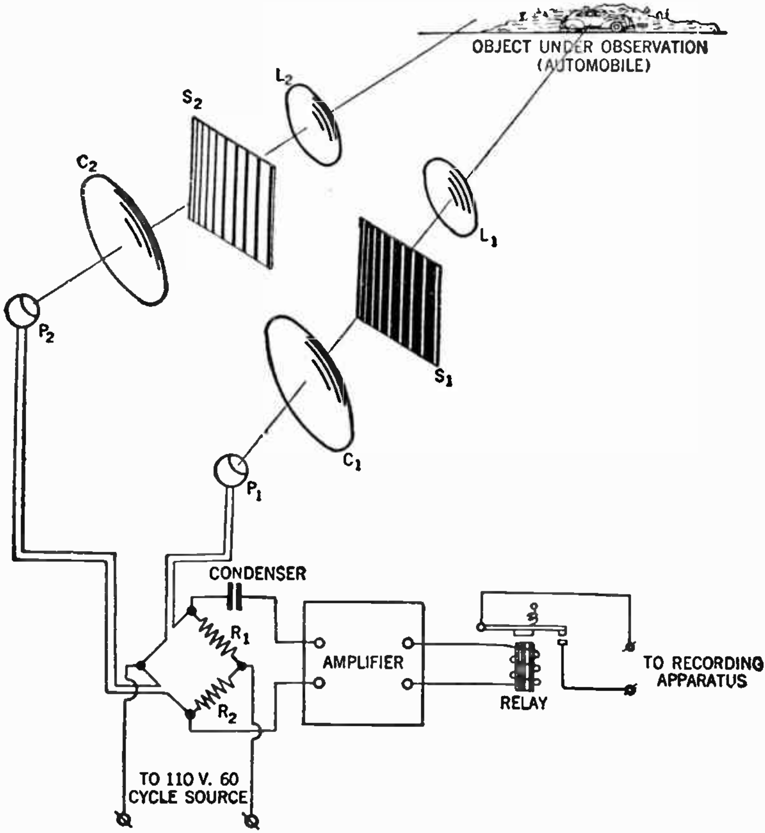


FIG. 40.—The Petescope and arrangement when an object moving in the horizontal plane is under observation.

Where as shown in fig. 40 an automobile is moving along a highway approximately at right angles to the optical axis of the apparatus, the latter being located at a known distance from the highway, the frequency of the signal emitted by the apparatus is a direct function of the speed of the car.

It is possible therefore to check the speed of vehicles on a highway in this manner by means of apparatus mounted on side of the road only, and installed, if desired, at some considerable distance from the highway.

By employing screens as shown in fig. 39 indication of the sense of the motion may be obtained. In fig. 40 the screens have vertical divisions and are thus intended to be actuated by horizontal motion. The vertical divisions are now, however, of uniform width, but are of increasing width from left to right.

Thus if an object traveling at uniform speed moves so that its image traverses the screens from left to right, a signal of decreasing frequency will be obtained. If the object moves in the opposite direction the frequency will increase. Thus, if the signals be transmitted or registered in any suitable manner, an indication or record of the sense of motion of the object may be obtained. For example, if the signal be listened to on a telephone it will have a clearly defined characteristic sound in accordance with the sense of motion. Alternatively the signal may be recorded on an oscillograph or string galvanometer.

As is suggested in fig. 39 *this principle has obvious possibilities in connection with military and naval reconnaissance.*

If the Petescope be properly adjusted and built for maximum sensitivity movements of airplanes can be easily detected at an altitude of 2,000 feet and under favorable weather conditions at altitudes up to 3,000 feet or more.

Miscellaneous Phototube Circuits.—The several circuits shown illustrate additional methods of using phototubes. In most cases operating voltages and circuit values are given.

It will, however, often be found that these do not represent the ideal condition for a particular purpose, and therefore the values which produce the best result should be used. In several of the circuits the phototube controls the grid bias of a vacuum amplifier tube, while in other circuits the phototube controls the grid bias of a thyratron.

This latter circuits are particularly useful in that they operate entirely from alternating current and the control current may be relatively large.

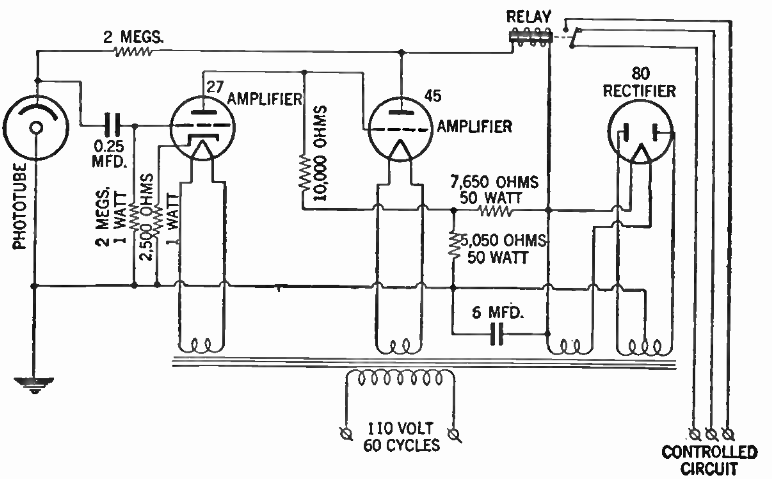


FIG. 41.—Amplifier circuit suitable for control of small motors.

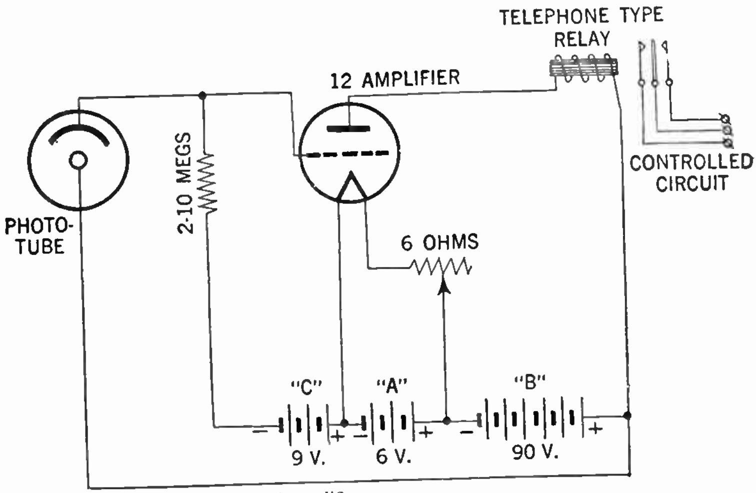
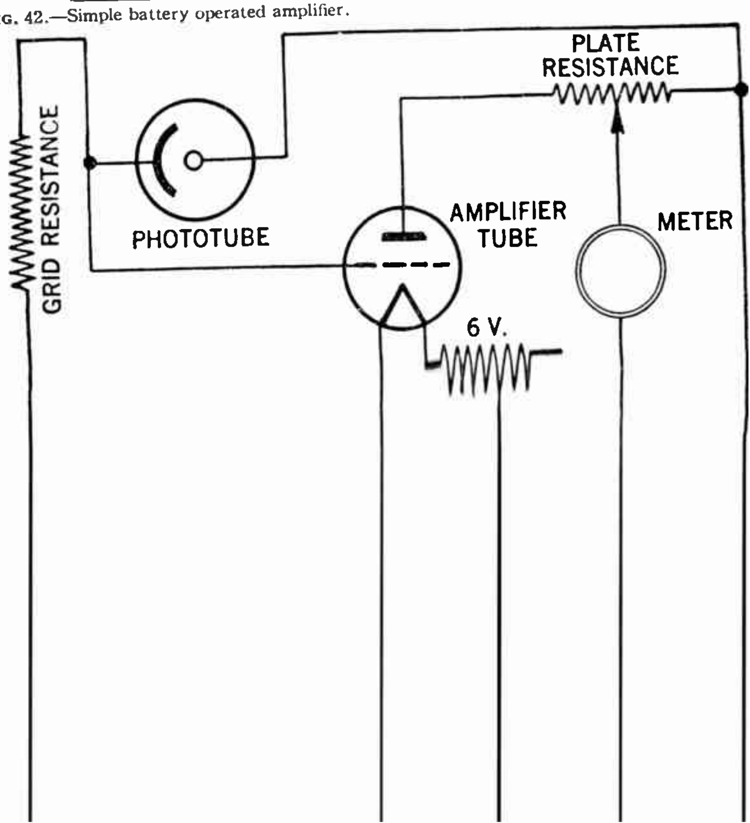


FIG. 42.—Simple battery operated amplifier.



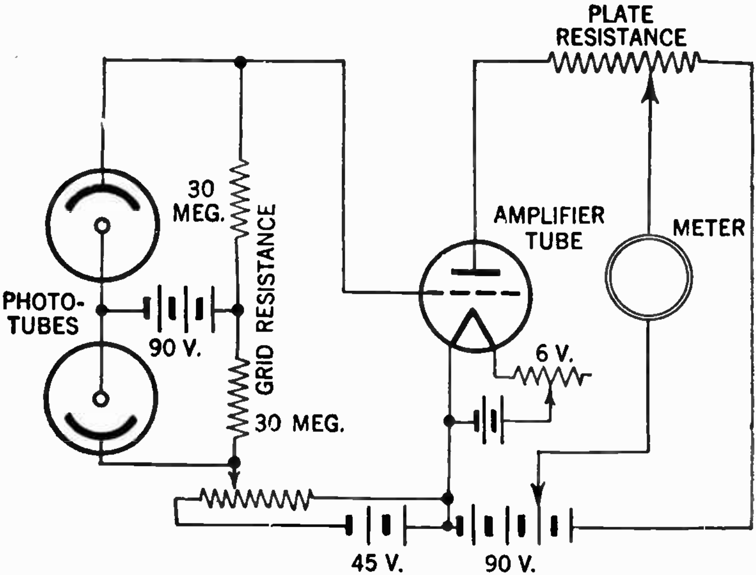


FIG. 44.—Differential D. C. circuit with neutralized anode current.

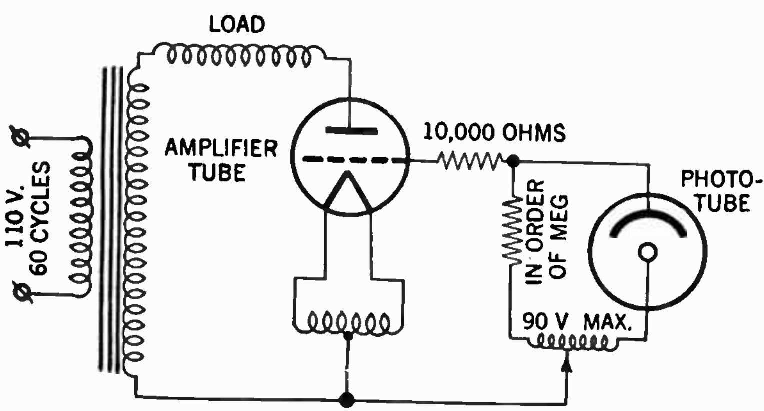
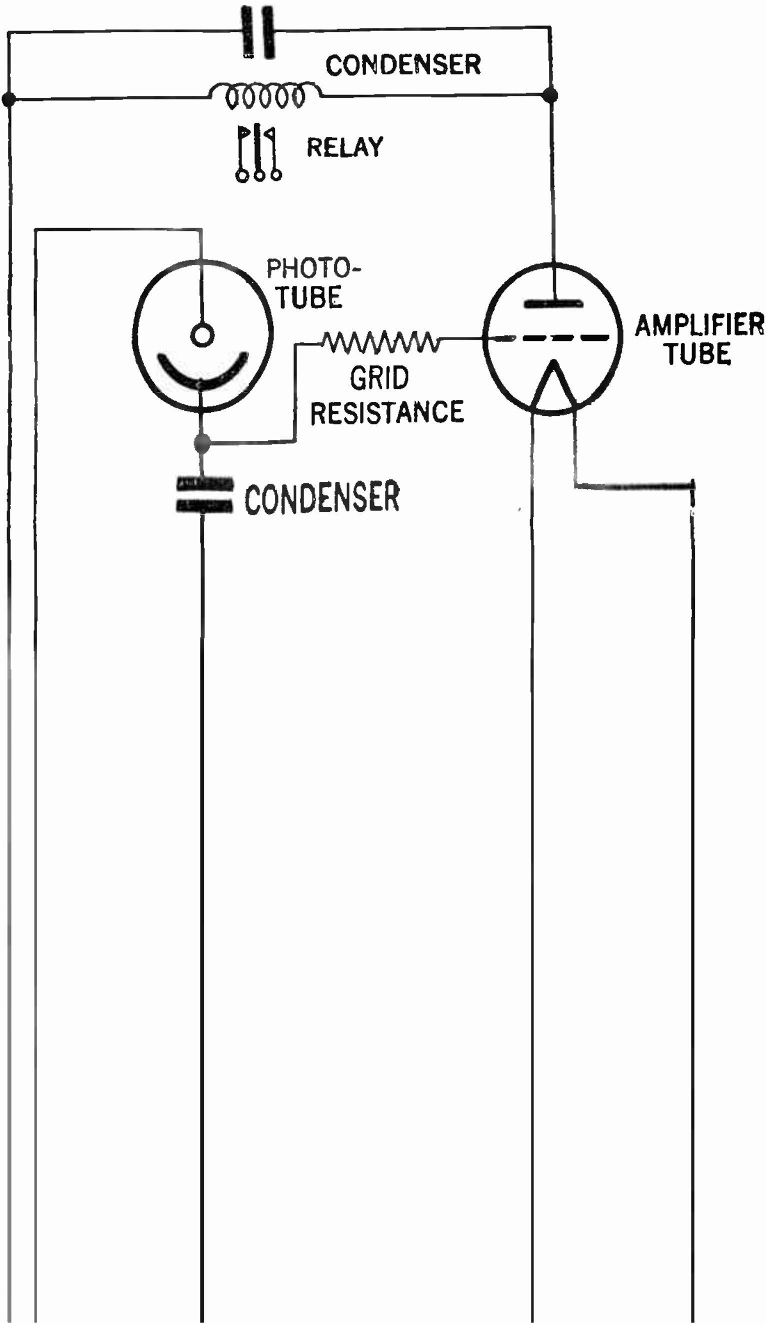
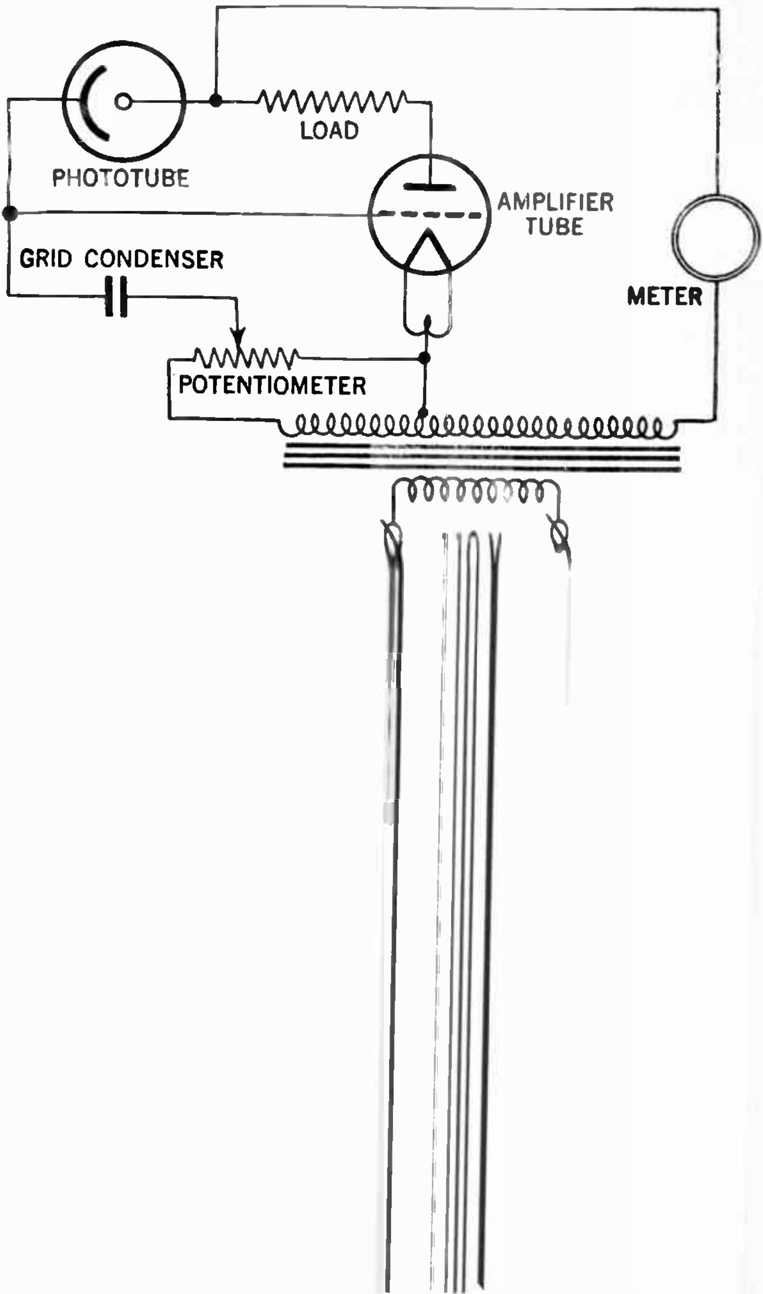


FIG. 45.—Negative control Grid-Glow relay circuit for A. C. operation.


