34 LESSONS IN RADIO AND TELEVISION

PUBLISHED BY

RADIO NEWS AND SHORT WAVE RADIO

34 LESSONS
IN RADIO AND TELEVISION

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Once upon a time...

The real reason for publishing this book goes back to the time six years ago when your editor decided to prepare a Radio Lesson Book to help Radio News readers learn something about elementary radio theory. When the material for the book was gotten together, it was found that it could be divided into twenty-three parts and the book was, therefore, called "23 Lessons In Radio." Since that time, this little book has been the most popular publication we have had any experience with. It was printed and reprinted, and the copies were snapped up just as soon as they came off the press.

Now, six years in radio is a long time and although the fundamental concepts remain the same, there have been so many new applications coming each year that it became evident a new Radio Lesson Book of increased scope and containing the latest data on such new developments as cathode-ray tubes and television itself would fill a distinct need.

This fine new book in which the lessons have been increased to 34, starts out with the fundamentals of electricity and wave motion, tells you what is necessary to know about radio symbols and circuits, vacuum tubes, amplifiers, various kinds of receivers, facts about antennas, the development of the cathode-ray tube, and the unfolding of television — and tells it in a simple and direct manner that anyone should be able to understand.

A glance at the contents page is enough of an introduction to "34 Lessons In Radio And Television" without many more words from me. It is hoped that these lessons, and the knowledge they contain, will give you a better understanding of radio and more complete enjoyment in your radio activities.

LAURENCE M. COCKADAY
Editor, Radio News and Short Wave Radio

LESSON ONE

Fundamentals Of Electricity

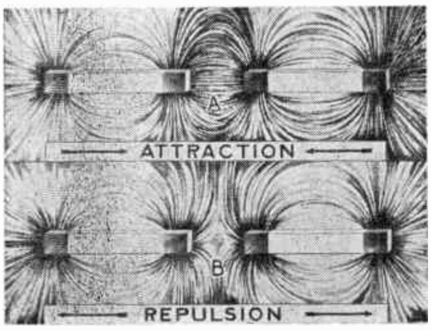
WHO would ever have believed, when in 1793 Alessandro Volta, a physics professor, finished his lecture before a Pavia audience, that from such a crude device as his original arrangement voltaic cells (see Figure 3), would come a development which, if only a little further understood, would teach us about the nature of materials, the constituents of metals and fluids, the ability to build electrical equipment of vast power to run our industries, and, finally, to enable us to communicate over the entire globe by radio. A first crude arrangement of batteries—zinc and copper plates immersed in an acid solution—in its systematic investigation made possible the study of the fundamentals of electro-chemistry. In consequence there came the investigation of the phenomena connected with the motion of electrical charges in gases, fluids, and solids and finally, the study of electrical charges much smaller than the others, namely—those practically free from matter—electronic physics.

How Currents Flow

What is actually concerned in the passage of electricity through conducting mediums? Is it different if we screw a lamp into a light socket, or if we receive radio impulses from the ether when we have current flowing through the vacuum of our radio tubes, or if we reflect radio waves on the Heaviside layers of an atmosphere 100 miles above the earth? Just how does *conduction* take place?

It is at this point that the scientist enters the scene. In showing the common source in the diversification of general laws that allow many phenomena to appear in different lights, he creates new variations and discovers new effects that eventually become of industrial importance. It is indeed a thrilling experience to compare the phenomena of radio and electricity of today with the experiments of 100 years ago, which in their various forms look so completely different, but which at bottom are fundamentally identical with today's technique, however varied they may appear.

Figure 2



ELECTRODE POTENTIAL SERIES
(MOLAL ELECTRODE POTENTIALS REFERRED TO THE HYDROGEN ELECTRODE AS ZERO)

ELECTRODES	POTENTIAL (VOLTS)	SIGN: METAL TO ION	SIGN: ION TO METAL	
Li-Li +	2.958	+	−	LR
Rb-Rb +	2.924	+	−	LR
K-K +	2.922	+	−	LR
Na-Na +	2.713	+	−	LR
Ba-Ba ++	2.8	+	−	LB
Sr-Sr ++	2.7	+	−	LB
Ca-Ca ++	2.5	+	−	LB
Mg-Mg ++	1.55	+	−	LB
Mn-Mn ++	1.0	+	−	LB
Zn-Zn ++	0.758	+	−	LR
Cr-Cr ++	0.557	+	−	IC
Cr-Cr ++	0.40	+	−	IC
Fe-Fe ++	0.441	+	−	LR
Cd-Cd ++	0.398	+	−	LR
Tl-Tl +	0.336	+	−	LR
Co-Co ++	0.29	+	−	LB
Ni-Ni ++	0.231	+	−	IC
Sn-Sn ++	0.136	+	−	LR
Pb-Pb ++	0.122	+	−	LR
Fe-Fe +++	0.045	+	−	LR
$(Pt\text{-}H_2)$-H +	0.0	+	−	
Sb-Sb +++	0.1	−	+	LB
Bi-Bi +++	0.2	−	+	LB
As-As +++	0.3	−	+	LB
Cu-Cu ++	0.345	−	+	LR
Ti-Ti +++	0.37	−	+	IC
$(Pt\text{-}OH)\text{-}O_2$	0.398	−	+	LR
Hg-Hg ++	0.799	−	+	LR
Ag-Ag +	0.800	−	+	LR
Au-Au +++	1.3	−	+	LB
Au-Au +	1.36	−	+	IC

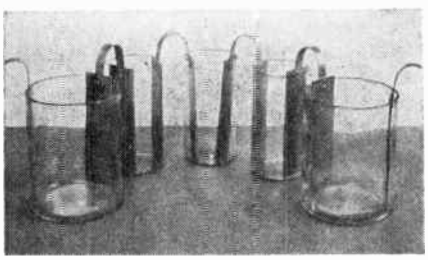
DATA MARKED LR, FROM LEWIS AND RANDALL, "THERMODYNAMICS"; LB FROM LEBLANC, "LEHRBUCH DER ELECTROCHEMIE"; IC FROM "INTERNATIONAL CRITICAL TABLES"

Figure 1

The Electron Theory

In the early parlance of electrical experimenters it was assumed that current traveled from *positive* to *negative;* it would be, perhaps, more correct to say that current travels from a higher to a lower electrical potential. However, the flow of electric current is now believed to be in the *direction of the flow of the electrons,* as established, for instance, in radio tube phenomena.

Figure 3



Fundamental experiments about the mechanism of the conduction of electricity in a liquid (called an electrolyte) had been carried out as early as 1853, and the physical laws of ionization in liquids have followed since that time.

As a starter, in considering the generation of electric potentials in batteries containing a fluid electrolyte, we might ask the question: How are these potentials started in batteries and how is conduction accomplished? An ordinary fluid without any energy passing through it may be thought of as neutral, electrically. But the atoms of a liquid may be decomposed under the influence of an electrical potential, and the ions resulting will carry tiny charges through the electrolyte to the electric terminals (sometimes called electrodes). These ions may be considered as tiny little "boats" which float through the electrolyte between the electrodes starting the current flow through the battery.

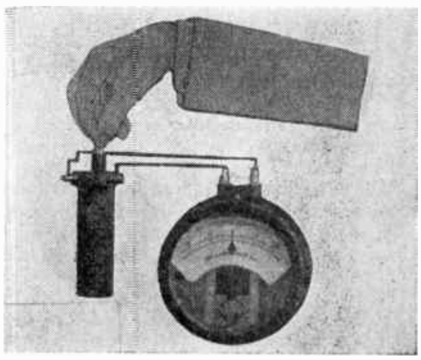
The material of the electrode governs the potential difference that will be generated by the battery and there follows in Figure 1 a list of electrode materials and their electrical characteristics in comparison to hydrogen in an electrode-potential series.

"Wandering" Electrons

While the motion of ions through fluids is one of the earliest actions of electricity to be investigated, there are a number of other phenomena that can be easily reproduced that have aided considerably to increase our understanding of electrical phenomena and that have helped us to make many of the tools and machines necessary for our 20th century civilization.

The conduction of electricity through solids seems to be a much more simple thing than that of conduction through liquids. In solids, a current of electricity is believed to be a wandering of free electrons, through the atoms, in a drift tending to equalize the distribution of such free electrons. In other words, the general understanding of conduction would include the idea of the free electrons

Figure 4



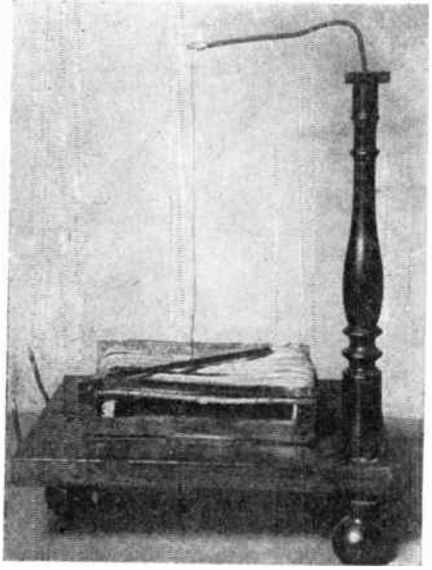


Figure 5

repelling each other and leaving locations in a conductor where "crowding" exists. In other words, a generator of electricity might be considered as an electron pump that produces a "crowd" of electrons at one of its terminals and they immediately drift through the conductor to the other terminal of the generator where there is a scarcity of said electrons.

Magnetic Fields

Another part of electrical phenomena of importance has to do with the relation of current flow and magnetism. This refers particularly to the phenomena of electromagnetism, the principles of which are of equal importance in the construction of huge dynamos, in the motion of the loud speaker, the galvanometer or the oscillograph, in the construction of electronic and radio apparatus, and even in the transmission of energy through space.

All these phenomena revert to the fact that flowing electricity develops a magnetic field and that changes in a magnetic field can also generate electricity. Figure 5 shows one of the earliest experiments ever attempted in this line. In its beautiful simplicity and clarity, consisting of a coil of wires, a suspended magnetic needle and two nails as contacts, it is indeed an example of the method of thinking and experimenting fundamentally and of far-reaching results even with meager means. The galvanometer referred to is a design of the great American physicist, Joseph Henry, who investigated, with this type of equipment, the phenomena of electro-magnetic induction one year before Faraday observed and published the same results. This suspension galvanometer was based upon the fact, discovered by the physicist Oersted in 1819, that a magnetic needle is influenced by a current of electricity. Current flowing through a coil in this galvanometer deflects the magnetic needle suspended on a thread above it, the needle being attracted with a certain force toward the magnetic meridian. It requires a definite force to deflect it from its original position. This force is a function of the amount of electric current flowing. It can therefore be calibrated in amperes (or multiples or fractions thereof) and will measure current.

It is indeed a long way from this original experiment of interaction between an electric current and a magnetic field to the construction of a modern string galvanometer or a velocity microphone, but the principle involved is the same. In this microphone thin ribbons are suspended within the magnetic field. But "cutting" the lines of force in the magnetic field, electric current is developed in these ribbons as they move, which current is conducted by wires to the amplifier equipment —giving us hundreds of thousands of times the energy output of the original sound wave that moved the metal ribbon in the magnetic field.

Electric Current Determined By Factor of Motion

This idea of cutting magnetic lines of force by a conductor is shown in Figure 4, in which the magnet is shown being inserted into a coil of wire. A magnet, as is known, is surrounded by what we call a magnetic field, such as is shown in Figure 2 at A and B, which at the same time show also the interaction of two magnetic fields upon each other. The coil, connected to a milliammeter, reads up to 20 milliamperes on each side of the scale. During the time the magnet is inserted, the milliammeter is deflected in one direction. If it is then held motionless, no current flows in the milliammeter. If the magnet is pulled out, the milliammeter shows current flowing in the opposite direction. The quicker we move the magnet, the stronger the needle is deflected; if we move the magnet very slowly, the deflection is minimized.

We see here that the electric current in addition to being proportionate to the force of the magnetic field (which we can readily see by inserting a stronger magnet in comparison with a weaker), is also determined by *the factor of motion*. The more lines of force cut per time unit, the stronger is the electromotive force developed in the conductor.

LESSON TWO

Vacuum Tubes

THE small glass tubes or bulbs with which most of us are familiar, due to their universal use in radio sets, are but one form of a large family of similar devices—all having their own purpose but working on a similar principle. All vacuum tubes from the tiny "peanut" tube, a little over an inch in height, to the gigantic 200 kilowatt radio transmitting tube standing almost six feet high, depend on their operation, first, on infinitely small particles called electrons, and second, on an empty space provided for the electrons to move through freely. Even the photo-electric cell, the mysterious electric eye, depends upon its operation on the motion of these tiny electrons. Other small tubes containing brilliantly colored glowing gases and which by an ordinary wave of the hand will set into motion tons of machinery depend also on tiny electrons for their operation.

The X-ray tube over which humans have always marveled is also another electron and empty space device. Many wonderful devices have been developed, based on the motion of electrons in a space.

The material of the entire universe is composed of intricate combinations of less than a hundred substances called elements. All substances known to man are either elements or combinations of two or more elements. Some of the better known elements are hydrogen, oxygen, aluminum, carbon, copper, gold, iron, and many others. Water, for instance, is formed by the combination of oxygen and hydrogen. When the element oxygen from the air goes into union with the element iron we have rust formed, and then we decide that a new coat of paint is needed to protect the surface. Millions of combinations of elements are possible.

Structure of Atoms

All of the ninety or so substances called elements are composed of atoms of the particular substance. An atom is the smallest possible particle in which an element can exist. Like the age-old question, "what lies beyond the universe," we may well ask, "what lies beyond the atom?" If we could sufficiently magnify the atom to examine its structure, we would find that all atoms are made up of but two things—a tiny particle known as a proton around which revolve at great speed one or more smaller particles known as electrons. The arrangement and number of electrons around the proton determines the type of atom and thereby the element. We see, therefore, that all matter is composed of elements or combinations of elements, elements are composed of atoms, and atoms are composed of two basic things known as protons and electrons. Between the proton and its electrons is empty space. About twenty-four centuries ago Democritus, a Greek philosopher, said, "in reality there is nothing but atoms and space." Little did he know how near he came to the facts which make up the basis of modern science.

The simplest atom known consists of a proton and one electron. This is the hydrogen atom. An atom of oxygen consists of a proton with eight electrons revolving about it. The iron atom has twenty-six electrons revolving about its proton. Radium, one of the heaviest of the elements, consists of a proton with eighty-eight electrons revolving about it. These arrangements of electrons and protons make up a sort of miniature solar system in which the proton is the sun and the electrons are the planets. The magnitudes, of course, are infinitely smaller than can be viewed under any microscope. Something like 250,000 hydrogen atoms

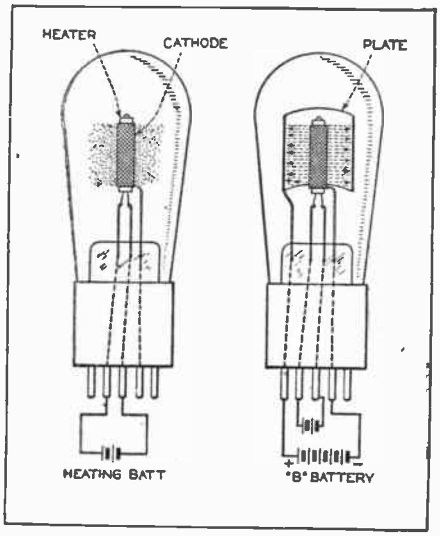


Figure 6—Left; Figure 7—Right

placed in a row would have a length of one hundred thousandth of an inch.