CONDENSER
RELAY
PHOTO-
TUBE
GRID
RESISTANCE
AMPLIFIER
TUBE
CONDENSER


PHOTOTUBE
LOAD
AMPLIFIER TUBE
METER
GRID CONDENSER
POTENTIOMETER

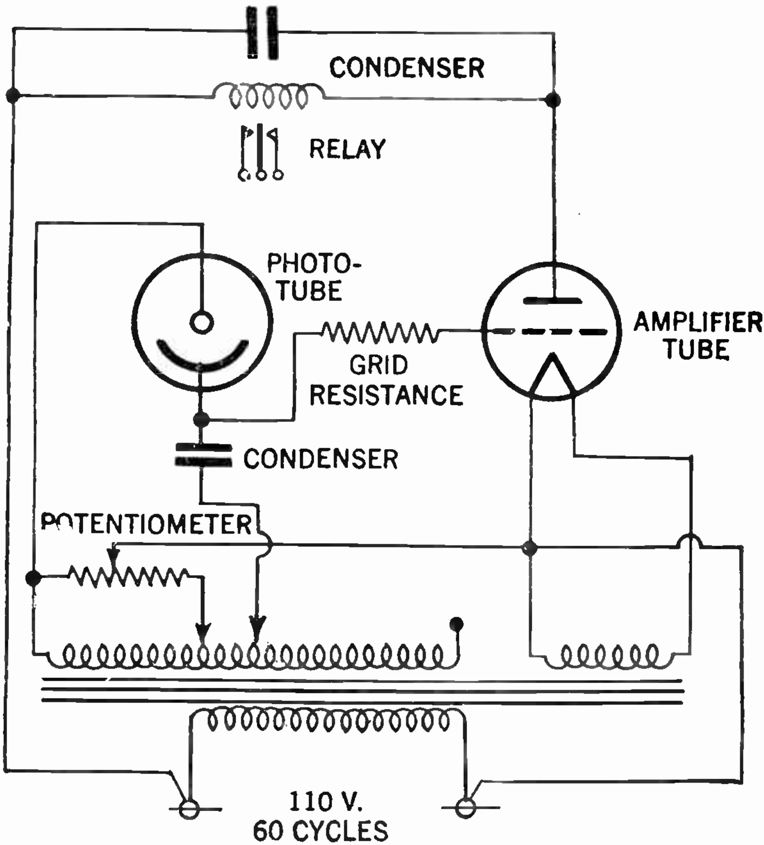


FIG. 48.—Simple amplifier for straight A. C. operation.

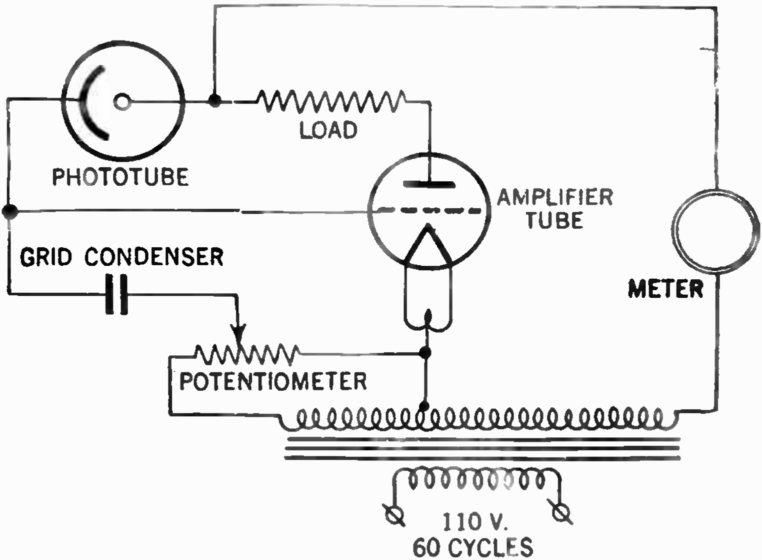


FIG. 46.—Simple amplifier for straight A. C. operation.

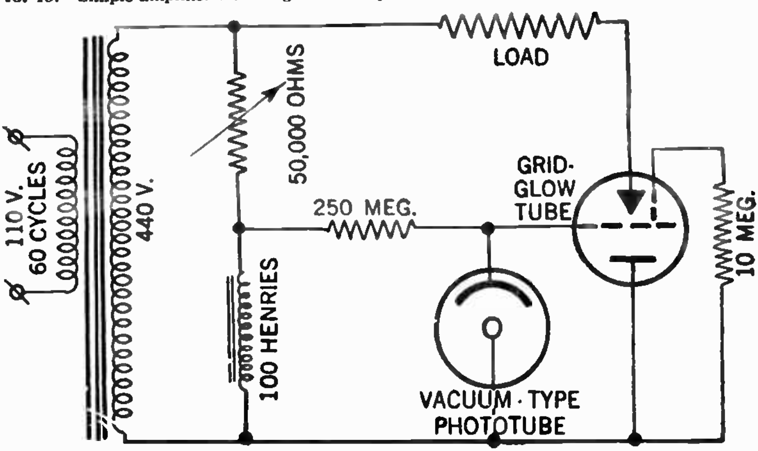


FIG. 47.—Grid-Glow relay circuit A. C. operation.

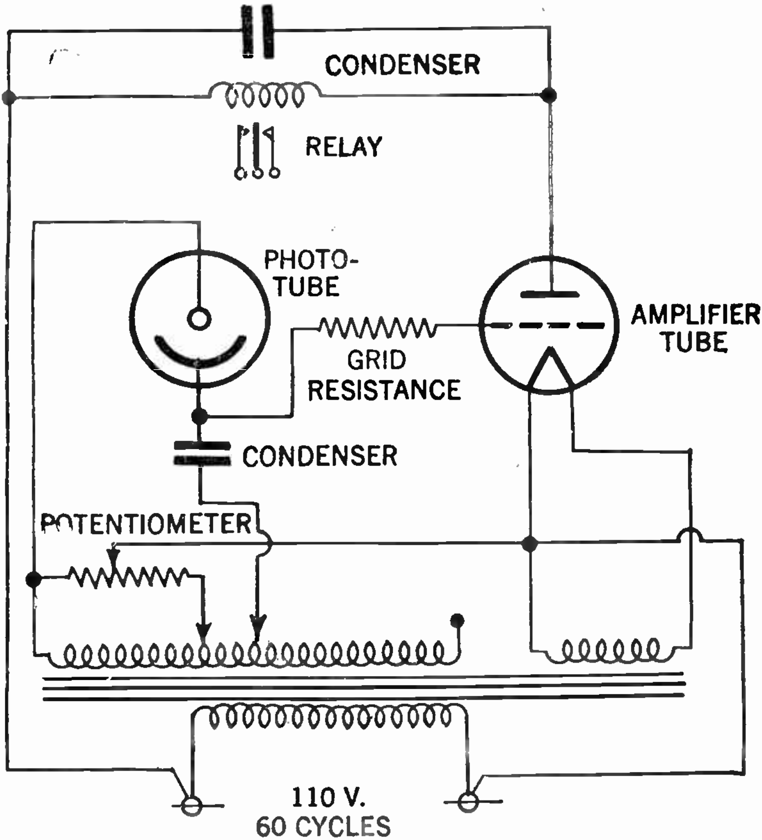


FIG. 48.—Simple amplifier for straight A. C. operation.

Maintenance and Operation Considerations of Electronic Apparatus.—*Installation.*—While generally electronic tubes are manufactured uniformly rugged in mechanical respects, to withstand a moderate amount of vibration, care should be taken to protect them from unnecessary vibration. However, in some cases a certain amount of vibrations cannot be avoided and in such cases it is recommended that the tubes be properly cushioned.

Generally electronic tubes will perform properly in any mounting position although it is recommended that they be installed in a vertical position with the base of the tubes either up or down. In the case of the phototube it is of course imperative that the cathode emitting surface face the light source upon which the function of the tube is dependent.

Usually tubes designed for industrial applications are equipped with rugged bases, made of a high quality moulded insulating material with a high resistance which remains practically constant for temperature changes of up to 70 degrees centigrade, and humidity up to 90 per cent.

Electrical Effects.—It is important to minimize the detrimental shunt effect of leakage between electrode connections and capacitance between the leads. Hence the importance of high quality sockets, and properly insulated leads and particularly so the lead which connects the anode or positive voltage supply.

The leads from the phototube to the amplifier should always be as short as possible to minimize capacity loss and pick-up from stray fields, and since the tubes are high resistance devices, it is extremely important that the insulation of associated circuit parts be as high as possible.

Care should be taken to avoid any extraneous or undesired light from reaching the phototube otherwise erratic results may occur. For both steady and pulsating light the sensitivity of the gas filled type of phototubes within their normal operating range is practically independent of the amount of light. Their sensitivity, however, is effected by the frequency of light modulation.

This is characteristic of gaseous phototubes and is due to the relatively large mass of the positive ions and their correspondingly sluggish motion.

Because there is a time lag between the disruption of a gas atom and the increase in current due to the resultant positive ion, fluctuation in the gas component of current, lag slightly behind fluctuation in the primary photo-emission component.

For high frequence of modulation, this lag tends to smooth out the pulsations in the phototube current, thus decreasing the alternating component of the current and, to some extent, the sensitivity.

For low frequencies, however, the effect is not important and the low-frequency sensitivity is practically equal to the static sensitivity.

Temperature Effects.—Most electronic tubes are designed to withstand nominal temperature changes, although the upper temperature limit for proper operation is usually 50 degrees centigrade. This refers to the ambient air temperature or the temperature of the air coming in contact with the tubes. For example, operation of a phototube consistently at too high a temperature may cause a change in the sensitivity of the light sensitive surface due to evaporation of the volatile materials within the tube, causing a consequent decrease in its semsitivity as well as its life.

Generally higher temperatures will slightly decrease the sensitivity of a phototube.

CHAPTER 44

Radar Fundamentals

General.—By definition the word Radar means radio detecting and ranging, the letters having been taken from the beginning of each word. More precisely radar may be defined as the process of locating the position of an object in space by radio waves.

This relatively new system of radio communication is brought about by the application of the laws of physics, radio principles and optics in harnessing electromagnetic waves for detection and location of an object, fixed or moving, by the aid of the difference in electrical properties from those of the medium adjacent to or surrounding it.

Although radar principles has been known for a great many years, the actual construction of workable radar came about in the early part of World War II as a means of detection and location of enemy aircraft.

Radar Applications.—Radars peace time application will undoubtedly be in the field of ship and aircraft navigation. Ships at sea will be able to proceed at full speed regardless of weather, unimpeded by the threat of obstructions, while fog will no longer delay their entrance to harbors.

Aircraft will for the first time have a means of precise navigation independent of atmospheric conditions—particularly desirable for trans-oceanic flights. At the same time the hazards for landing in overcast weather will be practically eliminated by radar blind-landing systems, and the utilization of radar in meteorology will vastly increase our knowledge of weather.

These applications of radar are obvious and real, but they give little indication of the full impact of the art. Indirectly the knowledge and techniques gained in the ultra-high frequencies will expand and accelerate developments in the whole field of electronics.

Radar Development.—As previously noted, radar was born of war need, and no one man can be given credit as its inventor; it was made workable rather by a number of the world's most outstanding electronic scientists working with unlimited resources—monetary and technical.

Thus it was possible for a group or groups of highly trained scientists to develop, coordinate and finally simplify this highly complicated mechanism in a relatively short time, due to the pressure of war.

In this connection it should be noted that in the early thirties, several scientists were experimenting simultaneously along the road of radio wave echo reflection.

Thus, for example, it is alleged that Sir Robert Watson-Watt of England around 1933, made experiments on position of atmospheric disturbances by means of radio wave deflection. It is further alleged that when during an experiment an aircraft flew overhead Watt found an echo reflected from it, and so the principle of detection and ranging was noted.

Speed of Sound.—In order to obtain a clear conception of the principles upon which radar works, it will be helpful to study the well known wave action of sound.

Sound waves travel through the air at approximately 1,100 feet per second. Thus it takes the sound waves 5,280/1,100 or 4.8 seconds to travel a distance of one mile. It is for this reason that an appreciable amount of time elapses between the sight of a distant lightning flash and the accompanying thunder, although they occurred simultaneously.

Similarly the report of a gun is heard some time after the actual flash of the weapon, the elapsed time depending upon the distance involved.

Another illustration of the fact that time is required for sound to travel from one place to another may be observed when a steam whistle blows at a distance of several hundred yards. If

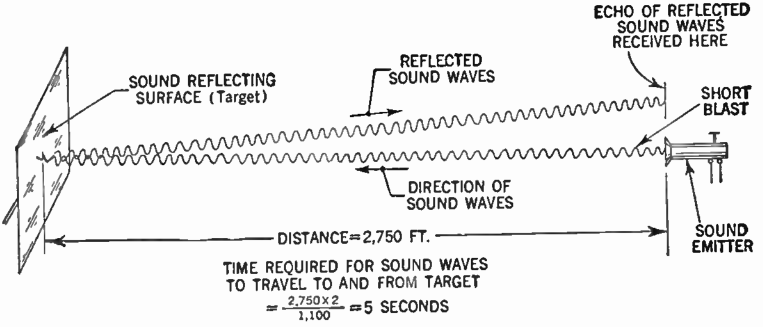


FIG. 1—Diagrammatical representation of distance determination by means of sound echo timing.

it is observed when blown, it will be noticed that the steam can be seen coming from the whistle a considerable length of time before the sound of the whistle is heard.

Sound Wave Reflection.—It is a well known fact that sound waves may be reflected back to their original source. The reflection of sound waves is called an *echo*, an example of which may be had when shouting or emitting sound towards a cliff or other sound reflecting surface.

One of the simplest kind of blind navigation systems has long been used by pilots of boats operating in the rivers and harbors, where obstacles are detected by the simple expedient of emitting a series of short whistle blasts and then listening for the direction and time interval of echoes.

In this connection it should be observed that whenever an echo or sound wave reflection is involved the sound waves must travel both forth and back to its source, thus for example if a certain sound wave be reflected back in say 2.4 seconds, the reflecting obstacle is located *not* one half of a mile distant, but only one quarter of a mile, since the sound waves have to travel the same distance twice.

Radar Waves.—Radio detecting and ranging is made possible by the simple expedient of transmitting radio frequency energy in pulses of high intensity and then to measure the round-trip travel time of the reflected energy with sufficient accuracy to establish the range to the obstacle.

Radio waves travel with the speed of light or 186,000 miles a second; 186 miles per millisecond or 0.186 miles per microsecond. This speed will be equivalent to 982 feet or 327 yards per microsecond.

If it be desired, for example, to find the time interval it takes for a radio wave to be reflected back from a target located one mile distant, it may easily be calculated as follows:

From the foregoing it follows that a radio wave takes 1/186,000 or 0.000005375 second to travel one mile, that is 5.375 microseconds. Inasmuch as all radar considerations are based on the round-trip travel time of the reflected energy, we

654,000 yards to reach the target and return. At 327 yards for every microsecond, it would take the beam 2,000 microseconds or one five-hundredth of a second for the round trip. Therefore, in this particular case the time between the outgoing signals must be no less than five-hundredth of a second; otherwise, the weak returning signal might be lost in the strong transmitting beam.

As an example of the extreme distance of radar, may be mentioned the recently successful experiment in reaching the moon, where the distance involved was approximately 240,000 miles.

Power Used.—The outgoing signal consists of a tremendous burst of energy, very often more powerful than the maximum output of the nation's largest radio station. This is necessary because the beam, as soon as it leaves the antenna, is dispersed through hundreds of square miles of space in search of a target.

Only a very small portion of the spreading rays strike the target, and of these a still smaller portion rebound to the receiver. On the return journey also the beam fragment is still further dispersed throughout space, so that by the time the beam reaches the receiver it is literally a mere shadow of its former self.

If, for example, 100,000 watts of short wave energy were projected by a certain directive radar antenna at a target 1,000 feet away, the effective power in the region of the target might be only 0.8 of a watt per square foot.

This tiny fraction of power is still further weakened on its return journey. Assuming that 50 square feet of the target is struck by the beam and reflects it back to the receiver, then the amount of power making the homeward trip is 50 times 0.8 or 40 watts. This fragment is in turn "dispersed" through the

1,000 feet of space, so that by the time it reaches the receiving antenna its power density has been reduced to 1/150,000 of a watt per square foot.

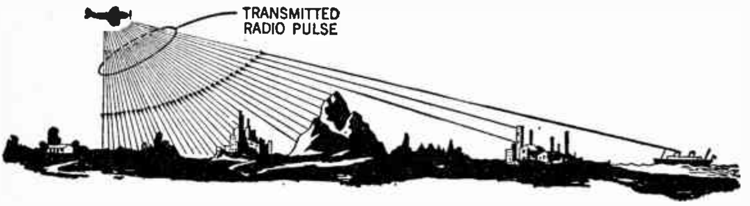


FIG. 3—Illustration showing how radio energy may be radiated from a radar set borne by aircraft. If the radio beam be directed towards the ground at a forward angle, the reflection will be a function of the aspect of the target. The energy which strikes the smooth surface of the water is reflected away from the source and leaves a dark region on the indicator tube. A shore line, buildings and normal incidence on the terrain directly below the aircraft will each provide a strong target echo. A radar beam of uniform intensity directed from the aircraft results in ground illumination and echo response as shown in figs. 3 and 4, respectively. These figures also illustrate how it is possible to correlate a radar picture with a relief map of the area.

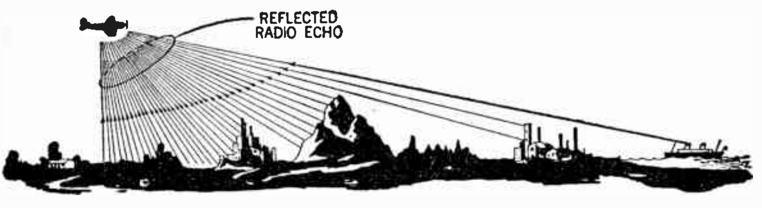


FIG. 4—An exaggerated view showing how the radio energy emitted from a radar antenna is reflected from the target. In reality only a tiny fraction of the radiated energy is reflected back to the receiver in form of an echo.

If the antenna is three square feet in area, then the total power entering the receiver would be three times 1/150,000 of a watt, or 1/50,000 of a watt. In short, the returning signal is one five-billionth of the orignal burst of energy. Yet sensitive receivers pick it up, electronic amplifiers increase its volume and its message is easily read by the radar operator.