Protons and Electrons

Protons and electrons, modern research has shown, are nothing but pure little particles of electricity. They are the "building blocks" of the universe, and all matter is made from them. The proton is a particle of positive electricity, while the electron is a particle of negative electricity. All electrons are exactly alike. It has been calculated that the electron is about one-thirteenth billionth of an inch in diameter!

When the proton has the proper number of electrons revolving about it, the positive charge of the proton and the negative charge of the electrons neutralize each other and we have a stable arrangement. Under certain conditions electrons may leave an atom, and when they do so they are free to go into combination with any nearby atom which has a deficit of electrons.

Principle of The Vacuum Tube

Now that we have had a glimpse of the infinitesimal world of protons, and know of some of their workings, let us see how the ingenuity of man has set these tiny particles or electric charges to work to perform his miracles.

Imagine a machine-gun such as that used in the war. It is aimed at a target at which it is firing. As the bullets strike the target they give up their energy. A slight pressure on the trigger of the gun is sufficient to start a rain of shells toward the target.

The vacuum tube such as is used in your radio set or in radio broadcasting is a device in which energy can be controlled by the application of a much smaller amount of energy than in the machine-gun. In the vacuum tube we have the machine gun and target on a very small scale. Even the projectiles are there, but this time they are not machine-gun bullets but our tiny electrons.

Construction of A Vacuum Tube

A vacuum tube consists of a cathode for shooting out electrons, the plate for the electrons to hit, and the grid for controlling the number of electrons reaching the plate. The air is thoroughly pumped out of the tube in order to allow the electrons free passage from the cathode to the plate. If the cathode is surrounded by atmosphere at ordinary pressure an electron could travel but a very very short distance from the cathode before it would bump into an atom of one of the gases present in the atmosphere and thus end its flight.

As we previously read, the electrons of an atom are continually revolving about a proton. When the atom is heated to high temperatures the electrons begin to revolve faster and faster until, if the temperature be sufficiently high, an electron is flung off with great velocity. We see, therefore, that when the cathode of the tube is heated to a high enough temperature, electrons are discharged from its surface or boiled off much as steam is boiled off from a kettle of boiling water. Materials, such as thoriated tungsten, or certain metallic oxides, have the property of emitting large numbers of electrons at comparatively low temperatures, therefore, they are generally used for vacuum tube cathodes. The cathode of the vacuum tube, then, is that element in the tube, sometimes in the form of a filament, which is heated in order to discharge electrons from its surface.

The Electron Flow

The plate is a piece of metal surrounding the cathode, and is used to receive the electrons which are emitted from the cathode. When the cathode is heated high above the temperature of its surroundings, millions and millions of tiny negative electrons are discharged into space, as in Figure 6. In order for the plate to draw these electrons to itself it must have a positive charge or a deficiency of electrons. This is accomplished by connecting the positive terminal of a battery or other source of voltage to the plate in order to pull electrons out of it.

We have previously read, that when an electron leaves an atom it is free to go into combination with any nearby atom which has a deficit of electrons. Therefore, when the cathode is heated and the plate is positively charged, we have a stream of electrons flowing from the cathode to the plate as in Figure 7.

Every electron which reaches the plate constitutes a minute electric current, and when a sufficient number of electrons reach the plate we have a measurable current of electricity. This current of electrons or electricity which is shot out of the cathode into the vacuum, reaching the plate, and flowing from the plate through the battery and other apparatus, must be conducted back to the cathode again in order to give back to it its deficiency of electrons. It is this current which is used in so many ways to perform many modern wonders.

Electron Policeman

We need now in order to complete our vacuum tube, the element for controlling the number of electrons which are allowed to reach the plate. This third element, for which de Forest is famous, is the grid and consists of a wire mesh between the cathode and plate. Every electron which finally reaches the plate must pass through the openings in this wire mesh which we have called the grid.

These tiny electrons speeding across to the plate are easily influenced by the electrical charge on the grid. If the grid has an excess of electrons on it or in other words a negative charge, it will repel any electrons coming near it and therefore send most or even all of the electrons

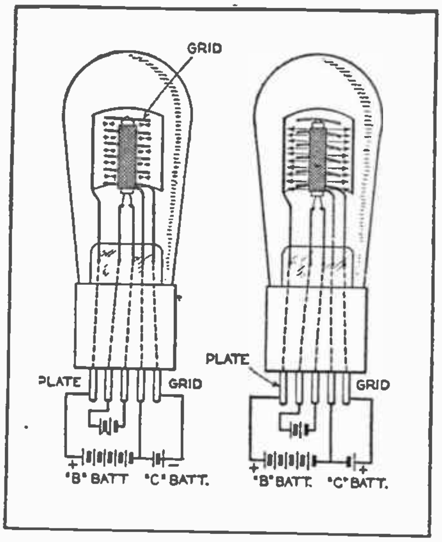


Figure 8—Left; Figure 9—Right

headed toward the plate back to the cathode (Figure 8). The plate current then is decreased, On the other hand, if electrons are taken away from the grid, leaving it positively charged, the number of electrons from the cathode reaching the plate will be greatly increased, because the grid will then aid the plate in attracting electrons. See Figure 9.

The grid in the vacuum tube may be likened to a traffic policeman on a one-way street. When the policeman raises his hand automobile traffic stops; when the grid becomes negative electron traffic stops. When the traffic policeman gives the signal to go, traffic again starts; when the grid becomes positive the stream of electron traffic to the plate is resumed.

We can see, therefore, that since the grid element of a vacuum tube can have such a marked effect on the number of electrons that reach the plate, we can, by varying the grid charge or grid voltage, regulate the plate current in any desired way. As electrons travel at hundreds of miles per second variations in grid voltages take instantaneous effect upon the plate current.

The Amplification Factor

Depending on the relationship and structure of the elements in the tube, a change of one volt of electric pressure on the grid may affect the plate current as much as a ten volt change in the plate voltage. In other words, an electron on the grid will have the power of ten electrons in the plate circuit. The amplifying action or amplification factor varies in the different types of tubes in general use from about three in the power tubes, to a factor of several hundred in the screen grid tube.

The amplification factor of a tube is controlled in a great measure by the mechanical construction of the tube, the grid-to-plate spacing, as well as the closeness of the grid mesh structure. A grid composed of a great many wires, close to the filament or cathode, provides a high amplification factor; a tube with a wide grid structure and not so close to the filament or cathode produces a low amplification factor. This amplifying property of the vacuum tube, in which electrical conditions in the circuit connected to the grid of the tube are exactly reproduced and magnified many fold in the plate circuit, is the basis of the hundreds of important and wonderful technical applications of the vacuum tube.

LESSON THREE

Reception Of Radio Waves

RADIO stations all over the world are sending out radio waves. Just what these waves are, we do not know. We do know, however, that a radio wave has the power to create an electrical pressure in any electrical conductor (such as wire) and this electrical pressure will cause a current to flow in the conductor. Thus the wave from a radio transmitter causes a minute electric current in any receiving antenna (or other conductor) within its path. The strength of this current will depend on the power of the station, the distance from the station and the length, location and direction of the receiving antenna.

This tiny electric current flows down to the receiver which must convert it back into the original speech, morse code, music, picture, etc., being conveyed by the radio waves. Note that there is no difference in the transmission of telegraph, telephone messages, music or picture. The nature of the wave, the transmitter or the receiver is the same, it is just the translating device (microphone, key, televisor) which differs.

Duties of the Receiver

The duties of the receiver are: first, to pick up the small electrical pressures or voltages; second, select the desired signal excluding all others; third, translate the signal into sound (or picture or code message, but in this lesson let us consider sound only). Before the latter can be accomplished a process, called "detection" must take place.

The natural question will be—what is detection and why is it necessary? Why can't we connect the headphones to antenna and ground and listen for stations? The answer is not so simple.

It is necessary to consider briefly how a radio station works. Most of us are familiar with alternation current or A.C. Any electrical current flowing through a

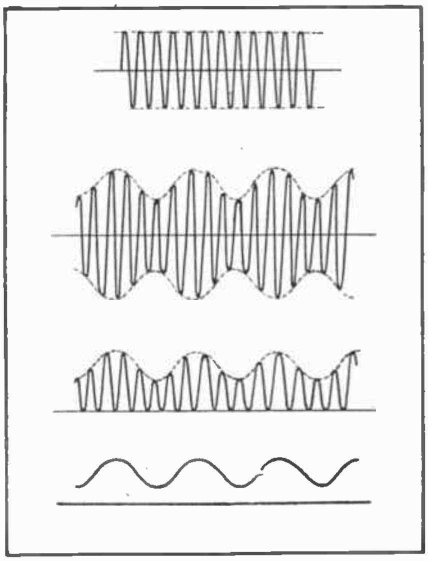


Figure 10—Top; Figure 11—Center; Figure 12—Lower Center; Figure 13—Bottom

conductor creates an electro-magnetic field around the conductor. If the conductor is coiled up, the field can be concentrated so that the coil will attract iron, nickel or cobalt. This electro-magnetic field represents energy. The energy was supplied by the electrical circuit and now resides in the space surrounding the coil. When the circuit is opened, the field disappears and returns the energy to the circuit by *creating a voltage* or electrical pressure in the coil.

How A Radio Station Works

The electro-magnetic field around a conductor which carries alternating current, is constantly collapsing and reversing in direction. It will return its energy to the wire as long as the reversing process is not too rapid. If the reversal occurs frequently enough, or the *frequency* (number of cycles or vibrations per second) becomes high enough, some of the energy in the electro-magnetic field travels away—is radiated. Therefore, the name radio-frequency. There is no sharply defined limit of radio frequency, but generally it is assumed to be from 25,000 cycles per second up. Frequencies lower than this, when sent through a loudspeaker, are translated into *audible* tones hence the term "audio-frequency."

Each broadcasting station, when it is "on the air," is sending out a steady wave at some particular radio frequency, and this is called the carrier wave. As a performer in the broadcast studio speaks into the microphone this carrier wave *varies in amplitude or strength* in accordance with the movements of the microphone diaphragm and the carrier is then said to be "modulated." Figure 10 graphically portrays the carrier wave at a moment when no sound reaches the microphone. Figure 11 shows the carrier wave when "modulated" by speech or other sound at the microphone.

Detection

An exact replica of this wave will reach the radio receiver and must there be converted back into sound. The first step in this conversion process is called detection. A perfect detector is nothing but a device which will permit electrical current to flow in one direction only and not in the reverse direction. When the received signal passes through this detector, it may be represented as in Figure 12. When such a current as that of Figure 12 flows through an electrical device which does not permit the fast variations of the individual radio frequency pulses (the headphone is such a device), the result is an average current, as shown in Figure 13.

LESSON FOUR

Radio Symbols And Circuits

BEFORE the beginner in radio can become proficient in the building of receivers, and the absorbing of more or less technical descriptions of radio apparatus or their functions it is first necessary that he familiarize himself with the tools with which he must work.

Just as the carpenter or cabinet maker must know the various special uses of the particular kind of tools with which he is expected to work, so too must the radio man, if he is to become successful, know how to master the use of the tools which are necessary in the art.

One of the most important tools, that the beginner in radio must learn how to use, is the symbol or graphical representation of a piece of radio equipment so that he may know how too read a radio circuit.

In radio a circuit diagram constitutes a short-cut "language" so to speak, which conveys an intelligent message from one individual to another.

Supposing one engineer wanted to describe a radio receiver to another engineer: that is, tell how many tubes were used, how they were connected one to the other, what battery connections were made, whether it used transformer or resistance coupling, whether a screen-grid tube or power tube were used, and so on. If he desired he could orally describe or perhaps write a lengthy description of the circuit employed, but the quicker way would be to graphically show the various pieces of apparatus employed and show

Figure 16

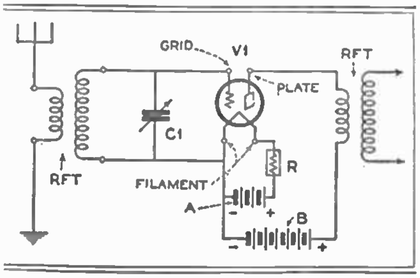


Figure 15

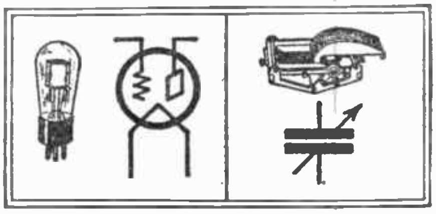
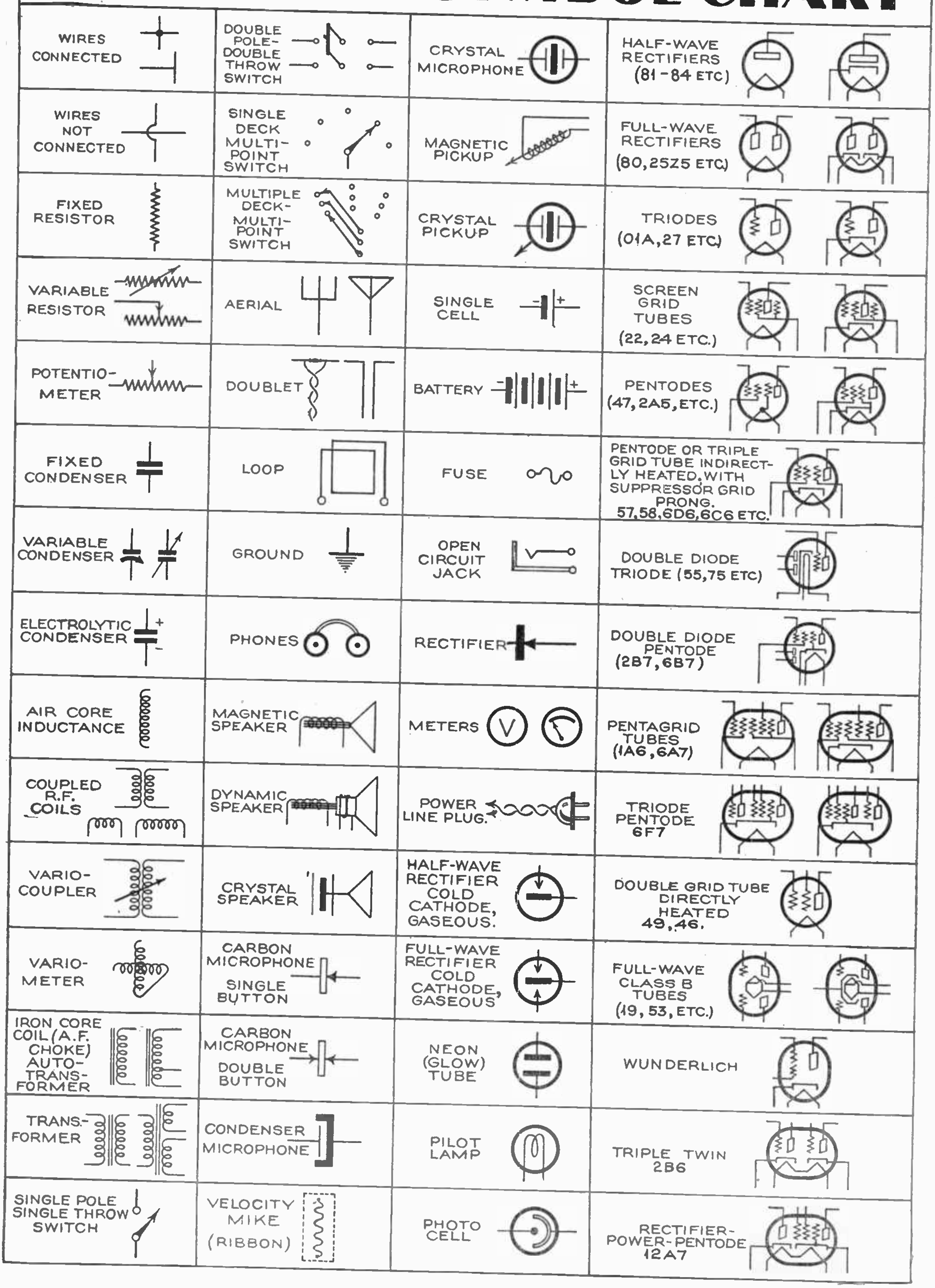
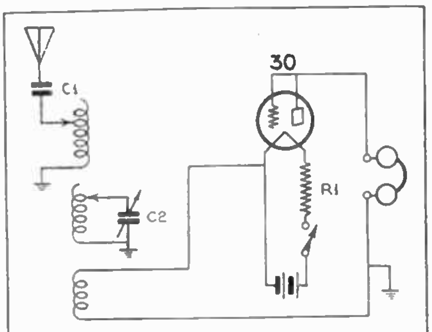
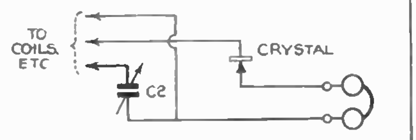