Radar Principles.—In most radar sets the principles of operation are briefly as follows: The output of the magnetron is delivered to the antenna through the "transmit-receive" (T.R.) tube whose function it is to protect the receiver during transmitter pulses and to close off the path to the magnetron during the receiving time, between pulses.

The returning echo from the "target" is collected by the parabolic reflector, focused on the antenna dipole, and carried through the T.R. tube to the receiver circuits. In the crystal mixer, the returning signal is caused to beat with the output of a klystron local oscillator, the resultant frequency being about 30 MC. This is amplified by a wide band I.F. amplifier, detected and further amplified by the video amplifier, thence applied to the control grid of the cathode ray tube.

In the meantime, the antenna assembly has been rotating continuously and its motion has been transmitted by a very compact and simple Selsyn system to the rotating magnetic deflection coil located around the neck of the cathode ray tube. Impressed across this rotating coil is the sawtooth sweep voltage which provides a linear, radial time axis. Time too, is synchronized with the transmitter, and as both the outgoing pulse and the returning echo travel at the speed of light, this time axis is really a distance measure.

The overall result is that as the radial time (i.e., distance) axis rotates, any returning echo will intensify a portion of this axis as the rotating antenna "beams" on the target. With an ordinary cathode ray screen, the bright flashes of light would indicate the presence of reflecting objects, but the operator would have to remember where the flashes occurred, obviously an undesirable disadvantage.

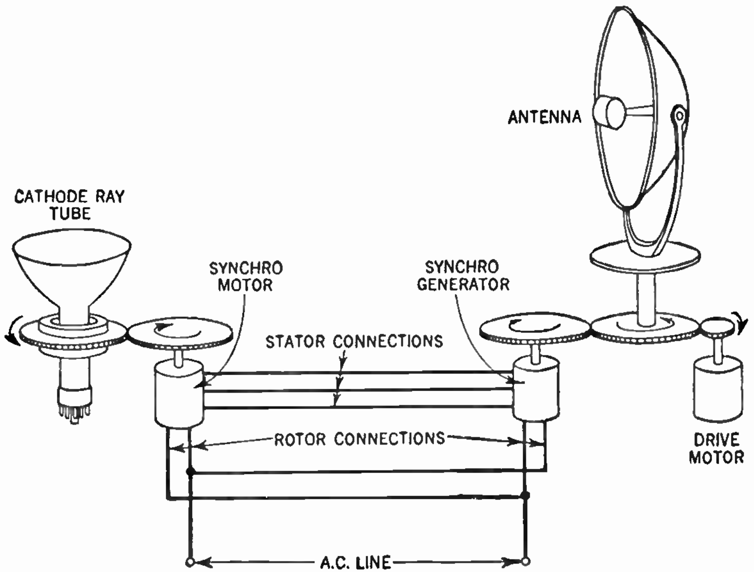
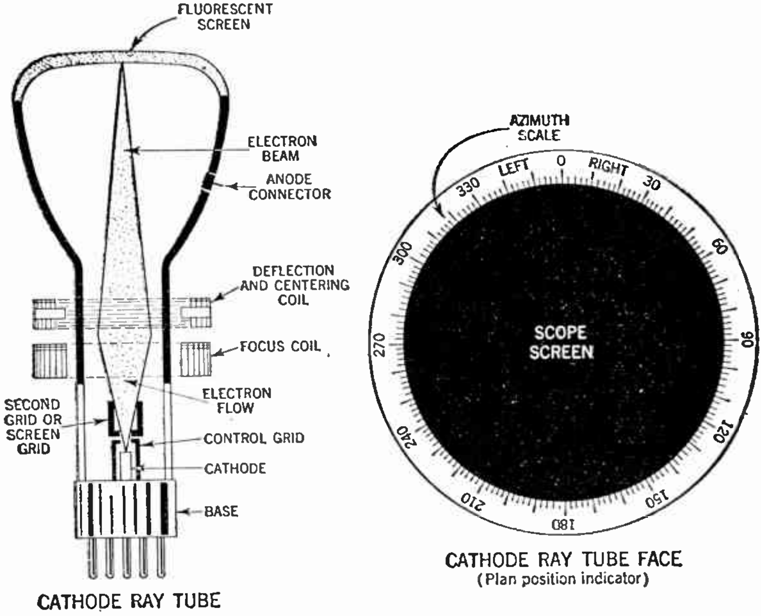


Fig. 5—Illustrating elementary principles of synchro system for turning cathode ray tube deflection coil in accordance with the rotation of the radar antenna. It is in this manner that the deflection coil geared to the motor is made to follow the motion of the antenna. A system of this type depends for its functioning upon the ability of A.C. generators and motors of identical construction to operate in synchronism, that is, the angular motion of each rotor of the interconnected system will always remain the same. In the system shown, corresponding stator and rotor terminals of generator and motor are connected together, and the rotor windings are connected to the A.C. line, causing the motor and generator to rotate in the same direction.

Hence, a long persistence screen is used in which the cathode ray first excites a short persistence phosphor, which in turn causes a second, long persistence phosphor to glow. This glow persists for a long enough time to "remember" a scene until rekindled by the next rotation of the radial sweep.

Since the resultant illumination is in the form of a plan view of the surrounding area, with the transmitter at the center, the



FIGS. 6 and 7.—Showing essential elements in a typical magnetic type cathode ray tube. The deflection coil is rotated in synchronism with the antenna by means of a synchro system such as that shown in fig. 5.

system is commonly termed "Plan Presentation Indicator" or simply "P.P.I.".

For comparison, the actual chart of the area to be scanned is printed beside the radar chart.

ESSENTIAL PARTS OF A RADAR SYSTEM

Practically every radar set is made up of the following parts or components:

1. Transmitter.
2. A radio frequency oscillator.
3. An antenna with suitable scanning mechanism.
4. A receiver.
5. An indicator.

While the physical form of each of these components may vary widely from one kind of radar set to another, each radar must have this complement in order to function.

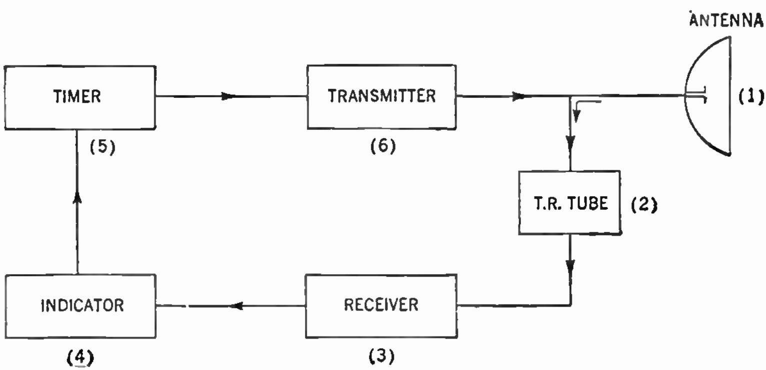


Fig. 8.—Block diagram showing a simple radar set. The function of the various components shown are as follows: (1) The antenna radiates strong bursts of radio energy into space and picks up reflected echo signals. (2) The T.R. (transmitting and receiving) tube automatically disconnects the receiver when the transmitter is operating. (3) The receiver amplifies minute echo signals sufficiently to actuate indicator. (4) The indicator transforms the echo signals in a form best adapted for efficient use of the set, by means of visual display on the cathode ray tube face. (5) The timer is the source of start and stop control pulses for transmitter and indicator. (6) The transmitter is the source of pulses of ultra-high radio energy which are fed to the antenna.

The Transmitter.—The transmitter is the source of pulses of ultra-high frequency radio energy which is fed to the antenna. The two principal elements of the transmitting system are the radio frequency oscillator and the source of high voltage pulses, variously called *modulator*, *keyer* or *pulser*.

This modulator or keyer is a device for taking power from the primary power source (which may be the commercial power line, a special engine or motor-driven generator or storage batteries) and forming suitable voltage pulses to drive the radio frequency oscillator in its burst of radio frequency oscillations.

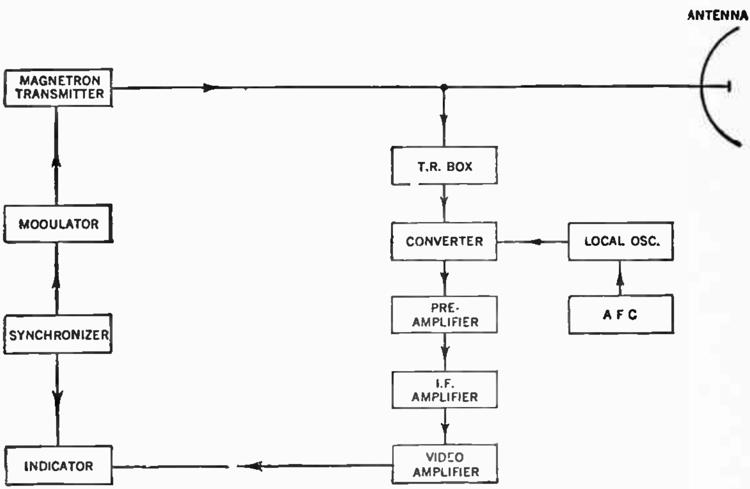


FIG. 9.—Block diagram showing essential circuit components of typical radar set.

These pulses of very high voltage are of the square-topped type of the order of a microsecond in length and spaced of the order of a millisecond apart. These specific values, however, may vary over a considerable range according to the specific purpose of the radar set.

There are generally two basic methods used to form the microsecond pulses:

(1) By means of short-circuiting or open circuiting a charged artificial transmission line, often called a charged pulse network, and

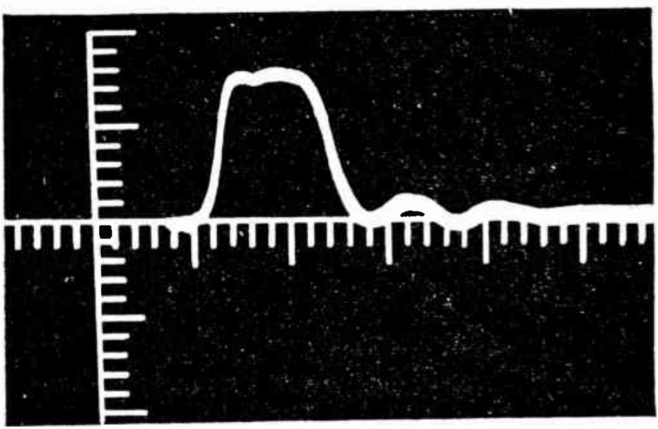
(2) By means of creating large voltage surges by driving a magnetic circuit into the region of saturation.

In the case of the first method, the switches used to open or short circuit the charged pulse network have been:

(a) High voltage vacuum tubes.

(b) A spark-gap discharge either of the open air or enclosed type, and

(c) The hydrogen filled thyratron.



$\frac{3}{8}$ μs, 800 PPS
MAG. CURRENT = 4.5 Ma (Average)
MAG. CURRENT = 14 AMPS (Peak)
RISE TIME = 0.03 μs
PULSE WIDTH = 0.42 μs
SCALE = 0.07 μs/div.

FIG. 10—Magnetron input current delivered by a hard tube modulator.

All of these systems were applied extensively in radar operaing systems, although recent designs favor the use of the thyratron.

During the brief interval of the pulse, powers ranging up to the order of a megawatt may be delivered by the pulser. Since the particular combination of current and voltage put out by the pulser may not be that required by the oscillator it is common to interpose a pulse transformer, the function of which is to step the voltage up or down to the desired level.

In some radar systems, a transmission line is required between the pulser and its associated transmitter, in which case pulse transformers may be required at each end of the line. A typical oscillogram of the magnetron input current as a function of time, delivered by a hard tube modulator used extensively in airborne systems, is shown in fig. 10.

Various forms of more or less conventional triodes found application as transmitting oscillators in the earlier longer wave radars. In this class of tube, time of flight of electron from cathode to plate must be short compared with the signal period, an increasingly serious limitation as the art moved into the microwave range. Velocity modulation tubes avoid this limitation in a sense by making use of the electron stream in flight. A particular form of velocity modulation tube, the cavity magnetron, fig. 11, has virtually monopolized the transmitting oscillator role in the more modern systems. In fact, its adaptation to very high power, very short pulse operation and its very high frequency stability make it ideally suited to this purpose.

In earlier forms, the magnetron was a fixed frequency device but more recently, external means of tuning over a moderate range have been devised and applied in practical design. While the frequency of the cavity magnetron is largely controlled by its built-in cavity construction it is, of course, necessary to couple the oscillations in the internal cavities with the output

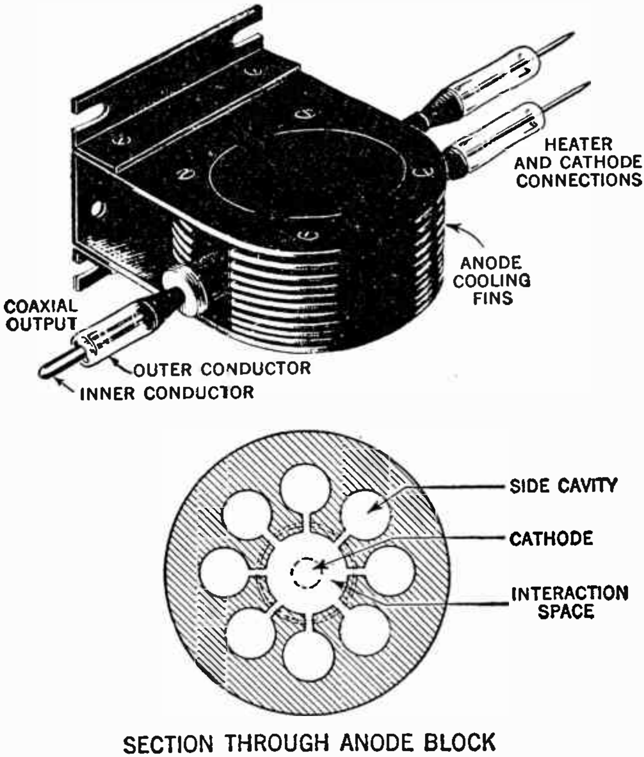
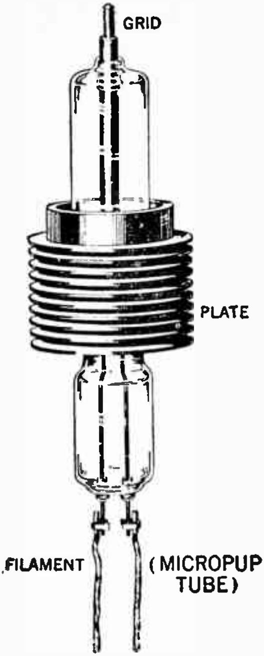
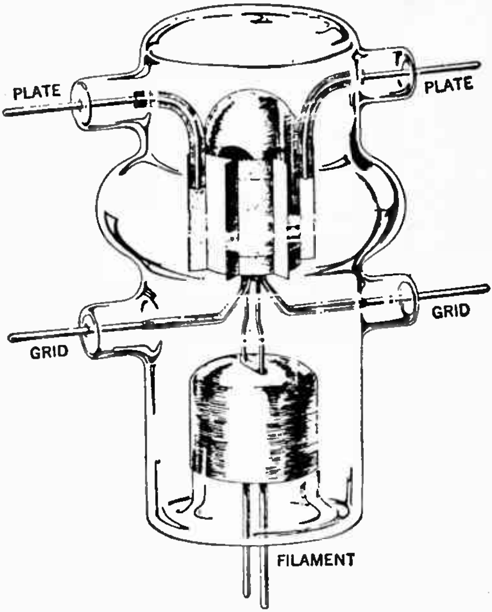
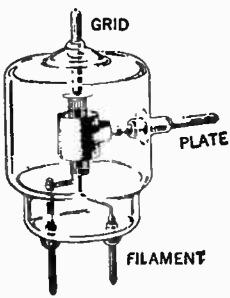


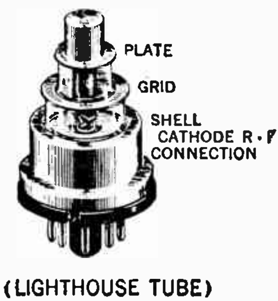
Fig. 11.—External view of typical 10 c.m. cavity magnetron and cross-section through anode block.

line and the reaction on the magnetron of this coupling imposes a complex problem of system design.









Figs. 12 to 15.—Showing typical radar triode transmitting tubes.

As the antenna scans, the impedance facing the magnetron varies due to varying reflections from discontinuities such as rotary joints in the output line to the antenna. These effective impedance changes, reflected back into the magnetron through its output coupling, tend to modulate or pull the frequency of the magnetron. Maximum power output calls for tight coupling between the magnetron and its antenna system but such tight coupling in turn accentuates this pulling effect. In addition, there is a "long line" effect which causes an impedance irregularity to be more serious the longer the transmission path between it and the magnetron.

Practical system design makes it necessary to take all of these factors into account and to tailor the characteristics of the magnetron to the degree of smoothness and excellence it is practicable to achieve in the radio frequency transmission system.

Function of the T.R. Tube.—To enable the same antenna to serve for both transmitting and receiving a T.R. (transmitting and receiving) tube or switch is used. Since the outgoing radar pulses occupies a very small fraction of time, characteristically about one-tenth of one per cent, a switch which would associate the transmitter with the antenna during this brief interval and then disconnect the transmitter and connect the receiver during this relatively long silent interval, was called for. If it be observed that the total cycle was only of the order of a millisecond, it is obvious that a very fast switch was required.

In practical design a gas filled T.R. tube such as shown in fig. 16, is almost universally used for this purpose. This consists generally of a partially evacuated resonant cavity containing a spark gap which breaks down during the transmitting pulse, thus preventing the transmitted power from injuring the sensitive receiver. The tube, however, recovers rapidly enough to admit echoes from nearby targets, thus achieving the desired minimum range for the system.

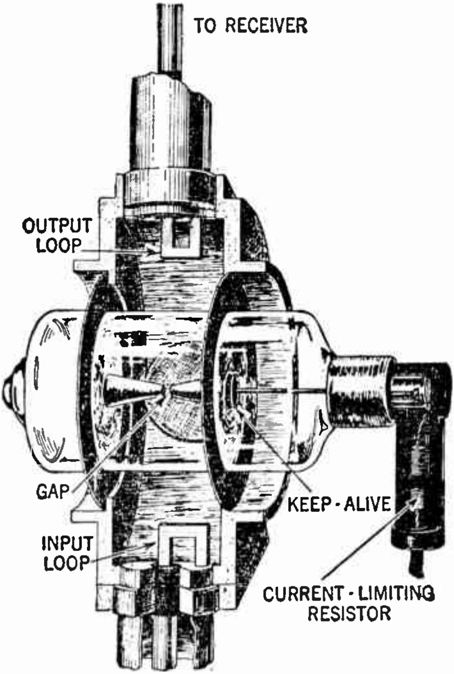


FIG. 16.—View of typical T.R. tube and cavity assembly. A device of this general appearance is typical of those used in the medium power 10 c.m. radar systems employing coaxial lines.

After amplification and detection of the received signal, the resultant video pulses are applied to an indicator which may present information in any of several different ways. Customarily the direction of the target (determined by antenna orientation) and its range (determined by reflection interval, 10.7 microseconds per mile) are shown.

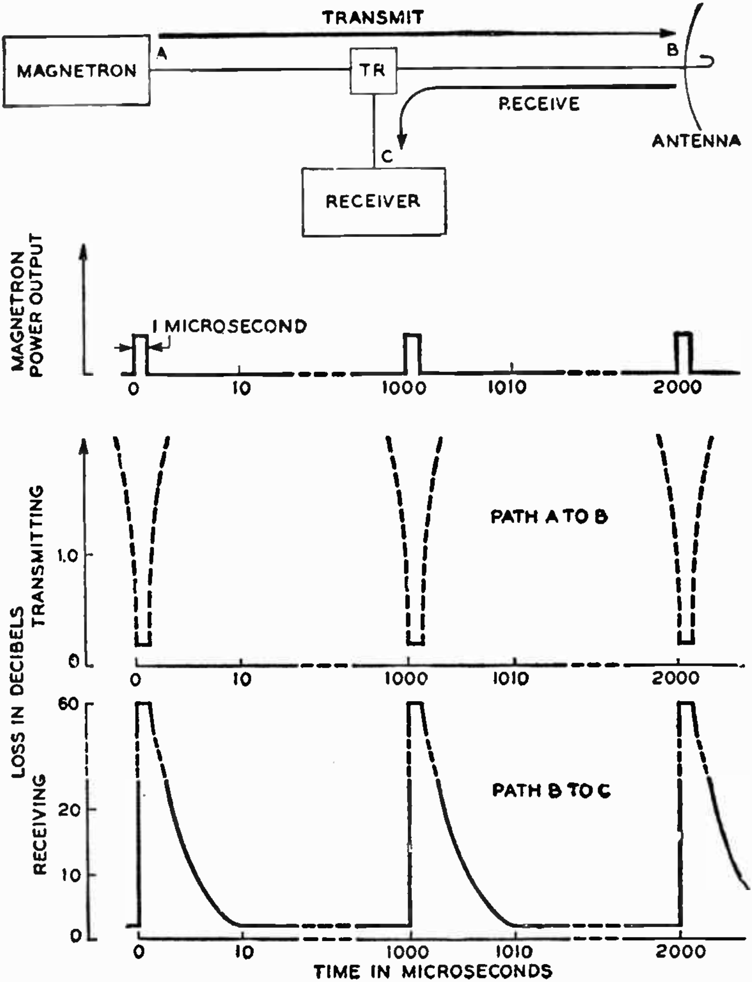


Fig. 17.—Showing transmission characteristics of T.R. tube assembly.

Fig. 17 shows the transmission characteristics of a typical T.R. tube assembly as measured in the transmitting and receiving paths over one complete cycle.

The Radio Frequency Oscillator.—The radio frequency oscillator is a vacuum tube of suitable design or a group of such tubes, which will oscillate at the desired radio frequency and give the desired bursts of radio frequency power when connected to the modulator. The development of suitable oscillator tubes has been one of the major achievements of the radar art. It is a relatively simple job to produce a radio frequency oscillator which will give oscillations of any desired frequency, provided one is satisfied with the power of only a few thousandths of a watt.

In the receiving part of a radar circuit this amount of power is adequate. A practical radar transmitter, however, must generate during its momentary burst of oscillations a power which may run into hundreds of kilowatts. Since the oscillator is turned on a small fraction of the time, the average power is usually hundreds of times less than the peak power, but even the average power may run up to the order of one kilowatt. Thus, practical radar equipment requires extremely high frequency oscillators running at powers thousands of time greater than was thought possible a few years ago.

The Antenna.—The problem of antenna design is also one of the major problems in radar, incomprehensible as this may seem to the operator of a home radio receiver, who finds a few yards of wire strung up on his roof adequate for this purpose. A suitable radar antenna must have the following characteristics:

(a) It must be directional, that is, it must concentrate the radio energy into a definitely defined beam, since this is the method by which the direction to the objects detected is determined.

(b) It must be highly efficient. All of the generated power must go into the beam and none must leak off into "side lobes" in other directions, since such side lobes may often be fatally confusing, and

(c) The radar antenna must be capable of being directed or scanned from one point into space to another, and on shipboard and in aircraft it must frequently be stabilized to take out the motions of the ship or airplane itself.

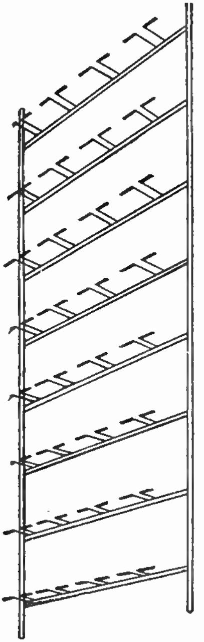
An antenna must be made directional either by building it up of an array of small antennas or dipoles, suitably spaced and phased to concentrate the energy in one direction, or it may be built on the searchlight principle of spraying the energy into a large parabolic "mirror" which focuses the energy into a beam. In either case, the larger the antenna, the sharper the beam for any given wavelength. Sometimes antennas may be longer in one direction than the other, giving a beam which is sharper in the first direction and thus fanshaped.

The scanning of the portion of space which the radar set is intended to cover must usually be performed by the mechanical movement of the antenna itself. This means that the structure, whatever its size, must swing around or up and down to direct the beam in the necessary direction. In certain cases where one needs to scan only a small sector, techniques have been worked out for rapid electrical scanning not requiring the motions of the whole antenna structure itself. So far, however, there has been no method for extending this rapid electrical scanning to cover more than a relatively small sector. Radars for directing guns which employ accurate and fast data in a small sector are making use, however, of this technique.

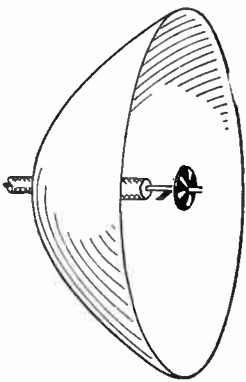
To carry the radio frequency energy from the oscillator to the antenna, and the echo from the antenna to the receiver, wires and co-axial cables are used for ordinary wave lengths. For microwaves however, it is more efficient to use wave guides, which essentially are carefully proportioned hollow pipes—and the transmission system hence is often called "plumbing."

Various Antenna Types.—The radar antenna takes various forms, depending upon the purpose for which the set is designed. Well known forms of directional antennas are:

1. The dipole type, and
2. The parabolic reflector type.



DIPOLE ANTENNA



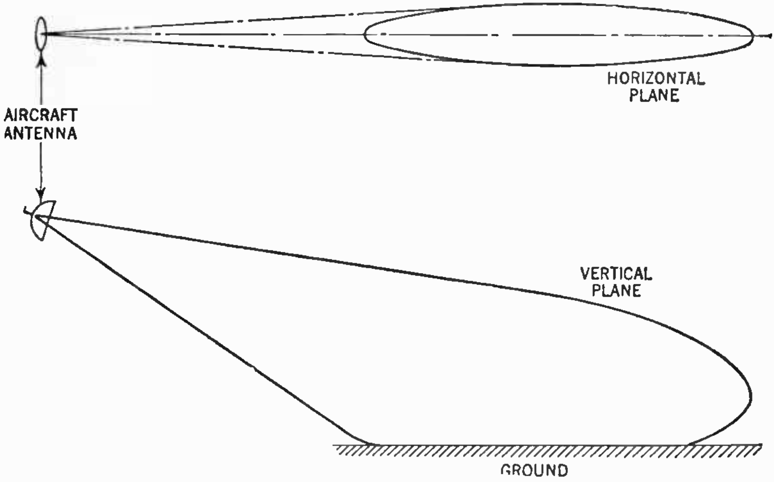
PARABOLIC ANTENNA

FIGS. 18 and 19.—Showing various forms of directional antenna used in radar sets. Fig. 18 shows the arrangement of a typical dipole array. Radar antennas of this type are built both for mobile use and for fixed-station installation, and has a reliable range of approximately 100 miles. Fig. 19 shows the form of the popular parabolic type.

The dipole form consists of a large number of stacked dipoles, having critical spacings with a reflecting screen, resembling a giant bed-spring.

This form of antenna is usually mounted on rotating platform either stationary or on top of a truck.

The parabolic type of radar antenna is of simple design and resembles a searchlight in that it consists of a suitable shaped



FIGS. 20 and 21.—Showing conventional antenna patterns for navigational radar. Note that the beam is narrow in the horizontal plane in order to obtain azimuth accuracy, while in the vertical plane the beam is broadened to sweep a large arc with a corresponding loss in elevation accuracy.

reflector illuminated by one or more sources of electromagnetic energy.

If the reflector be a paraboloid of revolution with the source at its focus, the radiation is of the single lobe or beam variety in which the angular width of the beam is inversely proportional to the diameter of the reflector and directly proportional to the wavelength of the radiation.

While such a beam antenna has been extensively used, many of the more recent radar systems have demanded more specialized radiation patterns. For example, in airborne search and bombing radars, a fanshaped beam has come to be considered optimum. At any one position, such an antenna illuminates a narrow wedge of the terrain below extending ideally from the point of the terrain vertically beneath the plane out radially to the maximum effective range of the system. The design objective here is to produce as narrow a beam as possible with a vertical pattern such that substantially equal signals are received at all ground ranges. This requires that the effective voltage be approximately proportional to the square of the cosecant of the vertical angle measured downward from the horizon.

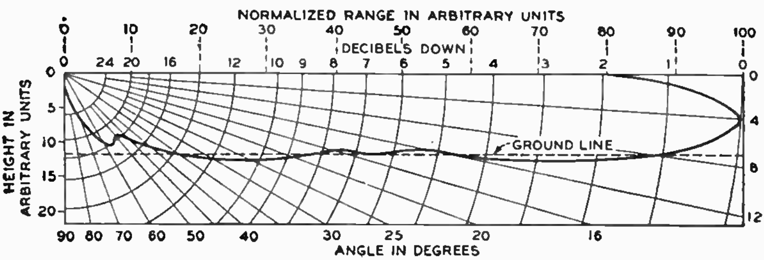


FIG. 22.—Showing vertical antenna pattern used in an airborne radar system.

A more recent study of this problem has indicated that some modification of this cosecant squared formula may be advisable. In any event, the fair approximations to the ideal that it has been possible to achieve in actual design give satisfactorily uniform ground illumination.

Other variations on antenna pattern include beams very much sharper in azimuth than in elevation for airplane search purposes and the reverse for height-finding purposes. One of the latest refinements here is illustrated by a typical vertical antenna pattern of a recent land-based air search antenna, as shown in fig. 23. In this case, in order to get high angle coverage, something approaching the cosecant squared pattern is achieved, the vertical angle being measured upward rather than downward from the horizon.

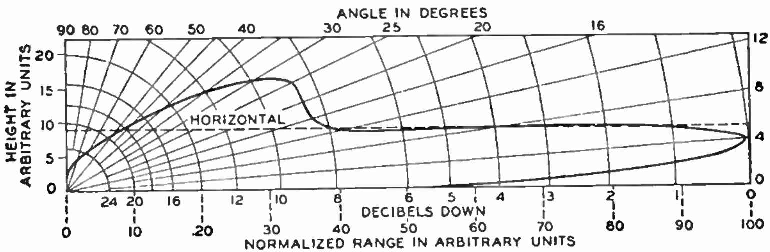


FIG. 23.—Showing vertical antenna pattern in a free space land-based search radar system.

In general, land and ship-mounted radars used to search the horizon for either ships or planes must take account of the fact that the intervening land or water surfaces reflect that part of the radiation directed below the horizon. Combination of the direct and the reflected waves produces a characteristic interference pattern in the vertical plane, greatly extending the range of the radar at certain elevation angles and correspondingly reducing it at intermediate angles. A typical vertical performance or coverage chart of a light early-warning system is shown in fig. 24. In this case, the beam in free space is fan-shaped with a horizontal width of about 3.5°. The horizontal pattern is not greatly affected by the surface reflection while the vertical pattern shows the very sharp lobes resulting from direct and reflected wave interference.

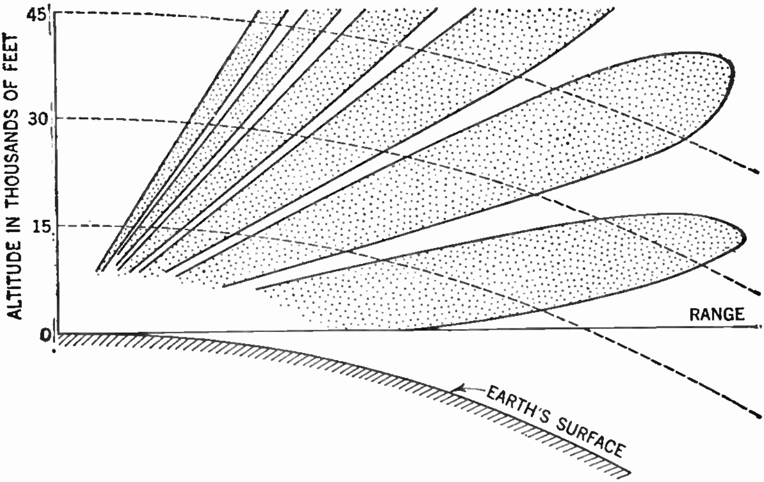


FIG. 24.—Vertical coverage chart of a land-based radar system at a low site overlooking water.

The Receiver.—The problem of the receiver for radar is also a complex one. In practically all radars the superheterodyne principle is employed which involves generating at low power a radio frequency fairly close to that received, and "beating" this against the received signals, forming an intermediate frequency which is then amplified many times.

Curiously enough the crystal used as a detector and mixer has again come into its own in microwave receivers.

The peculiar characteristics of pulse signals require that receivers be built with extremely fast response, much faster even than that required in television.

The final stages must prepare the signals for suitable presentation in the indicator. The receiver normally occupies a relatively small box in the complete radar set, and yet this box represents a marvel of engineering ingenuity.

A particularly difficult piece of development is concerned with a part closely connected to the receiver. This is a method of disconnecting the receiver from the antenna during intervals when the transmitter is operating so that the receiver will not be paralyzed or burned out by the stupendous burst of radio frequency energy generated by the transmitter. Within a microsecond after the transmitter has completed its pulse, however, the receiver must be open to receive the relatively weak echo signals; but now the transmitter part of the circuit must be closed off so it will not absorb any of this energy.

The most significant elements of the radar receiver in order in the circuit are:

(a) The beating oscillator.
(b) The first detector (converter).
(c) The intermediate frequency amplifier.
(d) The second detector.
(e) The video amplifier.
(f) The display system.

While each one of the foregoing elements has its own design problems, there are certain broad systems considerations.

For the early long wavelength radars, beating oscillators were of the more or less conventional triode construction and, in fact, one very special triode, the so called lighthouse tube, fig. 15, has been used as a beating oscillator up into the microwave range.

As in the case of transmitting oscillators, velocity modulation has been the key to the design of most of the receiving or beating oscillators used in microwave systems and for the most part, these have been of the single cavity built-in type.

The earlier forms had fixed or manually tuned cavities and beyond this, were tunable within a fairly narrow range by adjustment of the voltage of the repeller electrode. Not only was this voltage adjustment used for narrow range manual tuning of the receiver to its transmitter output, but automatic frequency control circuits employing an intermediate frequency discriminator circuit were devised which regulated the repeller voltage at the proper value for reception of echoes of the transmitted pulse.

These automatic frequency control circuits were not without their difficulties but various improvements were introduced so that those embodied in most recent systems are quite stable and satisfactory.

More recently, however, thermal means of controlling oscillator cavity size has been devised, the heating effect being regulated by a control voltage. Where thermal control of this type is available automatic frequency control may be built around it rather than resorting to repeller voltage control as in earlier systems.

First Detector (Converter).—In any radar system the selection of frequency is based among other things on the noise figure available in the receiver. The input circuit of the receiver is the low signal level point of the system and the problem here has been to achieve the greatest possible freedom from noise. The longer wave radar receivers employ a combination of vacuum tube pre-amplifier and detector to achieve the best noise figure.

In general, however, crystal detectors of the fixed cat's whisker-on-silicon type have been almost universally used at wavelengths of about 30 centimeters and less. Fig. 25 shows a comparison between the noise values of the lighthouse tube as an amplifier or detector, and the crystal type detector. A great amount of development work has been done on these crystals with the result that a uniform product has been achieved within a few db. of the theoretical resistance noise limit. While the crystal is not strictly frequency sensitive, optimum design calls for different crystal units for the different frequency bands. Means must be provided in the system to protect the crystal from high voltage overload which would destroy its sensitivity.