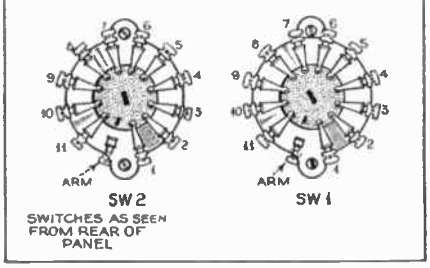
Figure 14

RADIO NEWS SYMBOL CHART









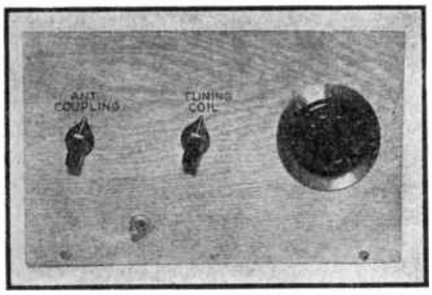


Figure 17—Left, top; Figure 18—Left, Center; Figure 19—Left, Bottom; Figure 20—Above.

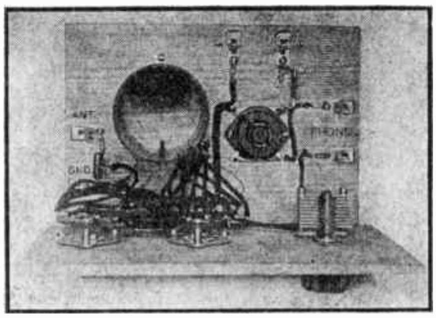


Figure 21

how they were connected to form a complete circuit. He might, in this graphical representation of the receiver, actually draw a picture of a tube, a coil, a resistor, a transformer and so on, but even that would be a long, drawn-out process. And so in radio, to make the job as simple as possible, we make use of symbols or characters to represent these radio parts.

Use of Symbols

For instance, in showing how a tube is connected in a radio circuit, instead of drawing the picture of a tube we use the symbol as in Figure 15 which has been adopted as standard by all the manufacturers, laboratories and radio engineering societies. Another important part which is commonly used is a tuning condenser, shown in the same figure.

And so we might go on indefinitely showing how each part used in radio would look in picture and in symbol. To expedite the assimilation of such knowledge, the Symbol Chart, showing practically all of the more common symbolic representations of parts used, is shown in Figure 14. This chart shows the several symbols for various kinds of radio tubes, different kinds of condensers, various kinds of coils and so on.

It is suggested that, as an aid in learning how to draw these symbols, you memorize a few at a time, then draw them from memory and compare your work with the symbol chart.

A Typical Radio Circuit

Figure 16 shows the construction of a typical circuit, by connecting together, in correct relation, several symbols. The antenna or "Aerial" is connected to the primary coil of the r.f. transformer, RFT. The secondary of this transformer has connected to its terminals a variable or tuning condenser, C1, and then connects to the grid and filament of the radio-frequency amplifier tube V1. This tube has connected to its filament the "A" battery and to its plate the primary of the succeeding r.f. transformer. The circuit is completed by the connection of the lower terminal of the primary of the r.f. transformer to the "B" battery, which has its negative end connected with the negative end of the "A" battery. And so we have a complete radio-frequency amplifier circuit.

To make yourself proficient in the drawing of circuit diagrams, it is recommended that you attempt to read and redraw the circuits which appear on other pages of this book.

One of the best ways in which to familiarize yourself with radio parts and radio diagrams is to actually build a receiver, part by part. The lessons to follow will show how to do just that. The construction will be by easy stages so that you may completely master all of the various problems with which you will be confronted.

Readers who wish to take maximum advantage of these lessons will want to build most of the units to be described. If parts from earlier units are again used wherever possible in building subsequent units, the cost can be held to a low figure.

It is recommend that you study up on radio fundamentals as you go along. Reading of radio books and periodicals will help materially, or enrollment in a regular radio school or correspondence course will result in a well rounded out training in which are combined both theory and prac-

LESSON FIVE

A Simple Diode (or Crystal) Receiver

THE simplest receiver that could be made would consist of a headphone and a detector connected between aerial and ground.

It is more satisfactory and more reliable to use a vacuum tube as a detector as it requires no adjustments of any kind, and so the receiver described here employs a type 30 tube.

This tube contains a filament, a grid and a plate. When the filament is heated, electrons will flow from the filament to the plate and grid (which is connected to the plate externally) but not vice versa.

The tuned circuit consists of the usual coil and condenser and in order to keep the condenser capacity small and still cover the required broadcast range, it is necessary to tap the coil and use a switch to employ any desired part of it. The next problem is

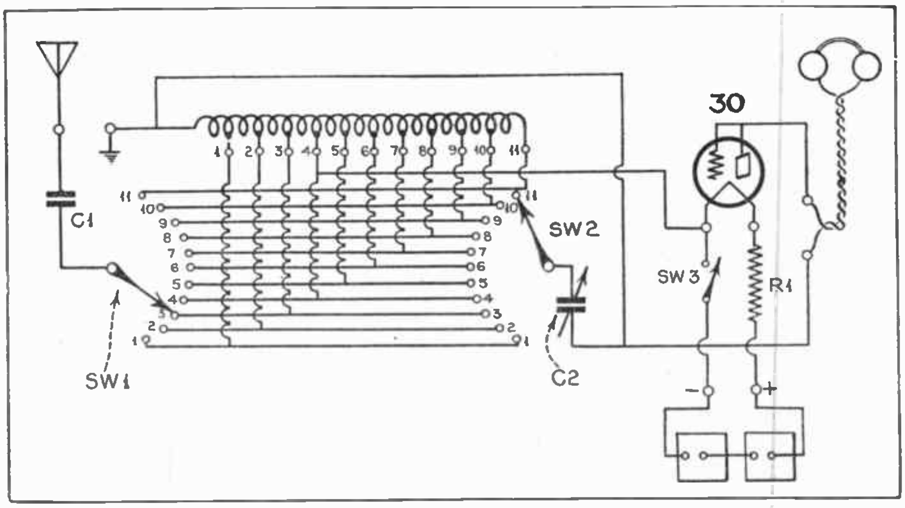


Figure 22, right, shows the circuit diagram.

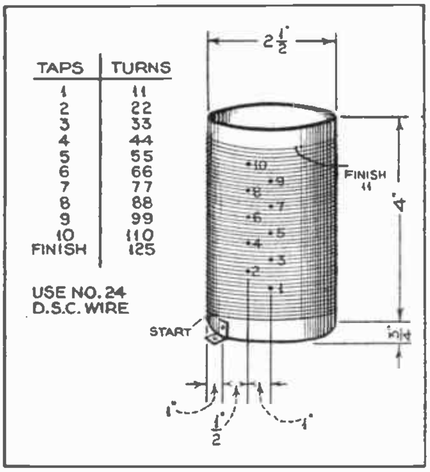
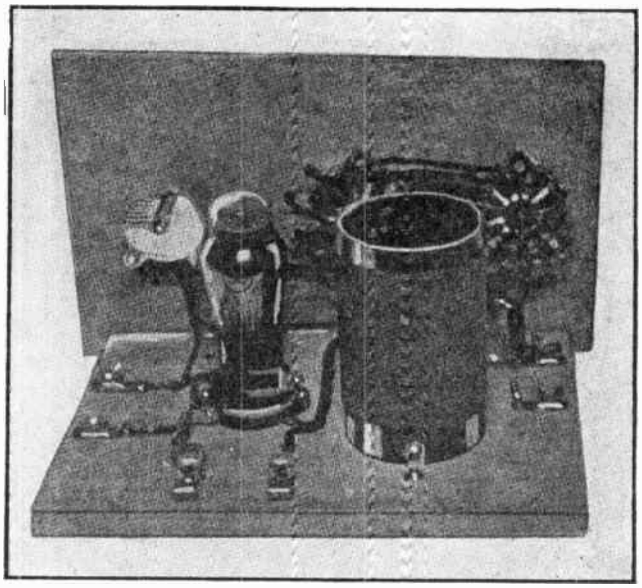


Figure 23 at right shows a rear view of the simple diode receiver.

Figure 24 at left shows the proper location of the taps on the coil.



to collect the signals and bring them to the tuned circuit. This could be done by running the received currents, on their way from aerial to ground, through another coil on the same form as the tuning coil, as shown in Figure 17. The combination would work as a transformer, the antenna winding being the primary and the tuned winding the secondary. The winding which serves as primary had better be variable, too, because the smaller this part, the better the ability of the tuned circuit to separate the signals but the more turns there are in it the louder the signals.

When a crystal detector is used, the detector circuit becomes as shown in Figure 18.

Instead of using the three coils as in Figure 17, it is possible to make a single coil do the work of three by means of taps. This system is employed in Figure 22 which is the diagram of the diode receiver to be built.

Constructional Details

When all the parts have been procured, construction may proceed in the following order:

Beginning with the panel, the centers for the holes should be marked off.

The screws for joining baseboard and panel should be ¼ inch from the bottom edge of the panel. The hole for switch 3 is located 3 inches from the left edge and 1½ inches from the bottom. Drill the holes to fit the various parts.

The panel may now be screwed to the baseboard and all other parts except the coil mounted on the baseboard, as shown in the photographs, Figures 20, 21 and 23. The tube socket should be turned so as to have the large holes towards the back of the baseboard.

After all parts except the coil are mounted, as much as possible of the wiring should be completed. A study of Figures 22 and 19 and the photographs will help. The middle lug of C2 should be the grounded side while one of outer lugs is connected to the moving arm of SW2.

When looking at the back of the panel the switches appear as in Figure 19. Connect point 1 of SW1 to point 1 of SW2, point 2 of SW1 to point 2 of SW2, etc. At the same time solder a few inches of wire to each point of SW2 except to point 11. These wires will later be connected to taps on the coil.

Locating the Taps

Figure 24 and the pictures show the proper location of the taps with reference to the mounting brackets. First drill the holes for the mounting brackets at such a distance from the lower edge that the brackets will be level with the edge of the tubing. Then drill two holes for fastening the beginning of the winding.

When taking off a tap, twist a little loop in the wire, but be careful not to break the wire. The taps of the coil in the illustration are in two vertical rows, making it much easier to make connections as the taps are spaced well apart. When the coil is finished, scrape the insulation from the taps and tin the exposed wire loops. Mount the coil in the proper position and solder the wires from SW2 to the proper taps. From point 1 on SW2 to tap 1, from point 2 to tap 2, etc.

In operating the receiver remember that the right-hand switch, SW2, and the dial both control the frequency of the tuned circuit. For the lowest frequency use the highest taps. The condenser in itself has not enough range to cover the whole broadcast band, so it will be necessary to go to lower taps for higher frequency. The condenser allows you to make finer adjustments.

Switch 1 adjusts the coupling of the antenna. The set will be more selective if the switch is set on the lower taps On the other hand, the higher taps make the stations come in stronger. The best compromise has to be found.

Parts List

C1—Aerovox mica condenser type 1467. .00025 mfd.
C2—Hammarlund "Star" midget variable condenser, 140 mmfd.
SW1, SW2, Yaxley one-gang 11 point switches, non-shorting, type 1211
Bud 2¾ inch dial
Bakelite coil form, 2½ inches in diameter. 4 inches in length
¼ lb. magnet wire, number 24, d.s.c.
4 Fahnestock clips, 1 inch overall
2 small angle brackets (for mounting the coil)
1 baseboard, wood, 6x9x½ inch thick
1 panel, wood, 10x6x¼ inch thick
1 pair of Acme headphones, 2000 ohms

When using tube as detector, add:

1 Eby basemount socket, 4 prong
R1—15 ohm filament resistor
SW3 s.p.s.t. toggle switch
2 Fahnestock clips, 1 inch overall
2 Burgess "Little six" dry cells
1 type 30 tube

When using crystal detector, add:

1 crystal with holder

LESSON SIX

Operation Of Vacuum Tubes

THE little receiver described in Lesson Five employed a vacuum tube as a diode detector. Lesson Seven will be devoted to describing minor changes in this receiver so as to employ the same tube as a much more efficient detector, providing louder signals and reception from greater distances. Before proceeding it will be best to review briefly the action of a vacuum tube.

A vacuum tube consists of a closed bulb of glass or metal wherein several metallic elements are placed. The simplest type ("diode") has two such metallic elements, a filament and a metal plate. When the filament is heated, electrons—the smallest known negatively charged particles—will be thrown off the filament wire. The heating of the filament is for no other purpose than to obtain a source of free electrons in this manner.