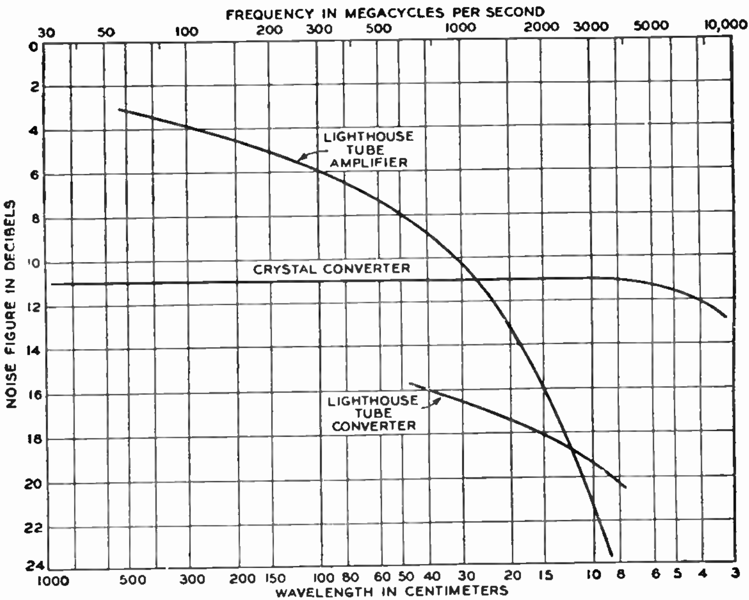


FIG. 25.—Showing effect of wavelength on radar receiver noise.

Intermediate Frequency Amplification.—Choice of intermediate frequency rests on a number of factors including signal-to-noise ratio, band width and others. About 90 db. of IF gain s required with a band width of from one to ten or more megacycles. Since resistance noise (power) is proportional to band width, the early tendency was to make IF amplifiers as narrow as possible consistent with the pulse length to be accommodated.

In more recent systems, there has been a trend toward wider band receivers as a means of sharpening up the picture. While, for example, a one megacycle IF system followed up by a one-half megacycle video system would be expected to give about optium signal-to-noise ratio for a radar employing a pulse of about one microsecond, it has been found in certain types of display that considerable advantage can be had by widening the band by a factor of as much as five. In such cases, the increased noise is more than offset by the greater sharpness of the signal and by the finer grain structure of the noise.

Actually, most of the IF amplifiers have been designed around a frequency of either 30 or 60 megacycles but it would go beyond the scope of the present chapter to discuss the relative uses and advantages of these two intermediate frequencies.

Great progress has been made in achieving very low noise amplification and in producing the desired gain and gain frequency characteristic with a minimum of tubes and other components.

Second Detector.—It is the purpose of the second detector to produce a rectified voltage that is proportional to the amplitude of the IF waves. It is important that this rectified voltage be proportional to the first power of the IF amplitude. One of the simplest types of detector used in radar receivers is the diode type connected in series with a load impedance consisting of resistance and capacitance in parallel.

The diode may be the 6H6 or 6AL5 although many other types have been employed.

Video Amplifier.—Following the detector one or more stages of video amplification is employed. The form of the video amplifier depends largely upon the number and location of the indicator tubes. In aircraft radar there may be only a single indicator, in which case the video amplifier will be very simple.

In ground and marine radar, on the other hand, there are usually several indicators remotely located, hence the video amplifier will be more complex. In this case, the video amplifier drives a terminated line at a level of a few volts and individual indicators are driven by video amplifiers bridged across this line.

The simplest and most common form of video amplifiers are the resistance capacitance, coupled type.

The Cathode Ray Tube.—The cathode ray tube is a vacuum tube with a rounded flat surface called *screen*. It is made of glass and may be anywhere from 14 to 24 inches in length, with a screen diameter of from 3 to 20 inches. The inner surface of the screen portion of the tube is painted with a fluorescent material.

When energized a current of electrons flows from the negative terminal of the tube past a grid in a straight beam toward the fluorescent screen. When the beam strikes the screen, it excites the fluorescent material producing a spot of light. This spot of light can be put to work in various ways. In several different kinds of radar oscilloscopes the spot can be made to travel back and forth a thousand times a second across the screen by means of a switching device governed by the master timer of the radar set.

The result to the eye is a glowing beam called a *time base* or *sweep*, lying across the center of the screen. This sweep is synchronized with the radar antenna as it scans. Any time pulse echo returning from a target is fed as a positive charge nto the grid between the negative terminal and the screen of :he tube. When this occurs, more electrons flow, causing a V-shaped break (called "pip") along the sweep. The position of the pip along the sweep is a measure of distance from the target.

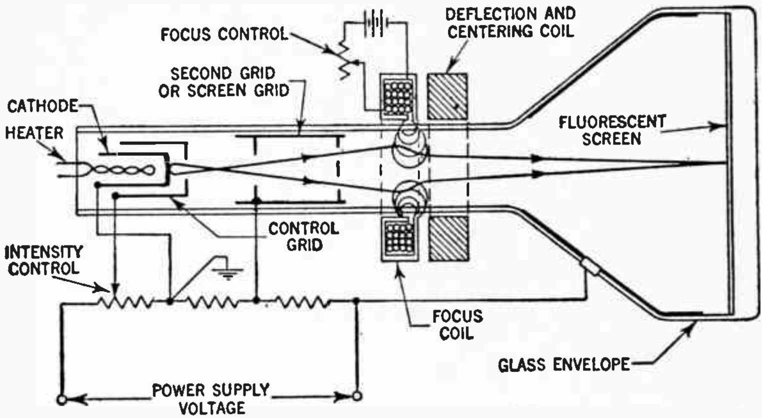


Fig. 26.—Schematic illustration showing arrangement of a magnetic type cathode ray tube. When a cathode ray tube of this type is employed in a radar set it is customary to mount the deflection coil in such a manner that the rotation of the antenna by means of gearings and a synchro system is transferred to the deflection coil. In some radar sets using synchro systems, the synchros are geared to rotate ten times as fast as the antenna system and rotating coil.

Another type of oscilloscope is called the P.P.I. (Plan position indicator). In this type the sweep may be made to travel in a radial streak from the center of the screen to its edge by switching on and off an electromagnet at the rim of the scope. By rotating a magnet around the edge of the tube in exact time with the rotations of the radar antenna. say at 15 times a minute, for example, the sweep can be made to follow the magnet around the screen like the hand of a clock.

In this case, an echo that has returned to the antenna and has been applied as a positive electrical charge to the cathode-ray grid, causes a very bright point of light along the sweep. After the sweep has moved on, the persistence of the fluorescence leaves on the screen a map-like outline of the area scanned by the radar beam.

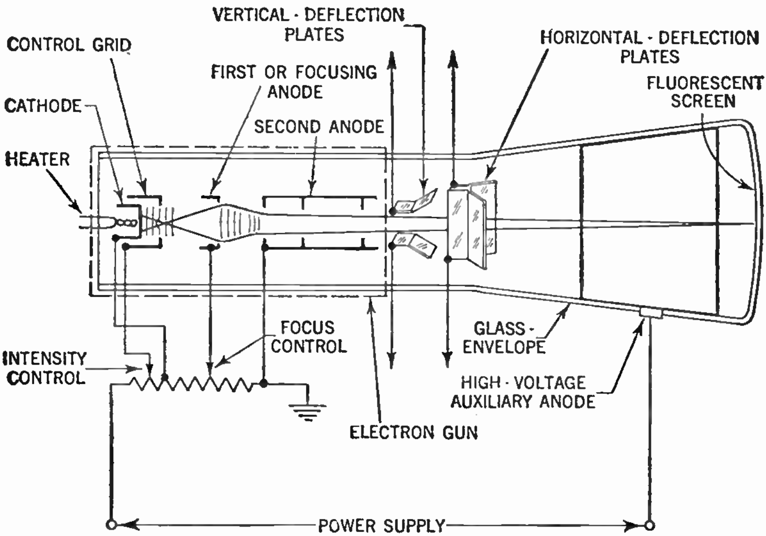


FIG. 27.—Schematic illustration showing arrangement of main components in an electrostatic type cathode ray tube. In a cathode ray tube of this type the electron beam is deflected by the electric field set up by the voltage applied to two pairs of plates located beyond the second anode. These sets of plates are mounted at right angles to one another, the plane of one set being horizontal and the other vertical. When a voltage is applied to one set of plates, the amount of beam deflection towards the plate with the higher positive charge is directly proportional to the difference in charge between the two plates.

By means of calibrations and scales the bright point may be read instantly in terms of *azimuth* (the angle with a fixed point such as true North) or *elevation* (the height above the earth) and *distance* (the time lapse between pulse and echo, plotted against their known rate of speed and shown on the screen as linear measurement).

These assembled data which together give exact location of a desired target or area, is the ultimate purpose of any radar system and are used for a multitude of purposes.

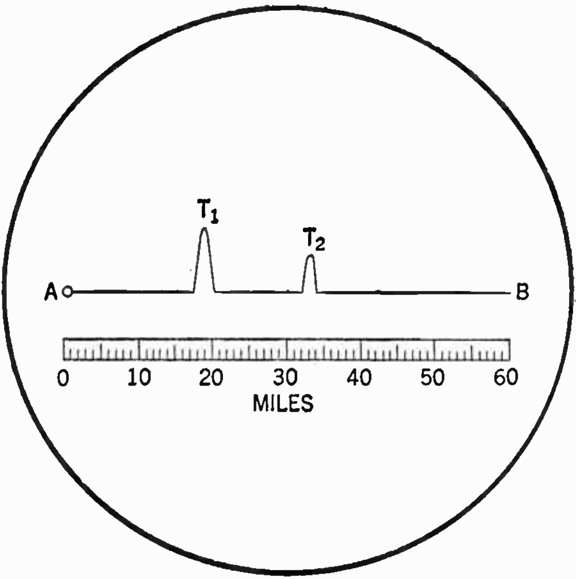


FIG. 28.—Type of echo display observed on the screen of the cathode tube. The fluorescent spot sweeps along the time base AB, in synchronism with the transmitted pulses. The received echoes from the two targets are seen at a distance from A, corresponding to the time taken for the pulses to travel to and from targets T_1 and T_2. The time base can be provided with range scale as indicated.

The type of picture obtained on the screen of the cathode ray tube is illustrated in fig. 28 in which the line AB represents the time base which is locked to the transmitter in such a way that the length AT, represents the time taken by an emitted pulse to arrive back at the receiver after reflection from target T_1. As we know the velocity of radio waves is substantially 186,000 miles per second, the scale of the time base can be graduated in miles, so that the distance of target T_1 is seen to be about 19 miles.

A second received pulse is seen at T_2 returned from another target at a range of about 33 miles. If one or both of these targets are moving, their changes in position are indicated by the movement of the pulses along the base line of the screen of the cathode ray tube toward or away from point A.

The amplitude of the pulse on the tube is proportional to the strength of its received signal, so that this naturally increases as the target from which the echo is received approaches the receiver.

When other conditions remain the same the amplitude of the echo is also a measure to some extent of the reflecting properties of the target, for example, its size; and an experienced observer may be able to guess the nature of the target from the echo pulse seen on the tube screen.

This measurement of the distance of the reflecting body responsible for the echo signals must be supplemented by a determination of the direction of arrival of the waves in both horizontal and vertical planes, before the actual position of the reflector in space is completely known. These measurements can be made by the well established methods for observing the bearing or azimuth (ϕ in fig. 29) and the angle of elevation above the horizontal (θ in fig. 29).

The first observation can be made by rotating the receiving antenna which may at certain wave lengths be a horizontal dipole, about a vertical axis until the amplitude of the corresponding pulse decreases to zero; it is then known that the bearing is in line with the direction of the dipole. Alternately a pair of fixed antennas at right angles to one another can be used, connected to the field coils of a radio goniometer in the usual manner of a direction finder. Rotation of the search coil to the signal minimum position again enables the bearing to be determined.

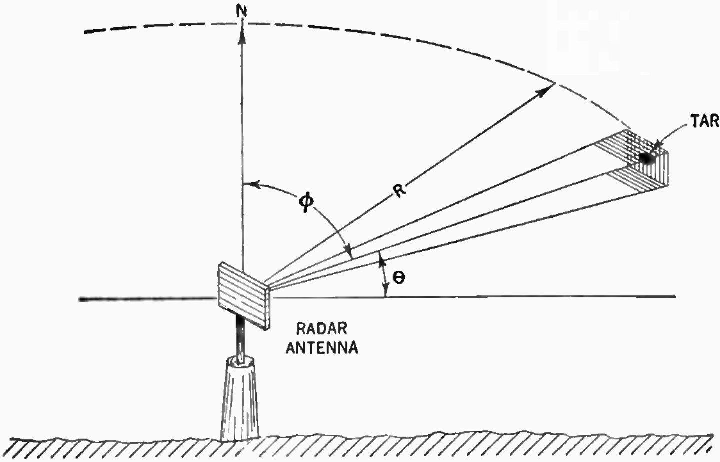
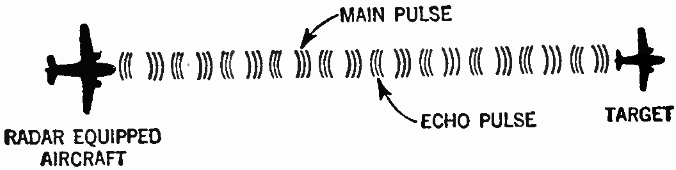


FIG. 29.—The position of the target is defined by its range R, angle of elevation θ, and bearing or azimuth ϕ.

The angle of elevation of the arriving waves can be measured by comparing the amplitudes of the voltage induced in two similar antennas mounted one above the other at a known distance apart, depending upon the wavelength in use and the range of angle elevation it is desired to cover

This technique has been used for many years past by several investigators for measuring the angles of arrival of radio waves over long distance communication paths, and is directly applicable to the problem under discussion.

If the reflecting object be an aircraft then a knowledge of range *R* and angle of elevation θ enables the altitude of which the craft is flying to be determined. If the object under observation be a ship then the angle of elevation is negligible and the range and bearing determines its position.



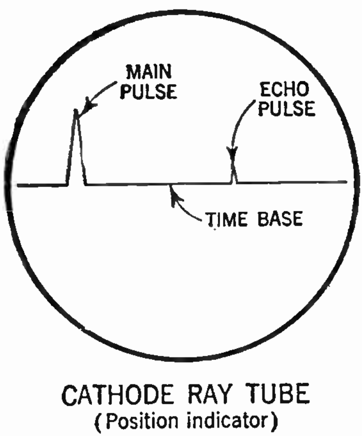


FIG. 30.—Showing time difference between transmitted and received signal as it appears on the cathode ray tube screen. Thus, by reading the time scale on the screen the distance to the target may be determined.

When microwave radar technique is employed and with the parabolic antenna trained on the target to give the maximum deflection of the received pulse, the azimuth and elevation can

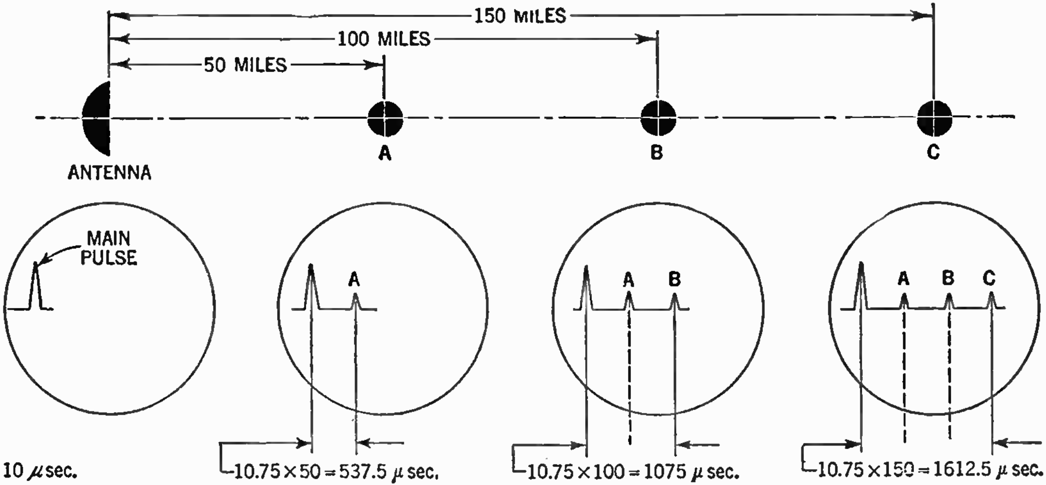


FIG. 31.—Schematic representation of three equally spaced targets and method of distance determination as represented on the scope. Assume the electrical impulse from the timer triggers the transmitter and for a certain period of say 10 microseconds it sends out a strong pulse from the antenna and then is shut off. Since the horizontal trace upon the scoop is associated with time and distance, a single target will cause a change on the time base line position only at one point, namely, that which corresponds to the distance of the target from the radar set. In our particular example, the echo from target *A* will return to the scope 537.5 microseconds after the main pulse, that from target *B* 1,075 microseconds, and that from target *C* 1,612.5 microseconds, etc. It should be observed that the total distance of travel for the radio waves are twice the single distance or loop miles in each instance.

be read off the horizontal and vertical scales respectively, while the range of the target is observed from the position of the pulse along the time base on the screen of the cathode ray tube.

Types of Radar Indicators.—It is the indicator of a radar that presents the information collected in a form best adapted to efficient use of the set. Nearly all radar indicators consist of one or more cathode ray tubes.

The more common type of data presentation are denoted as:

1. Type "A"
2. Type "B" and
3. Type "P".

In the simplest or "A" type of presentation, the electron beam is given a deflection proportional to time in one direction, say horizontally, and proportional to the strength of the echo pulse in the other, say vertically, as indicated in fig. 32.

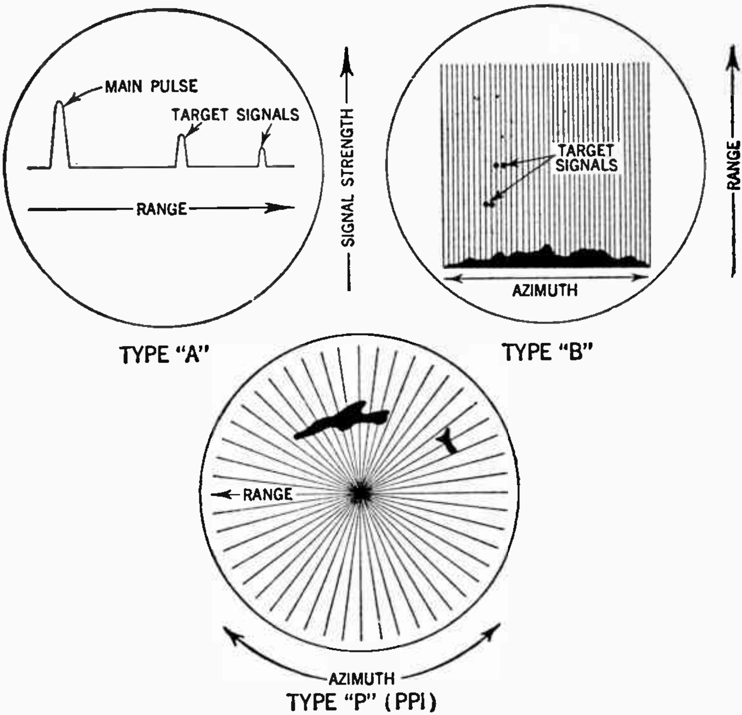
If no signals be visible, a bright horizontal line (the time base) appears across the tube face, the distance along this line representing time elapse after the outgoing pulse. A returning echo then gives an inverted V-shaped break in the line at this point corresponding to the time it took the echo to return back from the target.

When searching for a target the scanning spot is maintained at constant intensity and is set in uniform motion horizontally across the face of the scope at the instant at which the pulse of energy is radiated by the transmitter.

Upon reaching the extreme right side of the screen the spot is extinguished by grid control in the tube and is returned to the left where it is illuminated again to start another similar cycle.

As previously noted the horizontal distance across the screen from the end of the transmitting pulse to the end of one or several received pulses, constitutes indication of the distance to the respective reflecting objects.

In the type "B" presentation on the other hand both the azimuth and the range of reflecting objects are presented on the screen of the tube horizontally and vertically, respectively.



Figs. 32 to 34.—Types of data presentation. In the "*A*" type of display the range of the target (usually given in miles) is read horizontally and the signal strength vertically. Type "*B*" display gives the azimuth (or bearing) of the target horizontally and the range vertically. Here the target signals appears as two dots; left dot gives range and azimuth of target, whereas relative position of right dot gives an approximate indication of elevation. In the type "*P*" display method, the range of the target is measured radially from the center and the azimuth as a function of the polar angle.

When this method of presentation is employed, a highly directive antenna system is rotated about a vertical axis so that the radiated beam covers a horizontal plane.

Another type of presentation is known as the "P" or *Plan Position Indicator*. This method of presentation (abbreviated P.P.I.) is usually employed where it is required to obtain range and bearing indication, but not elevation indication, concerning objects in or near a horizontal plane centered near the radar station.

In a radar set employing this display method the antenna is rotated uniformly about a vertical axis so that the principal axis of the radiated beam periodically searches all angles in a horizontal plane. A very large number of pulses are transmitted with each revolution of the antenna and as each pulse starts the reflected spot moves outward with uniform speed along radial lines from the center of the screen, thus providing a radial range indication.

When reaching the edge of the screen, the spot or spots return to the center of the tube to begin a similar cycle. The polar angle of the radial line on which the spot appears indicates the azimuth of the antenna beam and hence of the reflecting target. The radial distance of the spot from the center of the screen indicates the range of the target. Targets then appear in the proper direction as well as at the proper relative distances from this origin and the result is a *map* of the territory surrounding the observing radar station displayed on the cathode ray tube.

Since the antenna can usually be rotated only slowly (e.g. from 1 to 30 r.p.m.) and since the light from an ordinary cathode-ray tube fades away almost instantly, one might expect not to see a "map" at all, but only bright flashes at various spots as the antenna revolves. Some way had to be found to make the brightness of these flashes persist for many seconds after they were produced. Special screens were developed which continue to glow for some time after being lighted by a signal. Thus the whole map is displayed at once.

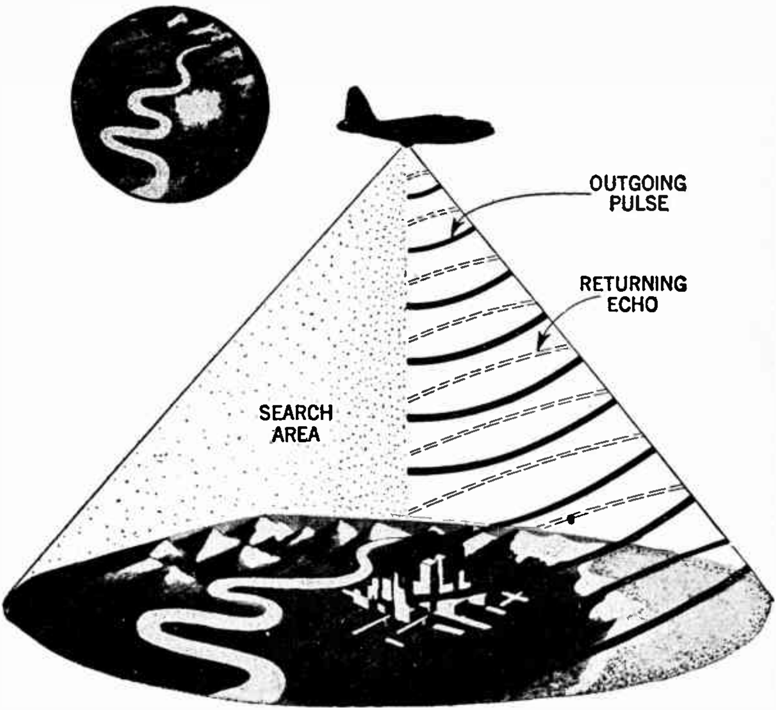


FIG. 35.—Showing how a radar map appears on the cathode ray tube when a certain area is scanned by means of an airborne radar set.

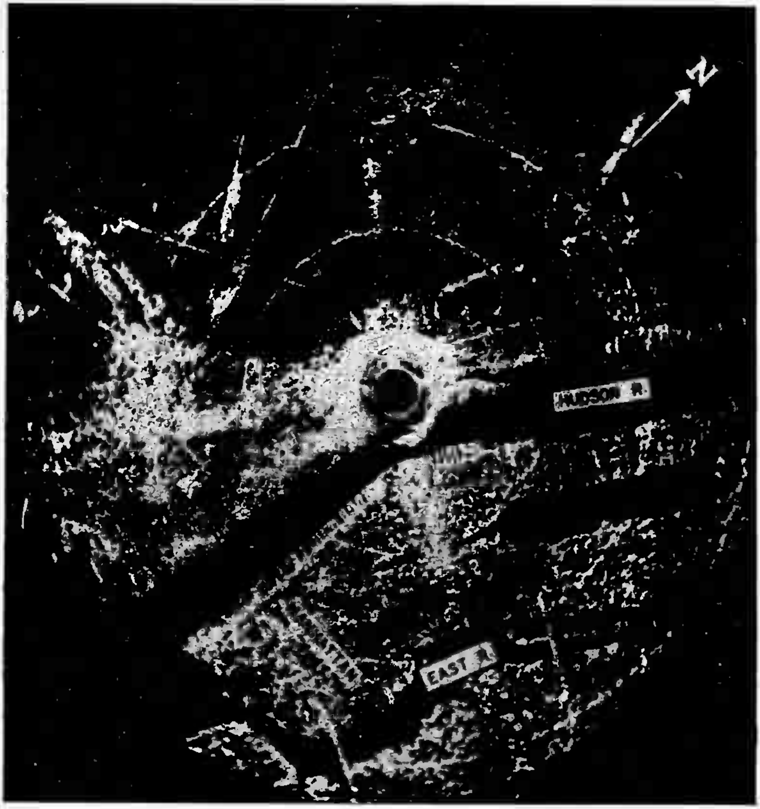


Fig. 36.—Radar map of greater New York. The photograph illustrates the definition obtainable when employing a very narrow beam system. In the photograph the individual docks on the Manhattan water front, the bridges across the East River and the Railroad tracks in Jersey City are clearly distinguishable.

CHAPTER 45

Radio Circuit Calculation

Example.—*A coil contains a resistance of* 10 *ohms and an inductance of* 0.1 *henry. If the frequency of the source be* 60 *cycles, find the voltage necessary to cause a current of* 2 *amperes to flow through the circuit.*

Solution.—With reference to previously derived formula

$$E_R = IR = 2 \times 10 = 20 \text{ volts}$$

$$X_L = 2\pi f L = 2\pi 60 \times 0.1 = 37.7 \text{ ohms}$$

$$E_L = IX_L = 2 \times 37.7 = 75.4 \text{ volts}$$

The applied voltage must therefore be

$$E = \sqrt{E_R^2 + E_L^2} = \sqrt{20^2 + 75.4^2} = 78 \text{ volts.} \quad \textit{Ans.}$$

Example.—*A coil that has a negligible resistance takes* 3 *amperes when connected to a* 180 *volt,* 60 *cycle supply. Determine the inductance of the coil.*

Solution.—

$$X_L = \frac{E}{I} = \frac{180}{3} = 60 \text{ ohms}$$

and $$X_L = 2\pi f L$$

from which
$$L = \frac{60}{2\pi \times 60} = 0.159 \text{ henry.} \quad \textit{Ans.}$$

Example.—*It is required to design an autotransformer fig.* 8 *for an input and output voltage of* 200 *and* 230 *volts respectively. If the autotransformer load is* 300 *watts, calculate:*

(*a*) *Input current.*

(*b*) *Output current.*

(*c*) *Current through the common section of the winding.*

(*d*) *Apparent wattage of each section of the winding.*

Solution.—Since the watt input into the primary equals the watt output of the secondary, neglecting losses, we may write:

(*a*) $I_pE_p = i_sE_s$ and $I_p = \frac{i_sE_s}{E_p} = \frac{300}{200} = 1.5$ amperes

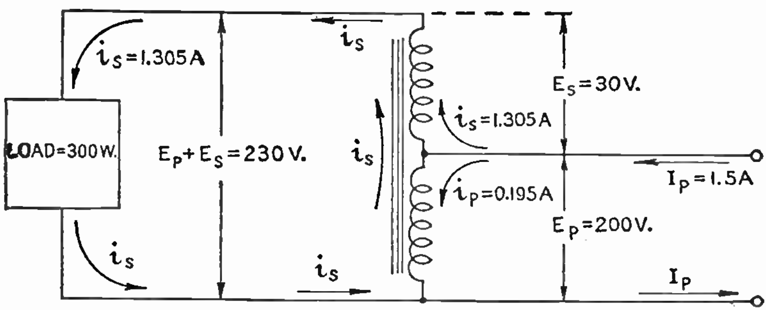


FIG. 8.—Typical autotransformer circuit having a voltage ratio of 230/200

(*b*) The output current similarly is

$$i_s = \frac{i_p E_p}{E_s} = \frac{300}{230} = 1.305 \text{ amperes}$$

(*c*) Current through the common section of the winding may be written as:

$i_p = I_p - i_s$ or $1.5 - 1.305 = 0.195$ ampere.

(*d*) The apparent wattage of each section of the winding may be written as,

$E_p\,(I_p - i_s) = E_s \times i_s$, or

$200 \times 0.195 = 30 \times 1.305 = 39$ watts.

It follows that this 300 watts autotransformer could be assembled on a core that would accommodate only 40 watts if double wound.

Example.—*An autotransformer, fig.* 9 *with an input voltage* =115 *an output voltage of* 230 *and a secondary load of* 80 *watts is required. Calculate:*

(*a*) *Input current.*

(*b*) *Output current.*

(*c*) *Current through the common section of the winding.*

(*d*) *Apparent wattage of each section of the winding.*

Solution.—Similarly to the previous example, we have:

(*a*) Input current $= \frac{i_s E_s}{E_p} = \frac{80}{115} = 0.695$ amp.

(*b*) Output current $= \frac{i_p E_p}{E_s} = \frac{80}{230} = 0.3475$ amp.

(*c*) Current through the common portion of the winding, consequently becomes

$$0.695 - 0.3475 = 0.3475 \text{ ampere.}$$

(*d*) Apparent wattage of each section of the winding is

$$115 \times 0.3475 = 115 \times 0.3475 = 40 \text{ watts.}$$

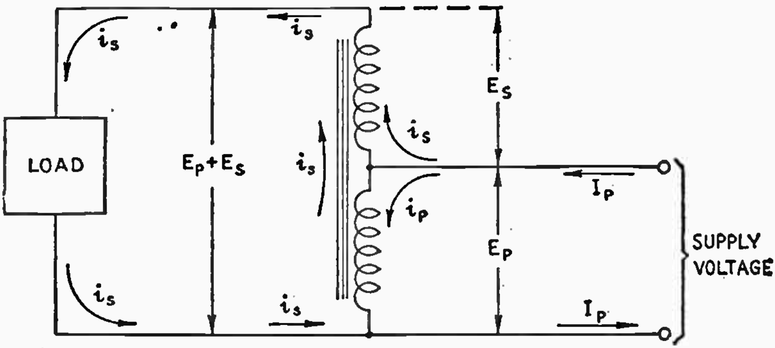


Fig. 9.—Typical autotransformer circuit having a voltage ratio of 230/115.

As in the previous case the core required must be capable of handling 40 watts when double wound. It should be noted that when the transformer ratio is 2:1 the current through both sections of the winding is the same, and therefore the same gauge of wire can be used throughout. This is the practice adopted for autotransformers designed to operate between the 100 to 120 volt and the 200 to 250 volt ranges.

Example.—*The ratio of the primary to secondary turns in a certain transformer is* 8/20, *and a load of* 4,000 *ohms is connected to the secondary winding. What is the impedance of this transformer?*

Solution.—The formula for impedance relations in a transformer is

$$Z_p = Z_s N^2$$

Where Z_p = Impedance of primary as viewed from source of power.

Z_s = Impedance of load connected to secondary.

N = Turns ratio, primary to secondary.

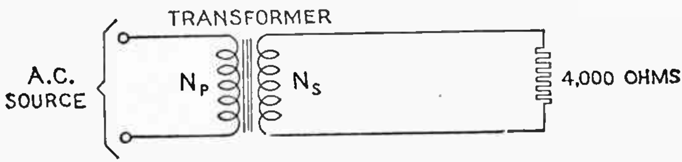


FIG. 10.—Transformer with 4,000 ohms secondary load.

In our particular problem the turns ratio equals 8/20 = 0.4. A substitution of values in the foregoing formula gives,

$$Z_p = 4{,}000 \times 0.4^2 = 640 \text{ ohms.} \qquad \textit{Ans.}$$

Example.—*A power supply circuit fig.* 11 *and associated multiple voltage dividers consists of* 5 *resistors as indicated. With the current drain to the various tubes and voltage drops as shown, calculate:*

(*a*) *Individual resistance values.*

(*b*) *Power dissipation in each resistance.*

Solution.—In the present example the total current drain obviously is the sum of the currents required by the individual tube circuits. To this must be added a bleeder current of approximately 10% of the total current requirements to accommodate increases in plate current due to signal-grid swings. With reference to fig. 11, the current rating of the power supply is:

$$I_2 = 0.0700 \text{ Amp.}$$
$$I_3 = 0.0050 \text{ Amp.}$$
$$I_4 = 0.0110 \text{ Amp.}$$
$$I_5 = 0.0050 \text{ Amp.}$$
$$I_6 = 0.0018 \text{ Amp.}$$
$$\text{Total drain } = 0.0928 \text{ Amp.}$$

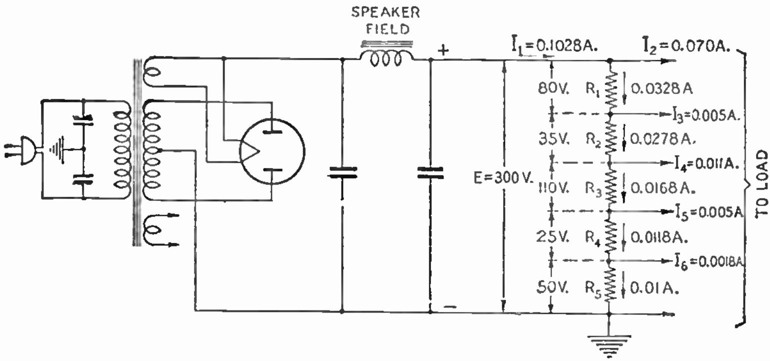


FIG. 11.—Typical voltage-divider circuit.

Assuming a bleeder current of 0.01 or 10 milliamperes, the total drain to be delivered by the supply as indicated will be $0.0928 + 0.010 = 0.1028$ or 102.8 milliamp. From this value a current of 0.070 amp. will be required by circuit I_2. The remainder or $0.1028 - 0.07 = 0.0328$ amp. must pass through the resistance R_1. The value of resistance R_1 may now be calculated by applying Ohm's law to this part of the circuit. We have:

$$R_1 = \frac{E}{I} = \frac{80}{0.0328} = 2{,}439 \text{ ohms.}$$

The current taken by I_3 equals 0.005 amp. Therefore the current flow in resistance R_2 is $0.0328-0.005=0.0278$ amp. Its resistance value is therefore

$$R_2 = \frac{E}{I} = \frac{35}{0.0278} = 1{,}259 \text{ ohms.}$$

The current flowing through R_3 is $0.0278-0.011=0.0168$ amp., since 0.011 amp. is required in circuit I_4. Resistance R_3 can now be calculated. As previously, we have

$$R_3 = \frac{110}{0.0168} = 6{,}548 \text{ ohms.}$$

Similarly, the current flowing in R_4 must be $0.0168-0.005=0.0118$ amp. Hence,

$$R_4 = \frac{E}{I} = \frac{25}{0.0118} = 2{,}119 \text{ ohms.}$$

Now, since the last circuit I_6 will require a current drain of 0.0018 amp., the value of R_5 may readily be calculated.
The current through R_5 equals $0.0118-0.0018=0.01$ amp. The value of resistance R_5 is finally

$$R_5 = \frac{E}{I} = \frac{50}{0.01} = 5{,}000 \text{ ohms.}$$

The power dissipation for each resistance may be calculated as follows:

$$W_1 = I^2R_1 = 0.0328^2 \times 2{,}439 = 2.62 \text{ watts}$$
$$W_2 = I^2R_2 = 0.0278^2 \times 1{,}259 = 1.00 \text{ watts}$$
$$W_3 = I^2R_3 = 0.0168^2 \times 6{,}548 = 1.85 \text{ watts}$$
$$W_4 = I^2R_4 = 0.0118^2 \times 2{,}119 = 0.30 \text{ watts}$$
$$W_5 = I^2R_5 = 0.01^2 \times 5{,}000 = 0.50 \text{ watts}$$

The total power consumption in the foregoing power supply (W) equals the sum of the power dissipated in the individual resistances. That is

$$W_1+W_2+W_3+W_4+W_5=6.27 \text{ watts}$$

The wattage rating of the various resistance units may also be obtained by using the formula watts $=E\times I$, that is, the current flowing through each resistance should be multiplied by the voltage drop across it.