What happens to the electrons? When enough of these negative particles leave the filament, the filament itself becomes

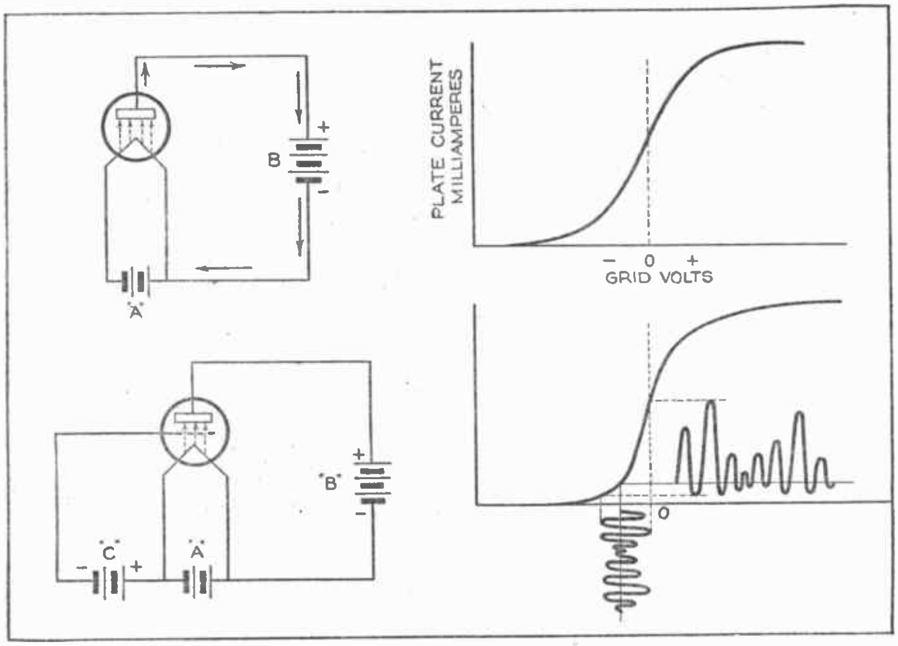


Figure 25—Upper left; Figure 26—Lower left; Figure 27—Upper right; Figure 28—Lower right.

positive. When this occurs the electrons tend to rush back to the filament unless a stronger attraction is provided elsewhere in the tube. The entire action of a vacuum tube hinges on the controlled movement of these electrons. The presence of air hampers this movement and for that reason the air is pumped out of the tube during manufacture, hence the name "vacuum" tube.

The Diode Tube

When a metal plate is nearby, and the metal plate is insulated, some of the electrons will settle down on the plate until it becomes negatively charged, in which condition it will repel other electrons. If the metal plate is connected to the filament, the electrons which went to the plate will return to the filament through the wire because the filament is positive (lacking in negative electrons). Thus an electric current will flow from the filament, through the vacuum to the plate and then through the wire back to the filament.

Suppose we go a step further and by inserting a battery, "B," between the plate and filament, make the plate positive with respect to the filament (Figure 25). Then the electrons will be attracted to the plate and pass through the battery and back to the filament. The current obtained in this way is much larger than without a battery, the amount depending on the voltage between plate and filament. If, on the other hand, the plate were made negative with respect to the filament (by reversing the battery connections), the plate would repel the electrons and practically no current would flow in the plate circuit. This type of tube is called a "diode" and is a device which conducts electricity in one direction only.

The first property is utilized in the use of such a tube as a detector (or rectifier). Since it conducts in one direction only, the negative half of an alternating voltage does not produce any current and alternating currents are therefore converted into direct current.

The Triode Tube

Introduction of a third element (making the tube a "triode") opens up new possibilities for the tube. When a "grid," consisting of a metal spiral or a mesh of wires, is placed between the plate and filament and the plate is made positive, it is possible to control the plate current by applying small voltages on the grid. This works as follows: Since the grid is much closer to the filament than is the plate, it has a greater effect on the electrons which are just emerging from the filament. When the grid is made negative, even a few volts, it may completely cancel the attracting power of the positive plate. On the other hand, reducing the negative voltage applied to the grid, will allow electrons to pass through the grid on their way to the plate. As long as the grid does not become positive, there will be no current in the grid circuit and it will take no power to control the larger power in the plate circuit.

To illustrate a tube's properties or characteristics the radio man resorts to the use of curves. One such curve showing the plate current for different grid voltages while the plate voltage is constant, is shown in Figure 27. Note that there are two bends in the curve. The upper bend is present because there is a maximum "saturation" current which exists when all the electrons emitted by the filament are travelling to the plate. There is a different saturation current for each plate voltage and each filament voltage, because a higher filament voltage will cause a greater emission and a higher plate voltage will exert a greater pull on the electrons, which is necessary to overcome the "space charge," which is a charge of the cloud of electrons themselves. This charge also limits the maximum plate current.

Plate Detection

There are several ways in which a tube can be made to detect (rectify). In Lesson Three we said that an ideal detector would be a device which is conductive only in one direction. However, a perfect detector has not been developed to date. Nevertheless this rectifying action can be performed and utilized even though the rectifier is not perfect.

The most simple way to use a tube as a rectifier or detector would seem to be to give the grid a steady negative voltage (as in Figure 26) so that the operating point is on a sharp bend of the curve. Figure 28 illustrates what happens when a signal voltage is applied to the grid. While the grid voltage varies up and down, the plate current will go up and down too but it responds much better in one direction than in the other because of the bend in the characteristic. The plate current now closely resembles the rectified current shown in Figure 12, and this current when passing through the phones will reproduce the original sound which first entered into the microphone at the transmitter.

The difference between the above described system and diode detection is that it is much more sensitive because the tube when used as a triode, serves as an amplifier as well as a detector. The increased power is supplied by the B-battery with the grid acting as a valve to control it, while in the diode system the received signal itself must supply the power for the phones. A triode receiver appears in Lesson 7.

LESSON SEVEN

Building A Simple Triode V. T. Receiver

THERE are several reasons why the method of operation described in Lesson Six, (Figure 26), is not popular for small sets. In the first place it requires an extra "C" battery and it is necessary to know the exact location of the sharpest point of the bend for a given plate voltage, so as to get most efficient detection.

A second system which does not require a "C" battery is more practical for a simple receiver. This makes use of a grid condenser and a grid leak. The circuit is shown in Figure 31. The gird-leak resistor, R2, is connected to the positive side of the filament, making the grid slightly positive and as a result a considerable plate current will flow when no signal is coming in. When the grid is driven more positive by a signal (the positive half of a cycle), electrons will be attracted by the grid itself and will charge the grid-condenser C3, the grid side of it becoming negative. During the next half-cycle (negative) no electrons can be attracted and the grid cannot get rid of its charge except through the grid leak R2. This takes a relatively long time and while a current is flowing through the resistor, there is a voltage drop across it making the grid negative except at the peak

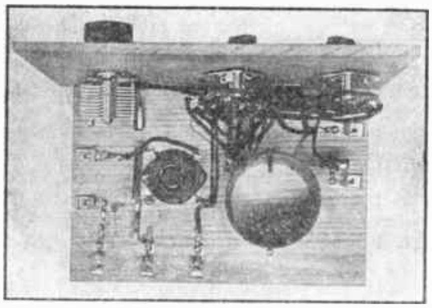
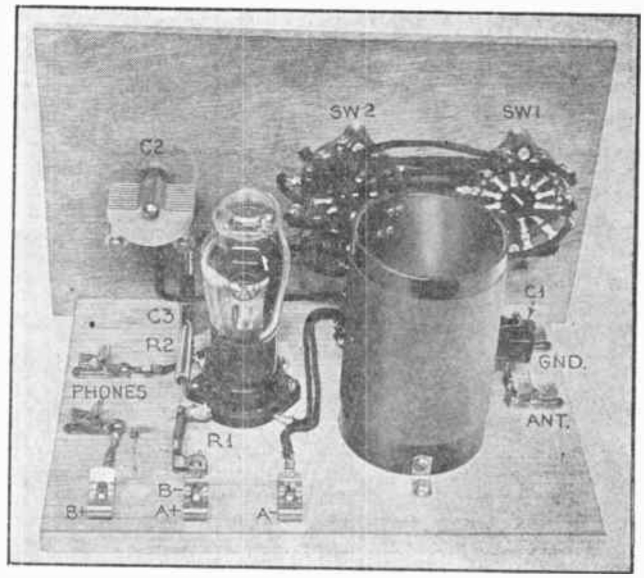


Figure 29 at the left shows a top view of the triode receiver with the tube removed.

Figure 30 at the right is a rear view, showing placement of the various parts. Note the additional clip, resistor and mica condenser.



of the positive half cycle. In this way the bias adjusts itself to a point where detection takes place.

Proper proportioning of the grid condenser and grid leak are necessary, so the charge will leak off at the required rate. Suppose, for instance, that the grid resistor has a very high value, it will take very long before the charge leaks off and during that time, the grid may stay so far negative that the tube is inoperative. On the other hand, if the resistance is too small there may not be enough bias and the tube will be insensitive.

The Revised Receiver

This circuit is used in the revised receiver and makes the signals much louder. For detection purposes a rather low plate voltage ("B" battery) will be satisfactory. It works well with only 22.5 volts. Since a standard 45-volt "B" battery is required for use with units to be described in other lessons of this series, the parts list shows such a battery rather than the 22.5-volt type. There is, of course, no objection to using a smaller capacity battery with 22.5 volts maximum for this receiver.

The complete circuit of the new unit is shown in Figure 31.

Changing the old circuit to the new one is simple. The connections to the coil and the tap switches remain the same; nearly all changes are made at the tube socket. First mount another Fahnstock clip at the right-hand back corner of the baseboard. This will become the B plus terminal. Disconnect and remove the leads to the phone jacks and to the plate and grid of the tube.

There is a wire which runs from the filament switch to tap 3 or 4 of the coil. Disconnect this wire from the coil and connect it to the ground wire. This connects the negative side of the filament to ground.

Connect the B plus Fahnestock clip to the nearest phone clip. The other phone clip is connected to the plate terminal of the socket. The grid condenser, C3, is connected from the stationary plates of the tuning condenser (one of the outside terminals) to the grid terminal of the tube socket. Then connect the grid leak, R2, from the grid terminal to the positive filament terminal. The photographs, Figures 29 and 30, will aid in making these changes.

When hooking up the set, note the correct polarity of the batteries and connect them as shown in Figure 31.

Additional Parts List

(for change over to triode detection)

C3—Aerovox, type 1467 mica condenser, .0001 mfd.
R2—IRC carbon resistor, 2 megohms.
1 Fahnestock clip
1 Burgess standard 45-volt B-battery, tapped at 22½ volts.

LESSON EIGHT

Radio And Audio-Frequency Amplification

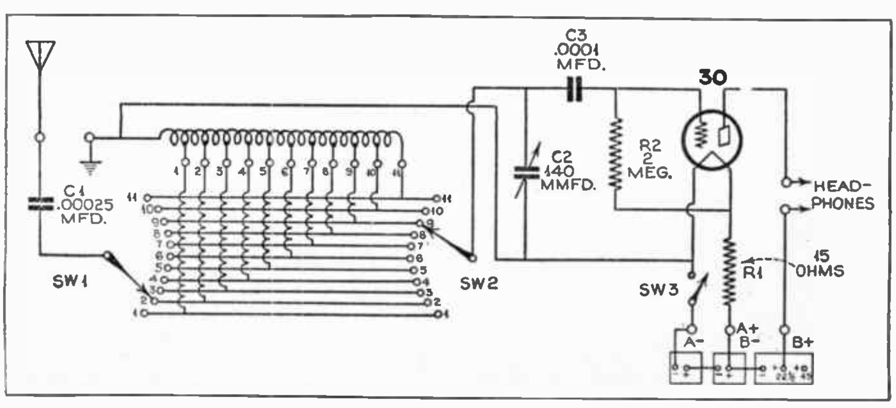
BESIDES performing all the functions described in the previous lessons, the modern radio receiver *amplifies* the signal (multiplies its strength or intensity) many thousands of times.

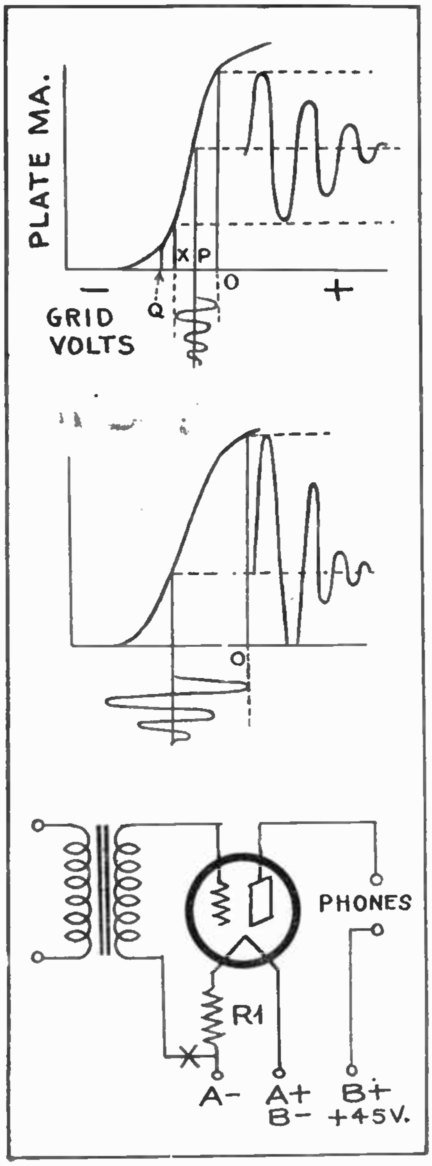
Amplification can be accomplished either before or after the detector of a receiver or both before and after. An amplifier ahead of the detector must operate at the original frequency of the incoming signal; it is called a radio-frequency amplifier. An amplifier stage after the detector is called an audio-frequency amplifier. The difference in results obtained is that an audio-frequency amplifier is intended primarily to make received stations come in louder. If the signal from a distant station is too weak to be detected, no amount of audio-frequency amplification can bring it in. Radio-frequency amplification increases sensitivity and will add new stations. It also provides the opportunity for additional tuned circuits and therefore sharper tuning.

Why is it that the same tube can work as a detector or as an amplifier? This brings us back to the theory of tubes.

An amplifying stage consists of a tube and some means of coupling it to the previous tube. First let us confine our attention to the tube itself. In Figure 27 we showed a so-called "static characteristic," which illustrates the variation in plate current due to changes in grid voltage while the plate voltage remains fixed. Actually the plate voltage does not remain fixed during operation because the phone or transformer in the plate circuit has resistance and inductance which cause a voltage drop across it when the tube plate current flows. This voltage drop will

Figure 31—The complete circuit of the triode receiver.





At left: Figure 32—Top; Figure 33—Center; Figure 34—Bottom.

change when the plate current changes, which results in a change of plate voltage. Curves which take these things into consideration are called "dynamic characteristics." These enable the radio man to determine the best plate and grid voltages, etc., and to find the other necessary constants of the circuit. However, these curves do not lend themselves to an easy explanation of the tube's functions. Therefore, we are sticking to the static characteristic which better illustrates what happens.

Used as Amplifier

The coupling device usually consists of a transformer or a network of resistors and condensers. It is important to prevent the plate voltage of the previous tube from reaching the grid of the next one. A transformer does this, generates a signal voltage in the secondary and gives some amount of step-up. The voltage in the secondary would be three times the voltage in the primary if a 3-1 ratio transformer were used, for instance. Of course this adds to the amplification.