Example.—*It is required to build a full-wave rectifier having the following specifications:*

Power source 60 *cycle at* 110 *volt.*

D.C. supply voltage required=500 *volts at a current drain of* 300 *milliamperes. The current ripple not to exceed* 2 *per cent.*

Solution.—Assuming the rectifier to be of the choke input filter type, fig. 12, the effective value of voltage developed across each transformer secondary must be slightly higher than the required 500 volts. To obtain the average output voltage of 500 volts the value of voltage on either side of the center tap should be larger than this value by a figure of approximately 10/9. We may therefore write,

$$E_s=\frac{E}{0.9}=\frac{500}{0.9}=556 \text{ volts } (r.m.s.)$$

This is the secondary voltage and to this should be added transformer, choke coil and tube drops. Since the voltage impressed on the primary is 110 volts, $110/\sqrt{2}\times 556$ would give the turns ratio.

The power rating of each section of the transformer depends upon the utility factor of a full wave rectifier transformer.

For the primary the utility factor is 0.9; for the secondary the utility factor is 0.637. Thus the average utility factor is $(0.637+0.9)\div 2$ or 0.768, so that a transformer would be satisfactory which has a rating determined by this average value. That is

$$\text{voltampere} = \frac{500 \times 0.3}{0.768} = 195$$

There is a critical value of inductance L_c below which the filter starts behaving as a condenser input filter. It can be shown that for a full wave rectifier

$$L_c = \frac{R}{1{,}132}$$

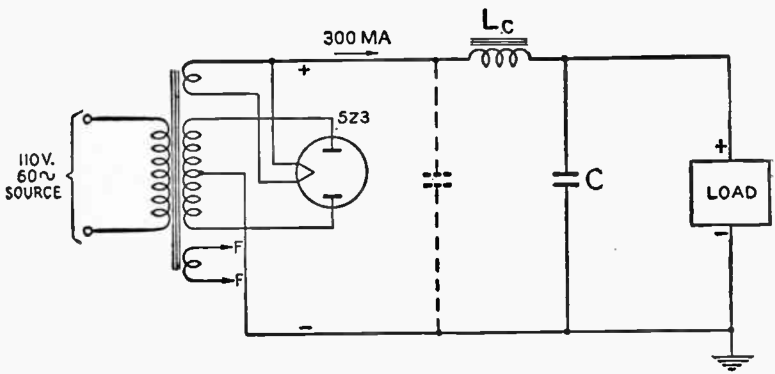


FIG. 12.—Typical full-wave rectifier circuit.

Where R is determined by the ratio of output voltage to load current. Therefore,

$$R = \frac{500}{0.3} = 1{,}670 \text{ ohms.}$$

It follows from the foregoing, that

$$L_c = \frac{1,670}{1,132} \doteq 1.47 \text{ henries.}$$

For conservative designs the inductance would be taken as $2L_c$ or 3 henries.

According to our specifications the value of the condenser must be chosen so that a ripple of 2 per cent is not exceeded. It can be shown that the voltage across the condenser due to the *nth* harmonic is expressed as

$$E_{nc} = \frac{E_{nc}}{n^2 \omega^2 LC}$$

If the ripple be taken as entirely due to the second harmonic, which is a good approximation, the ripple factor in the rectifier output which is fed to the filter is 0.482. For the output of the filter, the second harmonic voltage E_{2c} in terms of the *D.C.* voltage E_d is:

$$E_{2c} = \frac{0.482\ E_d}{2^2\ (2\pi 60)^2 \times 3 \times C}$$

$$\frac{E_{2c}}{E_d} = 0.02 = \frac{0.482}{2^2\ (2\pi 60)^2 \times 3 \times C} \text{ and}$$

$$C = \frac{0.482}{0.02 \times 4 \times 377^2 \times 3} = 0.000014 \text{ Farads}$$

That is, a 14 microfarad condenser and a 3 henry choke would accomplish the filtering in one stage.

The average current per tube would be one half the total current $0.3/2 = 0.15$ ampere. For safe operation, the peak current it should stand must be the entire load current or 0.3 ampere.

The peak inverse voltage the tube should be able to withstand is twice the peak voltage, that is

$$E_t = 2\sqrt{2}\text{x}556 = 1{,}570 \text{ volts.}$$

According to the tube manual a 5Z3 rectifier tube would satisfy the foregoing requirements.

Example.—*A series connected circuit consists of an inductive coil of 4 microhenries and a capacitor of 12 micro-microfarads. Calculate the wavelength in meters to which the foregoing combination will resonate.*

Solution.—If it be remembered that the wavelength in meters equals 3×10^8 divided by the frequency in cycles per second, we may write:

$\lambda = \frac{3\times10^8}{f}$ or $f = \frac{3\times10^8}{\lambda}$ Substituting f, in our equation for resonance, we obtain:

$$f = \frac{3\times10^8}{\lambda} = \frac{1}{2\pi\sqrt{LC}}; \text{ or } \lambda = 10^8\times6\pi\sqrt{LC}$$

Substituting numerical values in the foregoing equation we have,

$$\lambda = 10^8\times6\pi\sqrt{4\times10^{-6}\times12\times10^{-12}} = 13.058$$

say 13.06 meters. *Ans.*

Example.—*A 2 mfd. condenser is connected across a source of potential, the fundamental sinusodial component of which has a peak value of* 1,000 *volts and a frequency of* 60 *cycles per second.*

The potential has also third and fifth harmonic components which are respectively 35% and 20% of the fundamental. Calculate the r.m.s. *value of the current drawn by the condenser.*

Solution.—Reactance of condenser at the three frequencies:

$$(60 \text{ cycles});\ X_1 = \frac{10^6}{2\pi \times 60 \times 2} = 1326 \text{ ohm.}$$

$$(180 \text{ cycles});\ X_3 = \frac{1326}{3} = 442 \text{ ohm.}$$

$$(300 \text{ cycles});\ X_5 = \frac{1326}{5} = 265.2 \text{ ohm.}$$

The respective currents will be

$$I_{m1} = \frac{E_{m1}}{X_1} = \frac{1000}{1326} = 0.754 \text{ amp.}$$

$$I_{m3} = \frac{E_{m3}}{X_3} = \frac{1000 \times 0.35}{442} = 0.792 \text{ amp.}$$

$$I_{m5} = \frac{E_{m5}}{X_5} = \frac{1000 \times 0.20}{265.2} = 0.754 \text{ amp.}$$

The *r.m.s.* current may finally be obtained if it be remembered that

$$I_{r.m.s.} = \sqrt{\frac{I_{m1}^2 + I_{m3}^2 + I_{m5}^2}{2}}$$

$$= \sqrt{\frac{0.754^2 + 0.792^2 + 0.754^2}{2}}$$

$$= 0.94 \text{ amp.} \quad \textit{Ans.}$$

Example.—*A constant A.C. potential of* 100 *volts is impressed upon a series circuit, having a resistance of* 25 *ohms, an inductance of* 0.08 *henry and a capacitance of* 3.2 *microfarad. If the frequency be variable, at what frequencies will the power taken by the entire circuit be* 150 *watts? What frequency will produce the maximum voltage across the indutcance and what will this maximum voltaae be?*

Solution.—From data supplied, the following equation applies:

$$P = I^2R = 150 \text{ watts}$$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{150}{25}} = \sqrt{6} \text{ amperes}$$

$$\text{and } I = \frac{E}{Z} = \frac{100}{\sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}} = \sqrt{6}$$

Squaring both sides of the foregoing equation we have

$$\frac{10{,}000}{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2} = 6; \text{ substituting values for}$$

R, L and C, then:

$$10{,}000 = 6\left[625 + \left(0.503\, f - \frac{10^6}{20.1\, f}\right)^2\right] \text{ and}$$

$$1{,}041 = \left(\frac{10.1\, f^2 - 10^6}{20.1\, f}\right)^2; \text{ If the foregoing equation be}$$

solved with respect to frequencies or (f) we obtain

$$\left.\begin{array}{l} f_1=284 \\ f_2=348 \end{array}\right\} \quad Ans.$$

Maximum voltage across inductance (L) occurs at resonance

$$\text{Resonance frequency, } f=\frac{1}{2\pi\sqrt{LC}}$$

A substitution of values gives

$$f=\frac{1}{2\pi\sqrt{0.08\times3.2^{-6}}}=\frac{10^3}{2\pi\times0.506}=314 \text{ cycles}$$

At resonance $Z=R$; that is $I=\frac{100}{25}=4$ amperes

We also have $X_L=2\pi fL=2\pi\times314\times0.08=158$ ohms.

The maximum voltage across the inductance (X_L) is finally

$$E_L=I\times X_L=4\times158=632 \text{ volts.} \quad Ans.$$

Example.—*A certain radio-frequency generator fig.* 18 *having a generated voltage of* 10 *volts and an internal resistance of* 100 *ohms, is connected through an air core transformer to a resistance load of* 200 *ohms. The impedance of the primary and secondary winding of the transformer are* 50+j300 *and* 100+j600 *ohms respectively. The mutual inductance is* 80 *ohms. Calculate the current through the* 200 *ohms load.*

Solution.—The voltage equations may be written as,

$$E_g=I_1Z_p-I_2Z_m \text{ (vectorial)}$$

$$0=I_2Z_s-I_1Z_m \text{ (vectorial)}$$

By elimination of I_1 and solving these equations for I_2 we obtain

$$I_2 = E_g\left(\frac{Z_m}{Z_s\,Z_p - Z_m^{\,2}}\right)$$

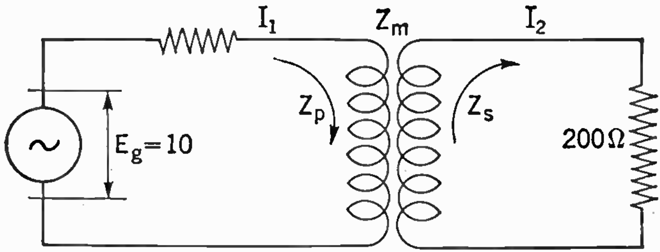


FIG. 18.—Typical radio-frequency generator circuit.

In our example, $E_g = 10$; $Z_m = +j80$; $Z_p = 100 + (50 + j300)$

$$Z_s = 200 + (100 + j600)$$

Substituting values in the foregoing expression, we obtain,

$$I_2 = 10\left(\frac{j80}{(150 + j300)\ (300 + j600) - (j80)^2}\right)$$

$$= 0.00294 - j0.0021 = 3.61 \text{ milliampere.} \quad \textit{Ans.}$$

Example.—*Calculate the values of capacitances C_1 and C_2, in circuit fig. 19, which will give maximum line current under an applied electromotive force at 50,000 cycles and minimum line current at 100,000 cycles. The values of L and R are* 0.01 *henry and* 80 *ohms respectively.*

Solution.—This is an example of series-parallel tuning in a radio circuit to prevent response to an interferring frequency. Adjust the parallel circuit for parallel resonance at 100,000 cycles (see example page 407) then without changing L, R or C_2 adjust C_1 to produce series resonance at 50,000 cycles fo the entire circuit. Assume no resistance in capacitances.

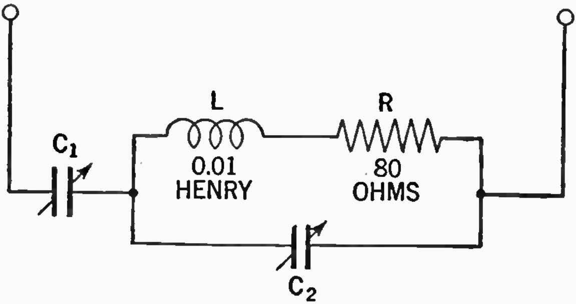


FIG. 19.—Typical series-parallel connected radio circuit components.

For parallel resonance at 100,000 *cycles, we have:*

$$\frac{X_L}{R^2_L+X^2_L}=\frac{X_c}{R_c^2+X^2_c}$$

The inductive reactance of the circuit is

$$X_L=2\pi fL=2\pi\times 100{,}000\times 0.01=6{,}283 \text{ ohms.}$$

$$\frac{6{,}283}{80^2+6{,}283^2}=\frac{1}{X_c};\ X_c=6{,}283 \text{ ohms.}$$

$$C_2=\frac{1}{400\pi^2}=0.0002533 \text{ mfd.}$$

For series resonance at 50,000 cycles, the resultant reactance for the entire circuit must be zero.

For the parallel branch we obtain:

$$X_C=\frac{10^6}{2\pi fC_2}=\frac{10^6}{2\pi\times 50{,}000\times 0.0002533}=12{,}560 \text{ ohms.}$$

$$X_L = 2\pi fL = 2\pi \times 50{,}000 \times 0.01 = 3{,}142 \text{ ohms.}$$

$$Y_C = 0 + j\frac{1}{X_C} = 0 + j\frac{1}{12{,}560} = 0 + j\frac{79.7}{10^6}$$

$$Y_L = \frac{R_L}{R_L^2 + X_L^2} - j\frac{X_L}{R_L^2 + X_L^2}$$

$$= \frac{80}{80^2 + 3{,}142^2} - j\frac{3{,}142}{80^2 + 3{,}142^2} = \frac{8.1}{10^6} - j\frac{318}{10^6}$$

$$Y_O = Y_C + Y_L = \frac{8.1}{10^6} - j\frac{238.3}{10^6}$$

$$Z_O = \frac{1}{Y_O} = 142 + j4{,}197 \text{ ohms.}$$

For the circuit containing C_1:

For series resonance X_{C1} must equal 4,197 ohms.

Therefore $C_1 = \frac{10^6}{2\pi f X_C} = \frac{10^6}{2\pi \times 50{,}000 \times 4{,}197} = 0.0007585$ microfarad. *Ans.*

Example.—*What is the resonant frequency of the circuit shown in fig. 20 if resonance be defined by current being in phase with the applied voltage i.e. unity power factor?*

Solution.—Since the conditions for resonant frequency is one in which the current is in phase with the applied voltage, we may write:

$$X_1X_2\,(X_1 + X_2) + R_1^2X_2 + R_2^2\,X_1 = 0$$

In this particular case $X_1 = \omega L$ and $X_2 = -\frac{1}{\omega C}$

Where $\omega = 2\pi f$. Therefore we obtain

$$-\frac{L}{C}\left(\omega L - \frac{1}{\omega C}\right) - \frac{R_1^2}{\omega C} + R_2^2\ \omega L = 0$$

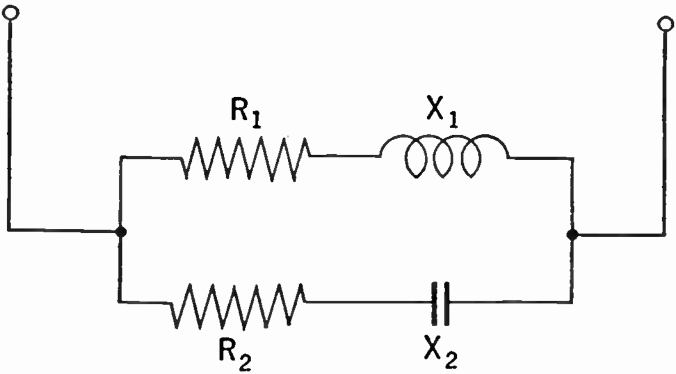


FIG. 20.—Showing elements of a parallel connected A. C. circuit employed to derive formula for resonant frequency.