Figure 32 illustrates the characteristics of a tube and shows the way it amplifies. The grid is given a fixed negative voltage so as to bring the operating point to the center of the straight portion of the curve. The detector utilizes the bend of the curve, as explained in Lesson Six, but the amplifier must work on the straight part. The way to make the tube do the required work is to give it the correct fixed negative voltage or "bias" also called "C-bias" because it would require a third or C-battery. So in the case of Figure 32 if the fixed bias is equal to OP, the tube is an amplifier, if it is equal to OQ it is a detector.

When working a tube as an amplifier, there are two things to look out for. The first one is to keep the variation of grid-voltage due to the signal within the limits of the straight part of the "curve," and never to let it run over a bent part. As long as the straight portion of the characteristic is utilized, the plate current will vary in exact proportion to the grid voltage. As soon as the grid-voltage becomes too large so that the tube works on a bend during a part of the cycle, the plate-current variations no longer correspond to the grid-voltage variations, in other words there is distortion. This is illustrated in Figure 33. It is seen that the tops have been cut off the highest peaks. For this reason, it is essential that the applied signal voltage should never exceed OP or PX. In a good arrangement OP should equal PX.

Grid Always Negative

The second limitation is that the grid should never be allowed to go positive. As soon as this happens grid current will flow and the grid current will cause a voltage drop in the grid circuit which usually has a high resistance. This voltage drop subtracts from the signal voltage and therefore is another cause for distortion. In practice then, it is only possible to use that part of the straight portion of the characteristic which is situated to the left of the zero line.

The fixed grid voltage or bias should then be chosen at the center of this straight portion.

The manufacturers have listed the proper grid bias for different plate voltages, so it is not necessary to make a curve (they are made by measurements). But this explanation should clarify the meaning of these figures. It should also be clear now that if the recommended grid bias is 2 volts, the peak of the signal voltage on the grid should never exceed 2 volts. This is equal to 1.4 volts as shown by an A.C. voltmeter as only the peaks reach 2 volts, whereas the voltmeter shows an average rather than peaks. If the signal is likely to exceed this value, one must look for another tube which has a larger fixed bias. Sometimes the same tube with a higher plate voltage will need the larger bias and would then be suitable, the very strongest stations could just reach the maximum signal allowable of 1 volt peak.

LESSON NINE

A One-Stage Audio Amplifier

NOW, we will employ a 30 tube with a plate voltage of 45 volts and build an amplifier unit for the receiver described in Lesson Seven. Since the plate voltage is so low and our signal is rather weak, we need a grid bias of about one volt. This can be obtained without the use of an extra battery. The filament requires but two volts while the battery supplies 3 volts, the extra volt is lost in the resistor R1. If we place this resistor in the negative leg of the filament circuit, the negative side of the battery will be 1 volt negative with respect to the negative side of the filament. All we have to do is to connect the lead marked "F" of the transformer to the negative A terminal and 1 volt bias results. See the circuit of Figure 34.

The illustrations, (Figures 35 and 37), clearly show the layout and construction of the unit. The Fahnestock clips are so arranged that it is easy to connect the two units together, or to operate either one separately. It was found necessary to make a small change in the unit described in Lesson Seven in order to have the original switch control the filament of both tubes. This

Figure 35

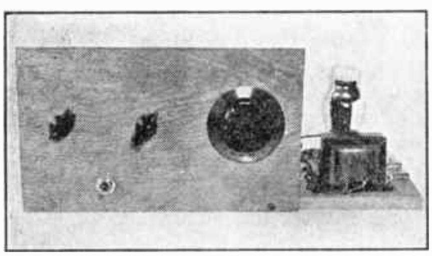
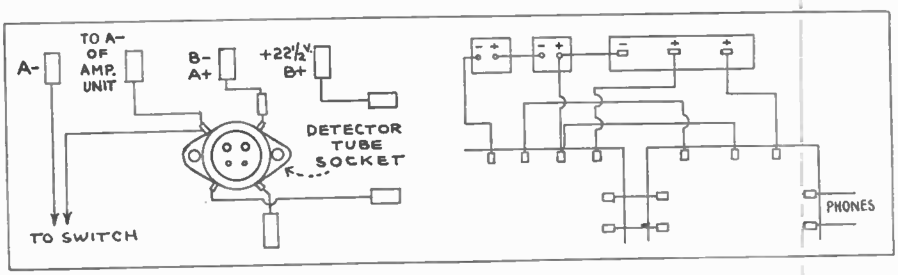


Figure 36—At left, the new layout for the clips. At right, the battery connections.



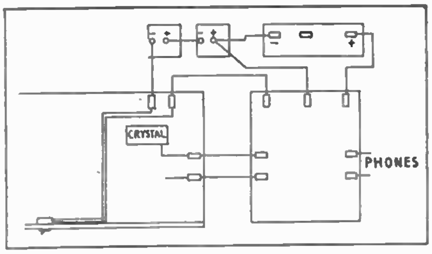
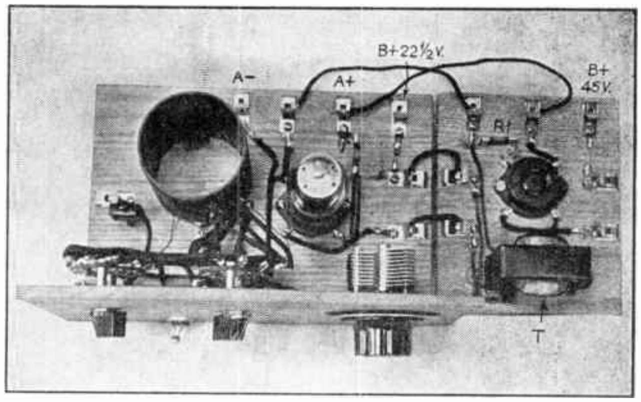


Figure 37, at right, shows the layout of parts in the amplifier unit and the proper connections to the previous set. Figure 38, at left, shows how the amplifier is connected to the crystal receiver.



is done by adding a Fahnestock clip and connecting it to the negative filament terminal of the detector socket. The original A— clip is moved over towards the left and the new one put in its place; then both are connected as shown in Figure 36, left.

Constructional Details

The amplifier is built on a ½-inch baseboard 5 inches wide and 6 inches deep (the same depth as the old unit). Mount the parts as shown in Figure 37. The transformer has its wires marked; the side which has the plate (P) and B plus wires coming out should be turned towards the front. The socket is mounted with the filament terminals towards the back.

The Fahnestock clips on the left edge of the baseboard should be placed so that they come exactly opposite the phone terminals of the one-tube set. Soldering lugs should be employed at each Fahnestock clip. You should also use a small drill to make holes for all screws to avoid splitting the baseboard.

The wiring is simple. Be sure to connect the transformer wires right. The red wire, marked G, goes to the grid terminal of the socket, while the one marked F should go to the A— Fahnestock clip, the one which has the resistor connected to it. This is important for obtaining the right negative bias on the grid.

Operation

Connect the two units together as shown in the top view, keeping in mind the polarity of the A terminals. Then connect the batteries as shown in Figure 36, right. A 45-volt B battery is employed, the same one as used with the original set. Those who wish may try higher voltages, but then a 3-volt battery should be inserted at X, (in Figure 34), with the negative side connected to the transformer, the positive side to A—. The actual operation and tuning remain the same as described in Lesson Seven, because the addition of the amplifier stage does not add any controls.

Adding Unit To Crystal Set

Readers who made the crystal set described in Lesson Five can also employ this amplifier unit. The two units can be connected up without any further changes except that there is no filament switch. You would have to take the tube out or disconnect one of the filament wires to turn off the amplifier. The remedy is to put a switch on the main panel and place two Fahnestock clips at the back of the baseboard, the connections are then as shown in Figure 38.

It is possible to use this amplifier with the diode detector described in Lesson Five, but this would be rather impractical and wasteful. It is therefore recommended that those having the diode receiver convert it for triode operation as described in Lesson Seven. In this way greater sensitivity and output volume will be obtained. Then the one-stage audio amplifier described in the present lesson can be added as explained above.

Parts List for Amplifier Unit

R1—15-ohm wire-wound filament resistor
T—United Transformer Co. interstage transformer, type U31
1 Eby base mount socket, four-prong
8 Fahnstock clips, 1 inch overall
Baseboard, 5 inches by 6 inches by ½ inch thick
Lugs, screws, push-back wire

LESSON TEN

How A Power Supply Works

PREVIOUS constructional lessons have covered battery-operated equipment, but, from now on the equipment to be described will be for operation from 60-cycle, 110-volt A.C. lighting lines.

All but the most simple radio receivers require direct current of several different voltages up to 300 volts and current values so large as to make batteries impractical. In order to meet this demand, the modern receiver includes a "power supply"—which turns the 110-volt A.C. into higher D.C. voltage and at the same time delivers A.C. of a few volts for the tube filaments.

This and the next three lessons will describe a general utility power supply and audio amplifier in one unit which can be used with the several tuning units to be described later. This unit is also an excellent audio amplifier for phonograph reproduction and it can be used with Lesson Nine's battery set to obtain high-volume loud-speaker reception. Lessons Ten and Eleven will describe how the apparatus works and the constructional details will be given in Lesson Thirteen.

Obtaining D.C. from A.C. is accomplished by means of a "rectifier"—a device which conducts electricity in one direction only and was described in Lesson Three. For several reasons it is necessary in the case of a power supply to utilize both halves of the wave and to arrange two diode rectifiers to provide "full-wave" rectification.

Operation of the 5Z4 Tube

Referring to Figure 39, the 5Z4 tube has been drawn upside down for convenience. The transformer winding, B, serves to heat the filament of this tube. This particular rectifier is one of the "indirectly heated" type. Its cathode consists of a tiny cylinder which is a good electron emitter when heated. The filament is inside of and heats the cathode but does not touch it—therefore the term "indirectly heated."

Transformer winding C delivers 375 volts A.C. each side of the center tap. On one-half of each cycle the plate P becomes positive with respect to the ground, or center-tap. A diode conducts only when the plate is positive; therefore, during this half cycle, electrons will flow from the cathode to plate P, through the upper part of winding C to ground and from ground through the resistor, the speaker field and the choke back to the cathode. Meanwhile, the lower half of winding C is not conducting any current.

During the next half cycle, the conditions are reversed and Q becomes positive. Consequently, electrons will flow from cathode to plate Q, through the lower half of winding C to ground and back again through R6 and the chokes. The direction of the electron flow through the resistor and the chokes is the same in both cases and the result is 120 pulses of D.C. per second. If this pulsating voltage were applied to the plates of the amplifier tubes, a loud 120-cycle *hum* would be heard in the speaker. To smooth out the pulsating voltage and remove the hum, a filter must be used.

The Power Supply Filter

The power supply filter generally consists of one or more sections, each section consisting of a choke in series with the rectifier output and one or two condensers across the output. The first condenser C4 serves as a reservoir. At the peak of each voltage impulse the condenser charges up to that peak, but as the voltage subsides the condenser discharges through the

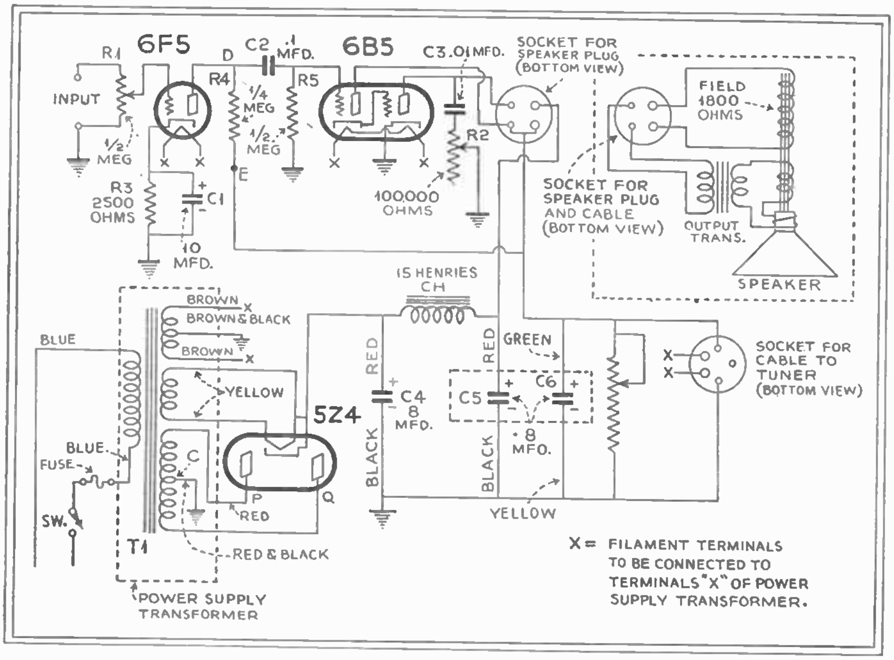


Figure 39—Circuit diagram of the amplifier and power unit.

chokes and the resistor. The net result is a partial smoothing out of the impulses as well as the raising of the average voltage.

The choke, CH, tends to oppose any change in current and therefore helps also in smoothing out the impulses. The function of condenser C5 might best be explained by considering that the current passing through the choke consists of the desired direct current plus some undesirable 120-cycle A.C. It is the purpose of C5 to remove the alternating current by providing an easy path to ground for it. The D.C. cannot, of course, pass through a condenser. In this filter the hum has been cut down about sixty times in the first section. In the next section the hum is cut down again about 200 or 300 times. These effects multiply so that the total reduction of hum in both sections is 60 x 300 or 18,000 times. Such a reduction is more than enough. Measurements have shown that the hum voltage across the primary of the output transformer is less than .1 volt, while the maximum signal voltage across this primary is nearly 200 volts.

The Speaker Field

A further explanation of the speaker field is needed. This and all other "electrodynamic" speakers require that a current be sent through the magnet or "field" windings. At the same time the field can serve as a choke in the filter, thus killing two birds with one stone. There are, however, complications to this arrangement. The field requires a certain minimum power to be properly magnetized and consequently the number of turns of the field must be just right for the total current flowing through it. These fields are usually specified by their resistance as well as the power consumption. When designing the power supply, the designer must arrange the circuit so that he makes best use of the field's filtering property without losing too much voltage in it.

More or less standard field resistances are 1000, 1800 and 2500 ohms, which usually require currents of 100 ma., 70 ma. and 45 ma. respectively. In our case, the power supply unit is designed to provide a maximum direct current of 85 ma. and so the 1800-ohm field was most suitable. During the employment of smaller tuning units with a total drain of only 50 ma., including the amplifier, extra current can be drawn through the bleeder resistor R6 by decreasing its resistance, in order to bring up the total current drain, if this is found necessary.

A 5-prong socket is provided for carrying the power to a tuner unit, although only 4 prongs are used. The extra prong is to prevent the error of plugging this cable into the 4-prong speaker socket.

LESSON ELEVEN

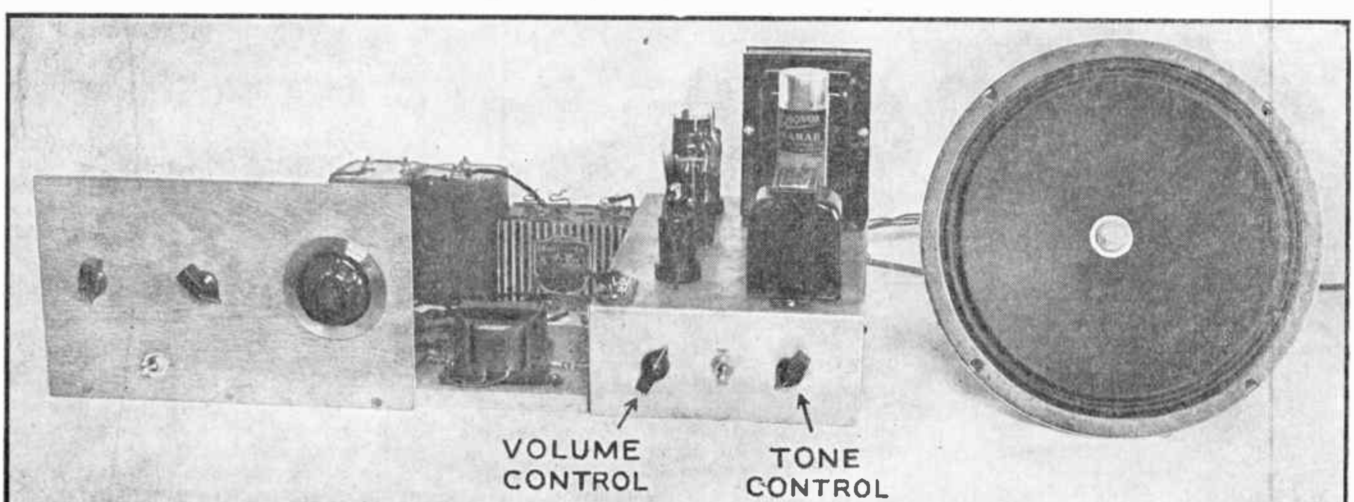
Operation Of An Audio Amplifier

THE amplifier in the circuit shown in Figure 39 employs two tubes, but it really includes three stages, because the 6B5 consists of two tubes and the coupling means, all with a single bulb.

The first tube, a 6F5, is an indirectly heated triode employing "automatic bias" or "self-bias." The plate current on its way to "ground" through the cathode circuit passes through a resistor, R3, with the result that a voltage drop is developed across it and the cathode is positive with respect to ground by the amount of this voltage.

Since the grid is connected to ground, the

Figure 41—The amplifier unit connected to the one-tube receiver.



grid is thus made negative with respect to the cathode.

The cathode resistor must be "by-passed;" that is, an easy path for alternating or voice currents must be provided by a condenser in parallel with it. If this were not done, the amplified signal would pass through the cathode resistor, causing alternating voltages across it, and the grid voltage would vary accordingly. This variation in cathode voltage would be in such a direction as to oppose the original signal and amplification would be reduced. The large by-pass condenser, C1, provides a very easy path for alternating currents and so practically nothing will be fed back to the grid.

The resistance coupling consists of the combination R4, C2, and R5. The plate current of the 6F5 passes through R4 and causes alternating voltages across it. Since the point E is held at a fixed potential (plus 300 volts), the voltage at D fluctuates. The ideal way of coupling would be to connect the grid of the next tube to D and the cathode to E, but unfortunately this is impractical, because the high plate voltage at D would likewise be applied to the 6B5 grid. C2, R4 and C6 may be considered in parallel with R5, with the result that the greater part of the signal voltage is also across R5. There is not much loss in the condenser coupling through C2 and C6 if the condensers are large enough. C6 is always large enough, but C2 has to be chosen so that its reactance is low compared to the resistance of R5. The reactance varies with frequency, so the calculation has to be made for the lowest frequency which has to be amplified.

On the other hand, C2 cannot be too large or a loud signal may make the grid of the 6B5 positive for a very short time. When this happens, the condenser C2 will be charged, making the grid negative and "blocking" the tube. The charge leaks off through the resistor R5. The larger C2 and the larger R5, the longer it will take before the charge has disappeared and the tube is working again. The values must be chosen so as to make the blocking time

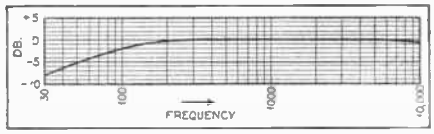


Figure 40—The fidelity curve.

very short. In the example of Figure 39, it will be one-twentieth of a second.

The story of the 6B5 is much too long to be told in this lesson. The tube was chosen because it does its work well and because it requires the simplest circuit. It is best to consider that it consists of two coupled triodes. The bias for the tubes is developed automatically inside the tube.

The power tube drives the speaker voice coil through a transformer. The voice coil consists of a few turns of heavy wire and therefore offers a relatively low resistance. For efficient operation this must be matched to the higher output resistance of the tube. The output transformer, included in the speaker, performs this function.

LESSON TWELVE

Fidelity Of Amplifiers

IN the previous lessons the discussion on the amplifier and power pack wasn't quite completed. Therefore the remainder will be covered in this lesson.

The tone control has been added because one or more of the tuners to be described in later articles will be of the all-wave type. Such reception often requires that interfering noise be reduced and since most such noise consists of high-pitched sounds, a tone control which reduces high notes is helpful.

The ordinary type of control depends on the fact that a condenser offers an easy path for high frequencies and not for low frequencies, its "impedance" becoming lower and lower as the frequency increases. Thus a condenser placed across the circuit by-passes some of the audio currents, particularly those of higher frequencies. A variable resistor in series with the condenser will regulate this action, the adjustment of the resistance value varying the degree of tone control. When the series resistance is large enough there will be no tone control action. In Figure 39, the tone control consists of C3 and R2.

The Fidelity Curve

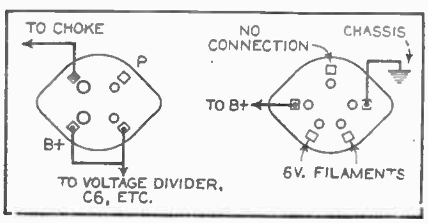
Whenever the best quality is desired the tone control should be adjusted for maximum resistance by turning the control R2 all the way to the left. Maximum noise reduction, on the other hand, is obtained with R2 turned to the opposite extreme. If a greater degree of tone control is required it can be obtained by changing C3 from .01 to .05 mfd.

In order to judge the performance of an amplifier the radio man makes curves showing the variation in output for different frequencies while the input is held constant. This is called the "fidelity curve" and in its most perfect form it should be a straight line. Figure 40 shows the curve of the amplifier as it was measured in the RADIO NEWS Laboratory. It was measured with the amplifier connected to a resistance load instead of the speaker. Therefore, it does not include the characteristics of the speaker.

The gain or amplification of the amplifier is 77 decibels. It is not possible here to go into an explanation of the decibel as a unit. One might think of a decibel as representing a change in sound level just sufficient to be noticeable to the ear. In practical language a 77 db. gain means that it takes .25 volts at the input terminals of the amplifier to obtain 4 watts output (the maximum output for the 6B5). The signal across the output transformer primary is then 170 volts approximately.

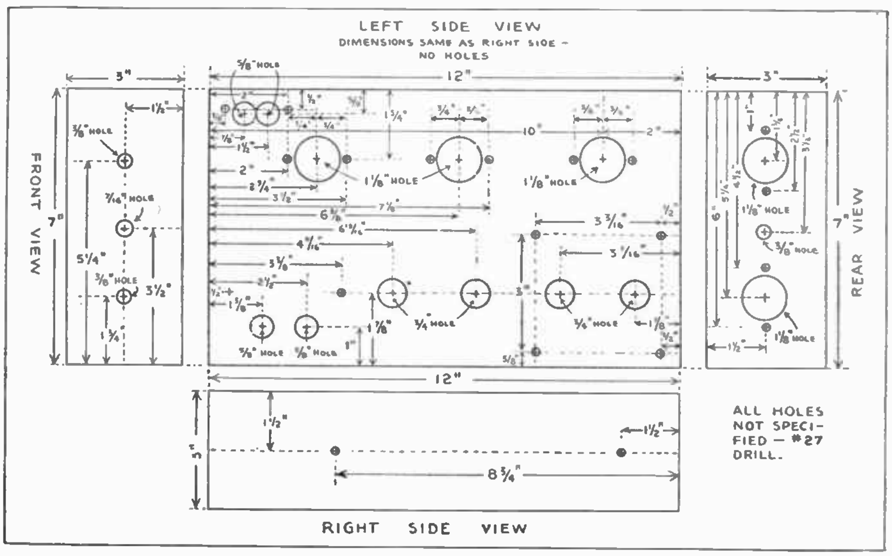
For those who wish to acquire the parts for this combination A. F. Amplifier and Power Supply Unit, a parts list follows. The drilling specifications of the chassis are given in Figure 43.

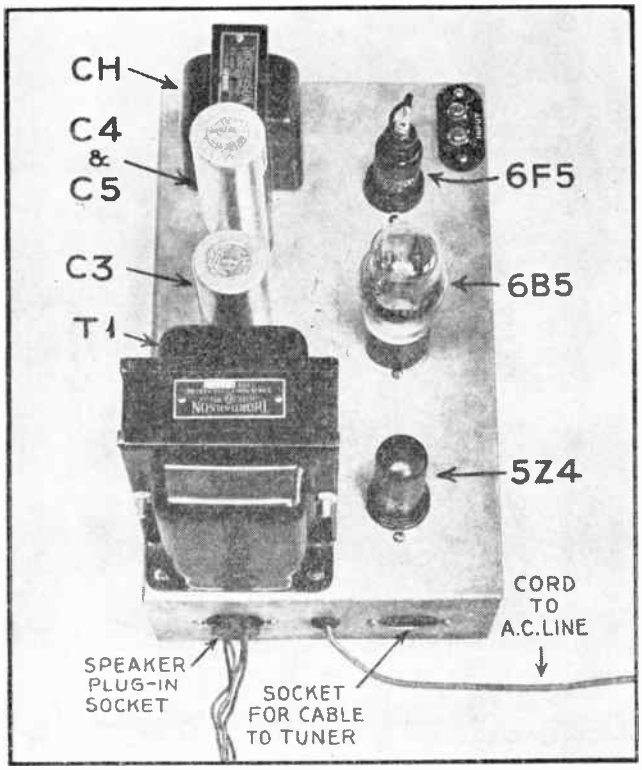
Figure 42—Below; Figure 43—Right



Parts List

C1—Aerovox electrolytic condenser, type PR50, 10 mfd., 50 volts
C2—Aerovox tubular paper condenser, type 484, .01 mfd., 400 volts.
C3—Aerovox tubular paper condenser, type 484, .01 mfd., 400 volts.
C4—Aerovox dry electrolytic condenser, type GL, 8 mfd., 525 volts
C5, C6—Aerovox dual dry electrolytic condenser, type GGL, 8-8 mfd., 525 volts.
R1—Electrad volume control, type 203, 500,000 ohms
R2—Electrad tone control, type 242, 100,000 ohms
R3—IRC carbon resistor, 2500 ohms, ½ watt





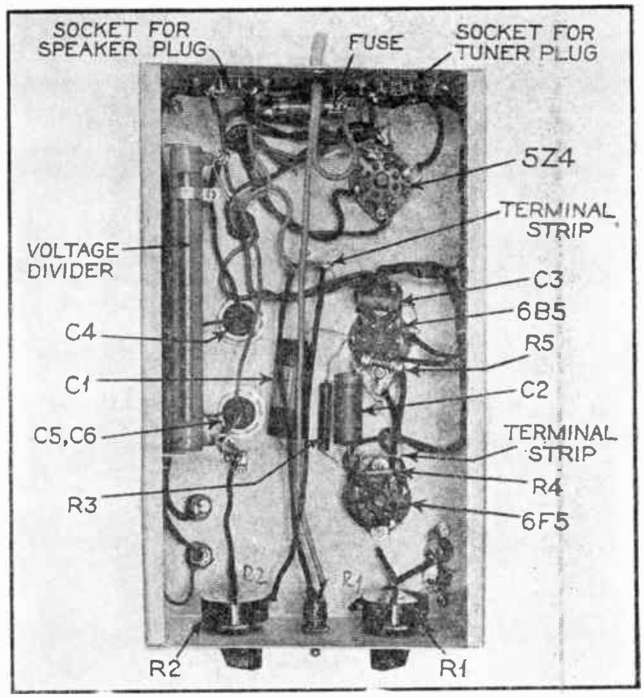


Figure 44 at left shows a top view of the amplifier-power unit. Figure 45, above, a bottom view.

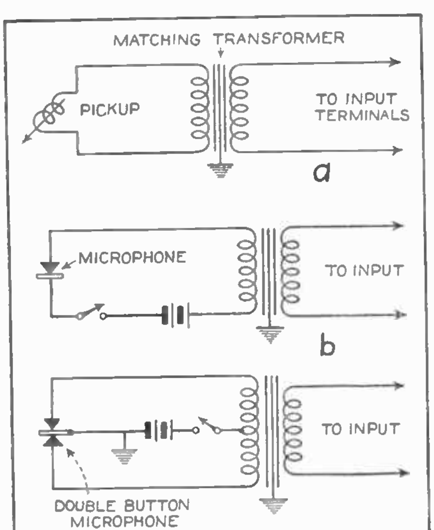
R4—IRC carbon resistor, ¼ megohm, ½ watt
R5—IRC carbon resistor, ½ megohm, ½ watt
R6—Electrad variohm, 25,000 ohms, 75 watts
T1—Thordarson power transformer, type T7062
CH—Thordarson power choke, type T1607, 15 henries, 85 ma.
Wright-DeCoster 10-inch dynamic speaker, model 820-B (speaker field 1800 ohms, transformer primary 7000 ohms)
1 four-prong, 1 five-prong, 1 six-prong and 2 octal wafer type sockets. Mounting centers 1½ inch
ICA cadmium-plated steel chasssis 12x7x3 inches high, type 1527, blank or drilled
SW1—ICA toggle switch, type 1230
2 ICA bakelite pointer knobs, type 1155
1 ICA terminal strip marked "INPUT," type 2417
1 ICA fuse mounting, type 2340
1 Littelfuse 2 amp. fuse
2 lug terminal strips, each having 2 terminals
1 rubber grommet for ⅜-inch hole
1 small grid-clip (for metal tubes)
1 line plug and 5 feet of line cord
Bolts, nuts, washers, soldering lugs, push-back wire
1 6F5 tube 1 6B5 tube 1 5Z4 tube

LESSON THIRTEEN

Constructing An Amplifier-Power Unit

IN selecting the parts employed in the model discussed in this lesson, every effort was made to keep the cost as low as possible, consistent with the required quality. It is not imperative that the parts employed by the constructor be of the exact makes and type numbers shown in the list of parts in Lesson Twelve, but it is important that the quality and electrical values be the same if results are to equal those provided by the model. If substitutions are made they may in some cases require some alteration in the drilling layout.

Figure 46



The first thing to do is to prepare the chassis. The socket holes can be made easiest with a punch such as the Livermore Five-In-One Punch on sale at many radio stores. Holes of five different sizes can be made with this tool. The holes for the socket mounting screws should be laid out after the large holes are punched, thus allowing for any slight error in placement of the large holes.