Multiplying both sides of our equation with (ω) we have

$$\frac{-\omega^2 L^2}{C} + \frac{L}{C^2} - \frac{R_1^2}{C} + R_2^2\ \omega^2 L = 0;\ \text{or}$$

$$\omega^2\left(R_2^2\ L - \frac{L^2}{C}\right) = \frac{R_1^2}{C} - \frac{L}{C^2};\ \text{that is}$$

$$\omega^2 = \frac{\dfrac{R_1^2}{C} - \dfrac{L}{C^2}}{R_2^2 L - \dfrac{L^2}{C}};\ \text{but since } \omega = 2\pi f$$

We may write $f = \dfrac{1}{2\pi\sqrt{LC}}\sqrt{\dfrac{L - R_1^2\ C}{L - R_2^2\ C}}$ *Ans.*

Example.—*At what frequency will* 50 *microhenries and* 0.000030 *microfarads resonate?*

Solution.—Using our well known formula we have

$$f=\frac{1}{2\pi\sqrt{LC}}=\frac{1}{2\pi\sqrt{50\times10^{-6}\times30\times10^{-12}}}$$

$$=\frac{1\times10^{9}}{2\pi\times38.73}=4.10\ Mc/_s \quad Ans.$$

Example.—*To what frequency will* 4 *microhenries inductance and* 12 *micro-microfarad capacitance resonate?*

Solution.—The frequency of resonance may be determined from the following formula:

$f=\frac{1}{2\pi\sqrt{LC}}$ where L and C are in henries and farads respectively. Substituting values we obtain:

$$f=\frac{1}{2\pi\sqrt{4\times10^{-6}\times12\times10^{-12}}}=\frac{1\times10^{9}}{2\pi\times6.93}$$

$$=\frac{1\times10^{9}}{43.54}=22.97\ Mc/_s \quad Ans.$$

Example.—*What inductance will resonate at* 5.0 *megacycles with* 300 *micro-microfarad?*

Solution.—Solving our resonance formula with respect to inductance in henries we obtain:

$L=\frac{1}{4\pi^2f^2C}$; A substitution of numerical values in our equation gives

$$L=\frac{1}{4\times 9.87\times 25\times 10^{12}\times 300\times 10^{-12}}=0.0000034 \text{ or}$$

3.4 microhenries. *Ans.*

Example.—*A series connected circuit consists of an inductive coil of 4 microhenries and a capacitor of* 12 *micro-microfarads. Calculate the wavelength in meters to which the foregoing combination will resonate.*

Solution.—If it be remembered that the wavelength in meters equals 3×10^8 divided by the frequency in cycles per second, we may write:

$\lambda=\frac{3\times 10^8}{f}$ or $f=\frac{3\times 10^8}{\lambda}$ Substituting f, in our equation for resonance, we obtain:

$$f=\frac{3\times 10^8}{\lambda}=\frac{1}{2\pi\sqrt{LC}}; \text{ or } \lambda=10^8\times 6\pi\sqrt{LC}$$

Substituting numerical values in the foregoing equation we have,

$$\lambda=10^8\times 6\pi\sqrt{4\times 10^{-6}\times 12\times 10^{-12}}=13.058$$

say 13.06 meters. *Ans.*

CHAPTER 46

Radio Data

(Symbols, Abbreviations and Units)

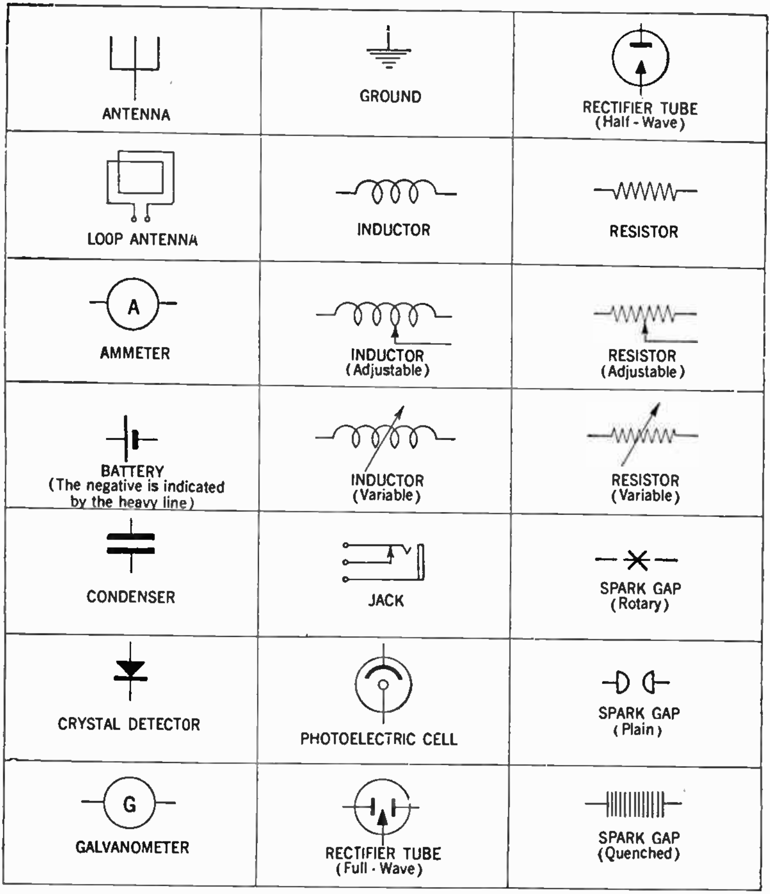
The purpose of symbols and abbreviations is to make it possible to illustrate and describe more briefly and clearly.

A drawing in which every part or piece of apparatus would be repeatedly described, would of necessity, be large and unintelligible; therefore symbols have been devised which represent every part and piece of apparatus and which take up little space. Similarly, where long words or terms are to be used, single letters or shortened words are substituted; these have been adopted as standard and to mean just the things specified.

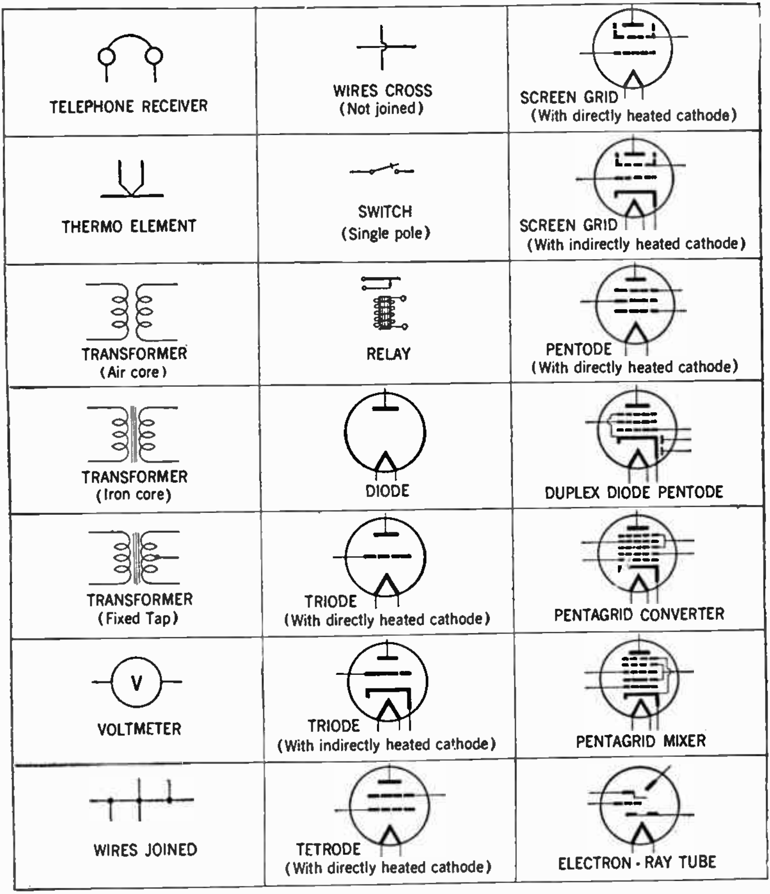
Engineering societies and manufacturers have adopted and authorized their use, and made them the specific way of indicating apparatus, equipment and terms in their fields; it is therefore necessary to become familiar with these in order to have a full understanding of the subject.

Diagrams should be made accordingly and descriptions should be written with the abbreviations; likewise, diagrams can be read only by a knowledge of the symbols; and descriptions understood only by a knowledge of the abbreviations.

On the following pages are given the most important symbols and abbreviations used:



The above symbols have been adopted as standard by engineers and manufacturers, and should be used in making circuit diagrams—also for reference, in reading diagrams.



In addition to symbols, given above, abbreviations are used for shortening descriptions. Abbreviations and formulas most commonly used are given on the following pages.

Electrical Prefixes:

Kilo Denotes a quantity one thousand times as great as a unit.
Milli Denotes a quantity equal to one-thousandth part of a unit.
Micro Denotes a quantity equal to one-millionth part of a unit.
Meg Denotes a quantity one million times as great; for example, 1,000,000 cycles = 1 megacycle, and 1,000,000 ohms = 1 megohm.

Ohm's Law for direct current

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

where I = amperes;
E = volts;
R = resistance.

Formula for resistances in series

$$R_{(\text{Total})} = R_1 + R_2 + R_3 \quad \text{etc.}$$

Formula for resistances in parallel

$$R_{(\text{Total})} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.}}$$

Determination of frequency of an alternator

$$\text{Frequency} = \frac{N \times S}{2}$$

where N = the number of field poles;
S = the speed of the armature in revolutions per second.

Fundamental frequency formula

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where f = frequency in cycles per second;
L = inductance of the circuit in henries;
C = capacitance of the circuit in farads.

Inductive reactance formula

$$X_L = 2\pi f L$$

where X_L = inductive reactance;
L = inductance in henries.

Capacitive reactance formula

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

where X_c = capacitive reactance;
C = capacity in farads.

Ohm's Law for alternating current

$$I = \frac{E}{Z} \quad \text{or} \quad I = \frac{E}{\sqrt{R^2 + \left[\left(2\pi f L\right) - \left(\frac{1}{2\pi f C}\right)\right]^2}}$$

where I = current;
E = voltage;
Z = impedance (total of all oppositions).

Condensers connected in parallel

$$C_{(Total)} = C_1 + C_2 + C_3 \quad \text{etc.}$$

Condensers connected in series

$$C_{(Total)} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ etc.}}$$

Resonance formula

$$2\pi fL = \frac{1}{2\pi fC}$$

where $2\pi fL$ = inductive reactance;

and $\frac{1}{2\pi fC}$ = capacitive reactance.

Wavelength formula

$$(\lambda)\ \text{wavelength} = 1884\sqrt{LC}$$

where L = inductance in microhenries;

and C = capacity in microfarads.

Antenna radiation formula

$$W = 1578 \times \frac{h^2}{\lambda^2} \times I^2$$

in which W = the energy radiated in watts effective;
h = the effective heighth of the antenna in meters;
λ = the wavelength of the antenna in meters;
I = the current in amperes at the base of the antenna or point of maximum current.

Signs

$\propto$	proportional to; varies as	$\angle$	angle
$=$	equal to	$<$	is less than
$\times$	multiplied by	$\ll$	much less than
$+$	plus; addition	$>$	is greater than
$-$	minus; subtraction	$\gg$	much greater than
$\div$	divided by	∞	cycle
$\odot$	circle		

Symbols

μ = permeability (B/H)
π = 3.1416
ρ = volume resistivity
τ = thickness
κ = susceptibility
λ = wavelength in meters
δ = logarithmic decrement
ϵ = 2.7183 (base of Napierian logarithms)
η = efficiency (per cent)
θ = phase angle (degree or radian)
ϕ = angle
ψ = difference in phase
ω = $2\pi f$ (angular velocity in radians per second);
Φ = magnetic flux
Ψ = electrostatic flux
Ω = ohm

a-f = audio-frequency
r-f = radio-frequency
e.m.f. = electromotive force
m.m.f. = magnetomotive force
a-c = alternating current
d-c = direct current
μf = microfarad
$\mu\mu$f = micro-microfarad
h = henry
mh = millihenry
μh = microhenry
f = frequency
MΩ = megohm
rms = root-mean-square
rpm = revolutions per minute
rps = revolutions per second

Greek alphabet

Letters		Names	Letters		Names	Letters		Names
Α	α	Alpha	Ι	ι	Iota	Ρ	ρ	Rho
Β	β	Beta	Κ	κ	Kappa	Σ	σ ς	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	Τ	τ	Tau
Δ	δ	Delta	Μ	μ	Mu	Υ	υ	Upsilon
Ε	ε	Epsilon	Ν	ν	Nu	Φ	φ	Phi
Ζ	ζ	Zeta	Ξ	ξ	Xi	Χ	χ	Chi
Η	η	Eta	Ο	ο	Omicron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

Abbreviations

C	capacity (electrostatic capacity)
E	effective electromotive force
I	effective current
K	dieletric constant
L	inductance
M	mutual inductance
N	number of conductors or turns
Q	quantity of electricity
R	resistance
T	period, or one complete cycle
W	watts
X	reactance
Z	impedance
d	diameter; distance
f	frequency; cycles per second
g	conductance
h	height
i	instantaneous current
k	coefficient of coupling
l	length
r	distance from a point (radius)
t	time
v	velocity

Letter Symbols—Vacuum Tube Notation

Grid potential	E_g, e_g
Grid current	I_g, i_g
Grid conductance	g_g
Grid resistance	r_g
Grid bias voltage	E_c
Plate potential	E_p, e_p
Plate current	I_b, I_p, i_p
Plate conductance	g_p
Plate resistance	r_p
Plate supply voltage	E_b
Emission current	I_s
Mutual conductance	g_m
Amplification factor	μ
Filament terminal voltage	E_f
Filament current	I_f
Grid-plate capacity	C_{gp}
Grid-cathode capacity	C_{gk}
Plate-cathode capacity	C_{pk}
Grid capacity (input)	C_g
Plate capacity (output)	C_p

UNITS.—Electrical units are based on the **metric system,** which is the name applied to the system of units employed in continental Europe.

The fundamental units in the metric system are the meter, the gram, and the second. The **unit meter** is the length of a certain metal standard *bar* which is preserved at the International Bureau near Paris.

From this unit of length, the units of volume (*liter*) and of mass (*gram*) are derived. The three units—*meter*, *liter* and *gram* —are simply related, thus one cubic decimeter equals one liter and one liter of water weighs one kilogram.

The above units are comparatively familiar to the radio man, as the meter is universally used for the expression of the length of radio waves. The meter is 39.37 inches or 3.281 feet.

Without giving any historical information as to the development of electric and magnetic units, it may be said that those now used are the so-called international electric units. The international units are based on four fundamental units—the *ohm*, *ampere*, *centimeter* and *second*. The first of these is the unit of *resistance*, and is defined in terms of the resistance of a very pure conductor of specified dimensions. The *ampere* is the unit of current and is defined in terms of a chemical effect of electric current, the amount of silver deposited from a certain solution for a current flow for a definite time. The other electric units follow from these in accordance with the principles of electrical science. Some of the units thus defined are given in the following definitions, which are those adopted by international congresses of science and universally used in electrical work:

One **ohm** = the resistance of a column of mercury (at the temperature of melting ice) of a uniform cross section of one square millimeter and a length of 106.30 centimeters.

One **ampere** = the current which when passed through a solution of nitrate of silver in water in accordance with certain specifications, deposits silver at the rate of 0.001118 of a gram per second.

One **volt** = the electromotive force which produces a current of one ampere when steadily applied to a conductor the resistance of which is one ohm.

One **coulomb** = the quantity of electricity transferred by a current of one ampere in one second.

One **farad** = the capacity of a condenser in which a potential difference of one volt causes it to have a charge of one coulomb of electricity.

One **henry** = the inductance in a circuit in which the electromotive force induced is one volt when the inducing current varies at the rate of one ampere per second.

One **watt** = the power expended by a current of one ampere in a resistance of one ohm.

One **joule** = the energy expended in one second by a flow of one ampere in one ohm.

The **watt** and **joule** are not primarily electric units, but they need to be learned in connection with electric units because the energy required or the power expended in electrical processes are among the most important phases of the actions.

The **horse-power** is sometimes used as a unit of power in rating electrical machinery. The **horse-power** is equal to 746 **watts.**

The **gram-calorie** or simply "**calorie**" is the energy required to raise one gram of water one degree centigrade in temperature. One **gram-calorie** is, very nearly, equal to 4.18 **joules.**

Another unit of quantity of electricity, in addition to the **coulomb,** is the "**ampere-hour**" which is the quantity of electricity transferred by a current of one ampere in one hour, and is therefore equal to 3,600 **coulombs.**

The units of capacity actually used in radio work are the **micro-farad** $=10^{-6}$ **farads** (a millionth of a farad) and the **micro-micro-farad** $=10^{-12}$ **farads** (a millionth of a micro-farad), since the farad is found to be too large a unit. Another unit sometimes used is the C.G.S. **electro-static** unit of capacity, often called the centimeter of capacity, which is approximately equal to 1.11 **micro-farads.**

The units of inductance commonly used in radio work are the **milli-henry** $=10^{-3}$ henry (a thousandth of a henry) and the **micro-henry** $=10^{-6}$ **henry** (a millionth of a henry). Another unit sometimes used is the **centimeter of inductance,** which is one one-thousandth of a **micro-henry.**

DEPARTMENT OF COMMERCE
BUREAU OF NAVIGATION
RADIO SERVICE

INTERNATIONAL MORSE CODE AND CONVENTIONAL SIGNALS

TO BE USED FOR ALL GENERAL PUBLIC SERVICE RADIO COMMUNICATION

1. A dash is equal to three dots.
2. The space between parts of the same letter is equal to one dot.
3. The space between two letters is equal to three dots.
4. The space between two words is equal to five dots.

A	· —
B	— · · ·
C	— · — ·
D	— · ·
E	·
F	· · — ·
G	— — ·
H	· · · ·
I	· ·
J	· — — —
K	— · —
L	· — · ·
M	— —
N	— ·
O	— — —
P	· — — ·
Q	— — · —
R	· — ·
S	· · ·
T	—
U	· · —
V	· · · —
W	· — —
X	— · · —
Y	— · — —
Z	— — · ·
Ä (German)	· — · —
Á or Å (Spanish-Scandinavian)	· — — · —
CH (German-Spanish)	— — — —
É (French)	· · — · ·
Ñ (Spanish)	— — · — —
Ö (German)	— — — ·
Ü (German)	· · — —
1	· — — — —
2	· · — — —
3	· · · — —
4	· · · · —
5	· · · · ·
6	— · · · ·
7	— — · · ·
8	— — — · ·
9	— — — — ·
0	— — — — —

Period	· · · · · ·
Semicolon	— · — · — ·
Comma	· — · — · —
Colon	— — — · · ·
Interrogation	· · — — · ·
Exclamation point	— — · · — —
Apostrophe	· — — — — ·
Hyphen	— · · · · —
Bar indicating fraction	— · · — ·
Parenthesis	— · — — · —
Inverted commas	· — · · — ·
Underline	· · — — · —
Double dash	— · · · —
Distress Call	· · · — — — · · ·
Attention call to precede every transmission	— · — · —
General inquiry call	— · — · — — · —
From (de)	— · · ·
Invitation to transmit (go ahead)	— · —
Warning—high power	— — · · — —
Question (please repeat after ......)—interrupting long messages	· · — — · ·
Wait	· — · · ·
Break (Bk.) (double dash)	— · · · —
Understand	· · · — ·
Error	· · · · · · · ·
Received (O. K.)	· — ·
Position report (to precede all position messages)	— · — ·
End of each message (cross)	· — · — ·
Transmission finished (end of work) (conclusion of correspondence)	· · · — · —

AUDELS RADIOMANS GUIDE

Covering

RADIO
TELEVISION
INDUSTRIAL ELECTRONICS
PUBLIC ADDRESS SYSTEMS

by
E. P. Anderson