All except the socket holes can be made with ordinary twist drills. Start the larger holes with a small drill, then use a larger one of the required size.

Mounting The Sockets

The centers of the tube sockets mounting screw holes are shown 1½ inches apart in Figure 43. There are three standard spacings of these mounting centers: 1½ inches, 1 11/16 inches and 1 27/32 inches. At present the smallest size is the most often used. If sockets with the wider spacing are used the holes in the chassis should be spaced accordingly.

All sockets on the chassis are to be placed with the filament terminals towards the rear; that is, the notches in the central hole of the metal tube socket should point towards the rear and the large holes of the middle socket should be at the rear. (See Figure 48). The sockets for the cables should be placed as shown in Figure 42.

Wiring Directions

When mounting the choke and the input terminals, care should be taken to prevent short circuits. The lugs stick through the holes and no part of the lug or any metal connected to it should touch the chassis. This is so important that a special test is recommended. This is done by connecting one terminal of a voltmeter to a battery, and the other terminals of the voltmeter and battery to the lug and the chassis respectively. If the meter shows a voltage reading it indicates a short circuit.

After all the parts have been mounted, the terminal lug strips are mounted with screws as shown in the bottom view, also the fuse holder.

In wiring it is perhaps easiest to begin with the transformer connections. The

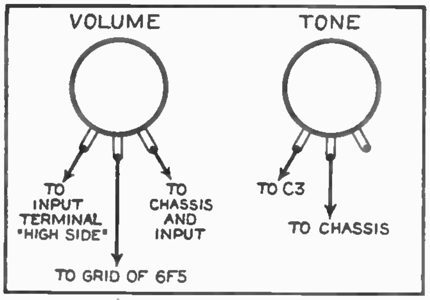


Figure 47

wires are distinguished by their color. A paper comes with the transformer which explains the color code; they are also shown in Figure 39.

The electroylytic condensers must be connected with due regard to their polarity. The electrolytic condenser consists of two aluminum foils separated by an electrolyte (a solution which conducts electricity and is decomposed by the current). The current causes an extremely thin film to form on one of the foils. This film being non-conductive, the whole becomes a condenser. Due to the fact that the film is extremely thin, the capacity can be made large in relatively small space. This type of condenser will be ruined if the polarity is reversed; they are good only in D.C. circuits, or when A.C. is superimposed on D. C. as in the power pack. In our case, all the negative terminals should be connected to the chassis. The condensers are marked and color coded; the colors are also shown in Figure 39.

The proper connections to the sockets are shown in Figures 42 and 48. Figure 48 shows the sockets on the chassis as they look from the bottom. Figure 42 gives the bottom views of the sockets at the rear of the chassis.

The terminal lug strips serve as a support for connections which would otherwise hang in the air. The first one serves to support R4 while the other one is used to support one side of the line and the junction between C3 and R2 of the tone control.

The volume control and tone control are wired as in Figure 47. This is a view of the bottom of the chassis looking from the rear.

The constructor might first complete the power pack and then test it by turning it on, seeing that all the tubes light and (with due caution) measuring the high-voltage.

With the voltage divider in the circuit as the only drain, there will be about 430 volts.

When the other tubes have been connected, the plate voltage will be dropped to approximately 310 volts.

With the power turned off, the slider on the voltage divider can be connected to the high side and adjusted until the total current is 70 ma. The slider will then be less than an inch from the high end. The plate voltages will be slightly over 300 volts.

Use of the Amplifier

The input of the amplifier can be connected to the two-tube receiver described in Lesson Nine. Remove the audio tube of the battery set and connect the input terminals of the amplifier across the secondary of the transformer being sure that the grounded side of the transformer connects to the chassis. If the set has a tendency to squeal it can be cured by a .00025 mfd. condenser across the primary of the transformer. It may also be useful to ground the speaker chassis.

If it is desired to use a phonograph pick-up of the "high-impedance" type it is simply connected to the input terminals direct. With a pick-up of the low-impedance type a suitable matching transformer is required, as shown in Figure 46a. The amplifier can also be employed with a carbon microphone, either single button or double button, as shown in Figures 46b and 46c. The other types of microphones such as the crystal, velocity, etc., are too low in output for use with this amplifier. In all these cases it is important to keep the leads in the amplifier input circuit short. Where a transformer is used with microphone input, etc., its case should be grounded and it may be necessary to shield the leads from it to the amplifier input in order to prevent instability and pick-up of hum.

The Speaker

The Wright De Coster Model 820B dynamic speaker used with this amplifier was selected for this use because it offers the attractive combination of good quality and low cost. Another advantage is that its 1800-ohm field is just right to permit the field to function as one of the chokes

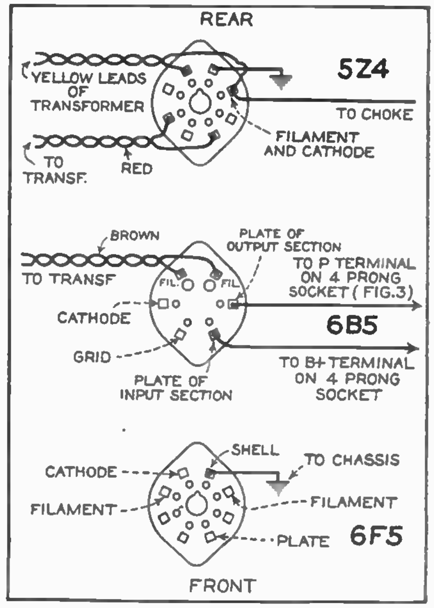


Figure 48

in the power-supply filter, thus insuring freedom from hum and saving the cost of an extra choke. Also it comes equipped with a cable and plug, thus simplifying the program of making connections to the main unit.

Without a baffle, which may be a flat board or a cabinet, a dynamic speaker will not properly reproduce low notes because in the case of low frequencies the sound from the back of the cone tends to cancel that from the front. The remedy is to make the path from front to back rather long by mounting the speaker on a baffle. The lower the note the larger this baffle should be. In order to fully reproduce a 50 cycle note, for example, the baffle would have to be 22 feet square. Of course, no one would care to make so large a baffle. For practical purposes a baffle three or four feet square gives very good results. Placing the baffle on the floor, extends its size at least in one direction.

When a speaker is placed in a cabinet, the sides of the cabinet constitute an effective part of the baffle. A smaller baffle or cabinet does not bring out the low notes fully but is better than none at all.

LESSON FOURTEEN

Regeneration

SO far these lessons have explained the action of diode and triode detectors. There is a way, however, to make a detector much more sensitive and also somewhat more selective. This is done by means of Armstrong's famous principle of regeneration, employing a circuit like the one in Figure 50 in which a coil, L1, in the plate circuit is in inductive relation with the tuned circuit L2, C connected to the grid.

Oscillation Method

This is what happens: As soon as the tube is heated, the tube plate starts to draw current; this current increasing rapidly at the beginning. This rapid increase of current in coil L1 induces a voltage across coil L2 making the grid positive. A positive grid further increases the plate current which causes a still more positive grid and a still greater plate current. Saturation current is reached, however, then the plate current stops increasing which means that the coil L1 no longer induces a voltage in coil L2, the grid-voltage is no longer positive and the plate current decreases. As soon as the plate current decreases, L1 induces a reverse voltage in L2 making the grid negative.

The negative grid further reduces the plate current which again makes the grid increasingly negative, etc., until the plate current cannot decrease any more. Then the induced negative voltage disappears. The plate current must then increase to become normal, but by increasing it induces another positive voltage on the grid and the whole cycle of operation will be repeated indefinitely. The result is that an alternating current will flow in plate and grid circuit, the frequency being determined by the sizes of L2, L1 and C. This condition is called oscillation.

The Regenerative Detector

If a fraction of the output power of a tube is fed back to the grid, it can keep itself in oscillation. There are various ways

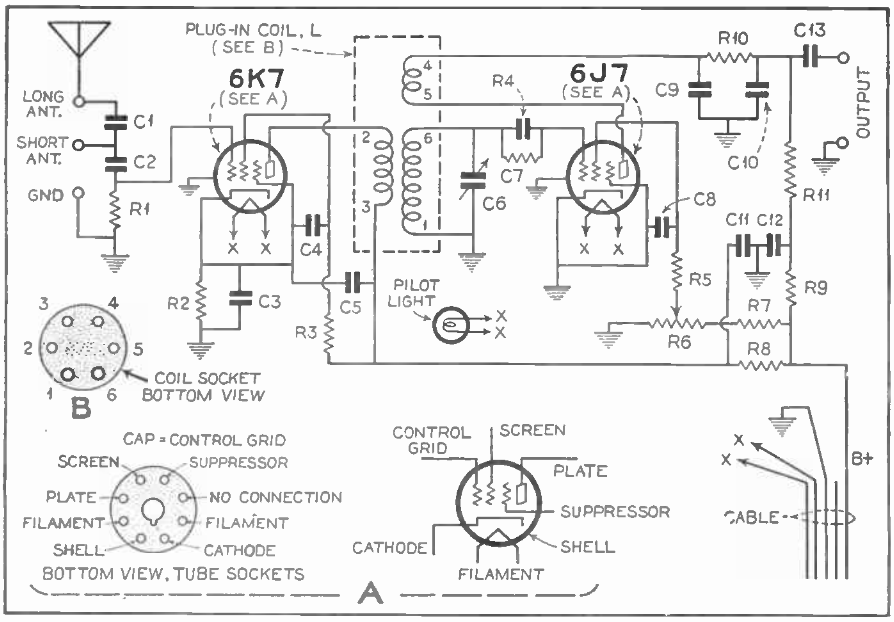


Figure 49—Circuit diagram of two-tube regenerative tuner.

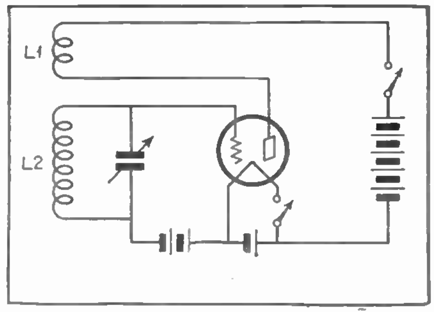


Figure 50

of accomplishing this result and there are many different forms of oscillating circuits. The energy need not be fed back by means of coils, sometimes it can be done through condensers or resistors. The main idea is to apply the proper amount with the proper timing (or phasing). Generally there is so much accidental coupling that oscillation may take place when it is not wanted, this is especially so in high-gain amplifiers and is the main reason for shielding.

When the voltage which is fed back to the grid is slightly decreased (by moving L1 farther away from L2, for instance) oscillation will stop. When a signal is now introduced in the system by a third coil L3 (not shown in Figure 50) the signal will cause large fluctuations in the plate circuit and these will again induce grid voltages which build up the signal tremendously. This is called regeneration. The greatest amplification of speech or music is obtained when the tube is almost at the point of oscillation. C. W. telegraphy, on the other hand, is best received with the feedback adjusted so that the tube is just barely oscillating.

The above statements illustrate the necessity of being able to control the regeneration (or the amount of voltage fed back). This used to be done by arranging the coil L1 to rotate within the coil L2, or to move away from L2, but that has the drawback of changing the tuning too. So, nowadays, we change the amplification of the tube. In a triode, this could be done by varying the plate voltage.

Radiated Interference

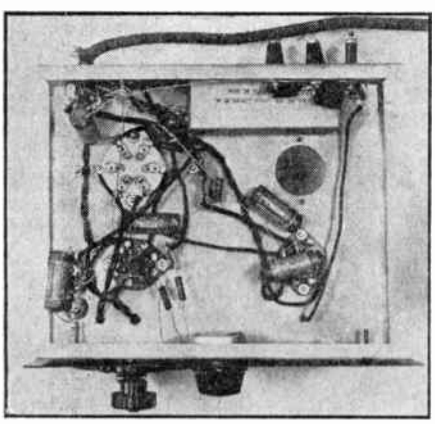
Now it clear that for reception the tube is sometimes oscillating and at such times it is a miniature transmitter capable of causing interference in neighboring receivers. In the interest of better reception, such a detector should not be coupled directly to the antenna. If an amplifying stage is inserted ahead of the detector, there is practically no energy reaching the antenna since the tube is a one-way device. For this reason, an untuned stage was included in the receiver described in Lesson Fifteen.

LESSON FIFTEEN

Building A Two-Tube Regenerative Tuner

THIS lesson describes the construction of a 2-tube all-wave tuner employing one untuned r.f. stage and a detector. Figure 49 shows the diagram of the unit, which is described. Metal tubes of the pentode type are used as both detector and amplifier in this circuit. In Lesson Sixteen some discussion of the pentode and its merits will be presented. It suffices now to explain that a pentode is a tube with five elements, three of which are grids. By placing proper voltages on these grids the tube acts as an amplifier, providing much greater amplification than a triode. Furthermore, amplification and regeneration can be controlled by varying the voltage on the "screen" (the second grid from cathode). The third grid, called the "suppressor" is simply connected to ground or to cathode.

Figure 51



The circuit of Figure 49 employs one of these pentodes, a 6K7, as an untuned r.f. amplifier. The antenna is simply connected to a 50,000 ohm resistor, no tuning being done here. The second tube is a 6J7, also a pentode but more suitable as a detector.

A set of three-circuit plug-in coils is used, covering the range from 16 to 550 meters. The detector circuit employs the well-known grid-leak, and regeneration is controlled by means of the potentiometer R6, which varies the screen voltage.

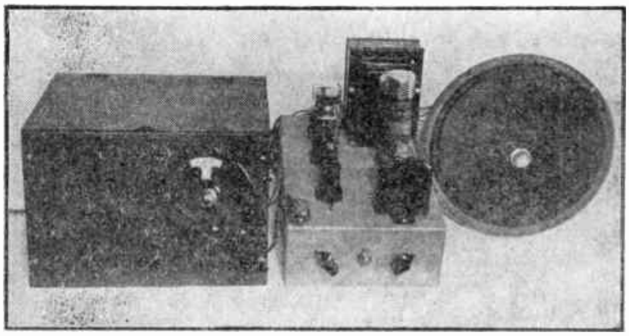
The Resistance Coupling

After the signal is rectified, the r.f. component must be filtered out, or else it will get into the audio amplifier where it may cause overloading and instability. The resistor R10 and the two mica condensers C9 and C10 form this filter which passes the a.f. currents but causes the r.f. currents to return to ground. The customary resistance coupling is employed between the detector and the audio unit.

Circuits with high-gain amplifiers require careful isolation of the stages so that no accidental voltages are fed back which might cause undesired oscillation. The shield can over the coil serves this purpose. The filters R9, C12 and R7, C11 are to overcome "motorboating," a form of audio-frequency oscillation occurring especially in resistance-coupled amplifiers.

Oscillation in any tube causes its plate current to vary from normal. The oscillating condition can be detected by touching the finger to the grid cap of the tube. If there is immediate silence, there is no oscillation but if a "plop" is heard in the loudspeaker both at the touching and releasing of the grid cap, the tube is oscillating. Grid-leak detectors work slightly differently, the finger should touch the stationary plates of the tuning condenser for the same test.

The first thing to do is to drill the chassis and cabinet and mount all parts. Figures 54 and 55 give the specifications of the chassis and panel and include the extra holes required for the changes to be made in Lesson Eighteen. It should be remembered that the chassis, when in the cabinet,



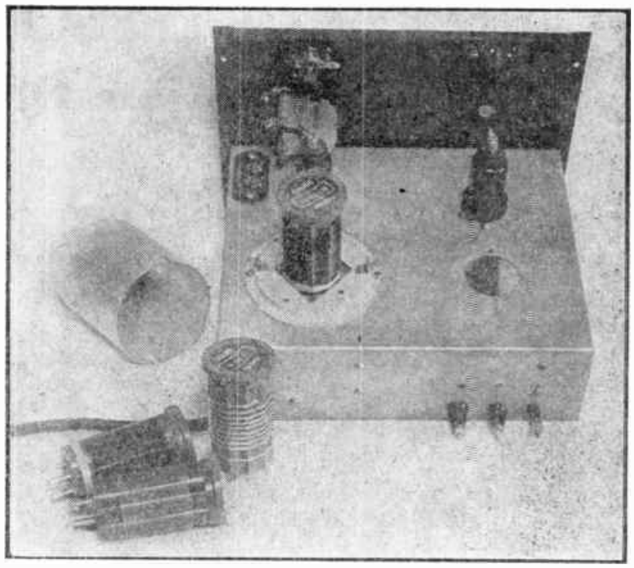


Figure 52, at left, shows the completed tuner with amplifier-power unit attached. Figure 53, at right, a rear view of the regenerative tuner.

is slightly raised. Holes in the cabinet, corresponding with those in the chassis should be made with this in mind. It is perhaps best to make the holes in the back of the cabinet somewhat oversize to allow some leeway in this respect.

There are two different kinds of socket holes, those for the coil sockets being larger. Mounting the coil shield over the socket, requires a hole in its base large enough to pass the coil form freely. These holes may be either square or round, whichever is easier to cut.

Constructional Details

When mounting the coil base, have the socket in place with a coil in it. Be sure to locate the base so the coil can be readily removed. The coil socket should be mounted with the large holes toward the front panel, the detector socket with the key toward the panel and the r.f. tube socket with the key toward the right.

The panel requires accurate drilling especially for the dial. There is a drilling guide with the dial and the correct dimensions are also shown in Figure 54. The chassis and panel are held together by two screws and the volume control shaft. They must be separated slightly by placing a nut between the two.

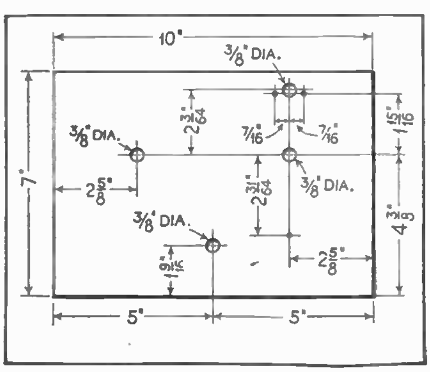
The dial illuminator is mounted on the two small screws but held back from the panel by washers. Use the screws that come with the dial.

The ground post consists of a long round-head machine screw with one of the bushings that come with the coil sockets. It is found convenient to cut away a part of the flanges at the front of the cabinet so that the completed chassis can be inserted or removed without disturbing the cabinet.

Wiring Details

The wiring is easiest done before the chassis is attached to the panel. Insulated terminal strips are employed to anchor joints between several resistors or condensers, which might otherwise hang in the air. The grounding should be done carefully. No grounds are made in the chassis except at the ground post. All other grounds are made to three bare wires which run from the terminal of the cable to various points. This system is found superior to using the chassis. All bypass condensers have one terminal marked "connect this side to ground." The rule should be observed as far as practical.

Figure 54



The cable is to be connected last because it must be threaded through both the chassis and cabinet and, once installed limits the movements of both.

When the wiring is completed, check it over carefully and connect the tuner to the amplifier unit, antenna and ground.

Tuning

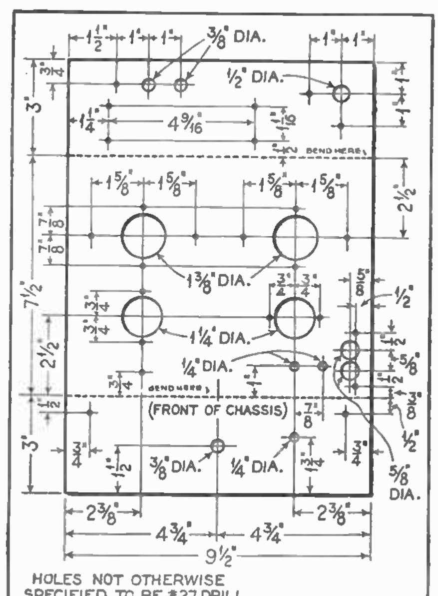
Tuning for weak stations should be done as follows: turn the regeneration control to the right until the detector is oscillating, which can be determined by the finger test mentioned above. Then each station tuned in will cause a whistle. Tune in one of these whistles and reduce regeneration just below the oscillating point. Stronger stations will easily be found without having the detector oscillating and the volume of sound may be regulated by the volume control on the amplifier. Having the regeneration control well up will help the selectivity.

It may be useful to experiment with aerials. If the antenna is too large it may be impossible to get the tube to oscillate. Two terminals are available, one for long and one for short antenna: these should take care of most conditions. The longer the antenna, the smaller the capacity of C1 should be. If the coils are home-made, go through the entire dial to see whether it is possible to obtain oscillation as well as to stop it at all settings of the dial. If this is impossible turns should be added or taken off the tickler (plate coil) whichever is required.

Parts List

C1—Cornell-Dubilier mica condenser, type 5W-5Q5, 50 mmfd.
C7, C9, C10—Cornell-Dubilier mica condenser, type 5W-5T1, 100 mmfd.
C2—Cornell-Dubilier mica condenser, type 1W-5D1, .001 mfd.
C3, C4, C5, C8, C13—Cornell-Dubilier tubular paper condensers, type BA-4P1, .1 mfd., 400 volts.
C11, C12—Cornell-Dubilier dual electrolytic condensers, type EH9808, 8-8 mfd., 450 volts.
C6—Hammarlund "Star" midget tuning condenser, 140 mmfd. (same as C1 in diode receiver.)
L—Set of Hammarlund plug-in coils, type SWK-6, 6-prong, 3 circuit. If broadcast band is also desired, add one Hammarlund coil BCC-6
R1—50,000 ohms
R2—500 ohms
R3—75,000 ohms
R4—2 megohms
R5—1,000 ohms
R7—100,000 ohms
R8—10,000 ohms
R9—100,000 ohms
R10—50,000 ohms
R11—250,000 ohms
All of the above are IRC carbon resistors, ½ watt
R6—Yaxley volume control, type K12, 50,000 ohms
Insuline metal cabinet, type 3826, 10 x 8 x 7 inches
Insuline metal chassis, type 1561, 9" x 7½" x 3 inches
One six-prong Insulex wafer socket, type 2600
One National shield-coil with base, type B-30
One National Velvet Vernier Dial, type 8, with illuminator and 6.3 volt pilot light
Two wafer-type octal sockets, 1½-inch mounting centers
Two Insuline porcelain stand-off insulators, type 2305
One Insuline terminal strip, type 2418, marked "Output"
2 feet 5-wire battery cable
1 5-prong cable-plug
1 knob
2 grommets for ½ inch holes
2 grid clips for metal tubes
Insulated terminal strips: two 3-terminal, one 2-terminal, three 1-terminal
Miscellaneous hardware: screws, nuts, lugs, push-back wire

Figure 55



LESSON SIXTEEN

Operation Of Pentode Tubes

IN order to fully explain the pentode, it is best to follow the development of the vacuum tube. The first tube made was a diode (two-element) which contained a filament and a plate only. This could be used only as a rectifier (as a detector or a power rectifier). The device was invented in 1904 by J. A. Fleming, an English physicist.

The next improvement was due to Lee de Forest. He interposed a grid between plate and filament which made possible amplification and oscillation. The action of this tube, the triode, has already been described.

Obtaining More Amplification

After amplification had been obtained, the next demand was, of course, more amplification. The triode has definite limits along this line. In Lesson Fourteen it was explained that undesired oscillations may occur due to some coupling between plate and grid circuits of a tube. The plate and grid together form a small condenser which causes some coupling or "feedback." This coupling happens to be in the right phase to cause oscillations. Whether or not such oscillations will take place depends on the magnitude of the voltage fed back. This in turn, depends on the amplification in the tube, the frequency and the size of the elements. The higher the amplification and the higher the frequency, the more feedback. Therefore, the obtainable amplification is limited. Power tubes too are limited, when the electrons are on their way to the plate, they are so numerous that they form a cloud. This cloud of electrons is negatively charged (called the "space-charge") and therefore repels the electrons following them. The whole action reduces the maximum plate current.

The Screen Grid Tube

Both of these limitations are overcome in the screen grid tube (tetrode, four-element tube). Such a tube, as its name implies, has an extra grid which *screens* or *shields* the plate from the grid. In actual construction the extra or screen grid consists of two grids (helical wires or mesh) one inside and one outside the plate. These two parts are connected together and form a shield practically surrounding the plate. Yet, the electrons can reach the plate by going through the openings in the screen. In order that the screen be effective, it must have a d.c. voltage applied, yet it must be grounded, or rather it must have a low resistance path to ground for the frequency to be amplified. This is accomplished by connecting a condenser across the voltage supply, as C4 and C8 in Figure 56.

The positive voltage on the screen neutralizes the space charge with the result that higher power is available. When used as a voltage amplifier, the plate to grid capacity is reduced several hundred times and the result is a greatly reduced tendency toward oscillation. Such a tube can be made so as to have a large amplification factor but the a.c. resistance is high, which makes it hard to realize the greater part of the high amplification.

These screen-grid tubes again had a limitation. When the electrons hit the plate they may knock one or more electrons out of the plate. This is called "secondary emission." These electrons will be attracted back to the plate if the plate voltage is higher than the screen voltage; otherwise they may travel to the screen. A large signal will cause the plate voltage to swing up and down and when it becomes lower than the screen voltage, the "secondary" electrons travel to the screen. The plate loses some of its current and this causes distortion. Consequently, in screen grid tubes the screen voltage is the practical lower limit of the plate voltage swing.

Suppressor Grid

In the pentode (five-element tube) an additional grid has been placed between the screen and the plate. This grid, which is called the "suppressor," serves to prevent the passage of the secondary electrons from the plate to the screen. The suppressor is connected to the cathode, so when the electrons are knocked out of the plate, the negative potential of the suppressor repels them, while the plate attracts them and they have to return to the plate. It might be thought that the suppressor would also prevent the passage of electrons the other way but this is not so. An electron, when leaving the cathode, is attracted by the plate and the screen while the control grid has a retarding action. By the time the electron has passed through the meshes of the screen, it has attained such speed that the suppressor does not stop it.

LESSON SEVENTEEN

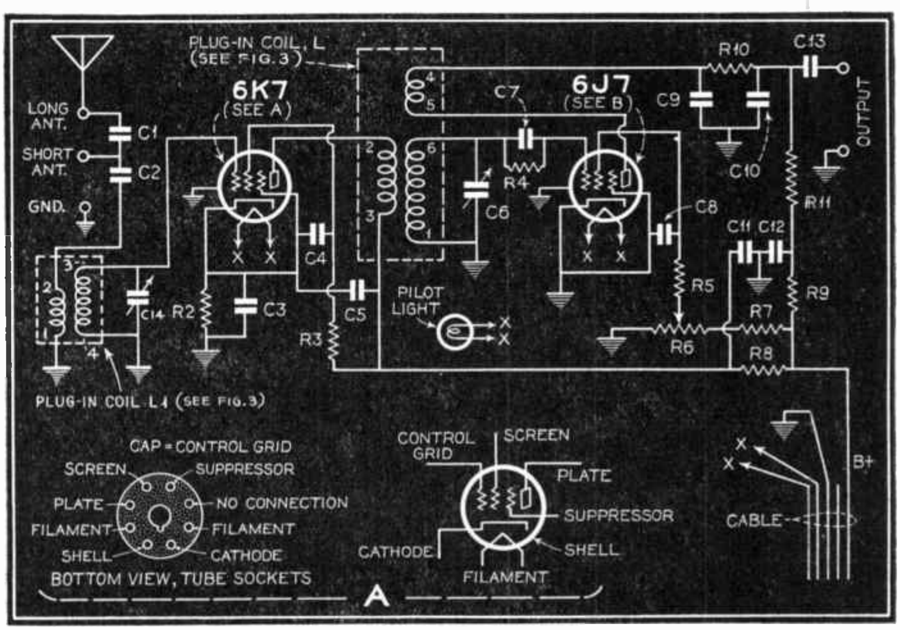
Advantages Of Pentodes

THE advantage of the pentode as a power tube is that the screen voltage can be higher and the plate-voltage can swing below the screen voltage, in other words more power can be delivered by a smaller tube. As a radio-frequency amplifier, the coupling between plate and grid is still further reduced and still more amplification can be obtained. In some pentodes the connection between suppressor and cathode is made inside the tube, while in others the suppressor has a separate prong. This was done to give constructors an opportunity to use the tube in special circuits where the third grid might be employed for another purpose.

The "Variable-Mu" Pentode

Among the voltage amplifier pentodes, one finds the "variable-mu" pentode and the ordinary pentode. The variable-mu pentode, also called "super-control pentode" and "remote cut-off pentode" has a control grid which is wound helically with the pitch of the winding gradually increasing. The pitch of the winding is one of the factors controlling the amplification factor or "mu.". It is possible to control

Figure 56—Circuit diagram of tuned R. F. receiver.



the amplification of the tube by changing bias on this same grid. The more negative the bias, the less the amplification. Moreover, this happens without rectification because the bend in the characteristic is so slow and gradual that both halves of the cycle are amplified equally.

The variable-mu pentode is used wherever it is desired to vary the amplification of the stage, as is the case in most radio-frequency amplifiers. The standard pentode is employed as a detector, or whenever the amplification is held constantly at maximum. In the receiver described in Lesson Fifteen, the first tube, the 6K7 is a variable-mu pentode, while the detector is of the standard type. The amplification of the r.f. stage can be varied by changing the value of the bias resistor R2. The value recommended is 500 ohms. More amplification is obtained with a lower value and less amplification with higher values of resistance. The reader might experiment to convince himself of these facts. However, do not make the bias resistor less than 200 ohms, for then the plate current will rise beyond the maximum limits recommended by the tube manufacturers.

Tube Constants

When speaking about the performance of tubes, the following terms are commonly employed.

The *"amplification factor,"* also called "mu" or "u," is the ratio between small increases of plate voltage and grid voltage, which will have the same influence on the plate current. For instance, if the grid-voltage is made .1 volt more negative—reducing the plate current—and it takes 10 additional plate volts to return the plate current to its previous value, the amplification factor is $\frac{10}{.1} = 100$. The oldest tubes had an amplification factor of only 6 or 8, but the 6J7 has a mu of 1500.

The *"a.c. plate resistance"* of a tube is simply the resistance of the plate circuit for alternating currents.

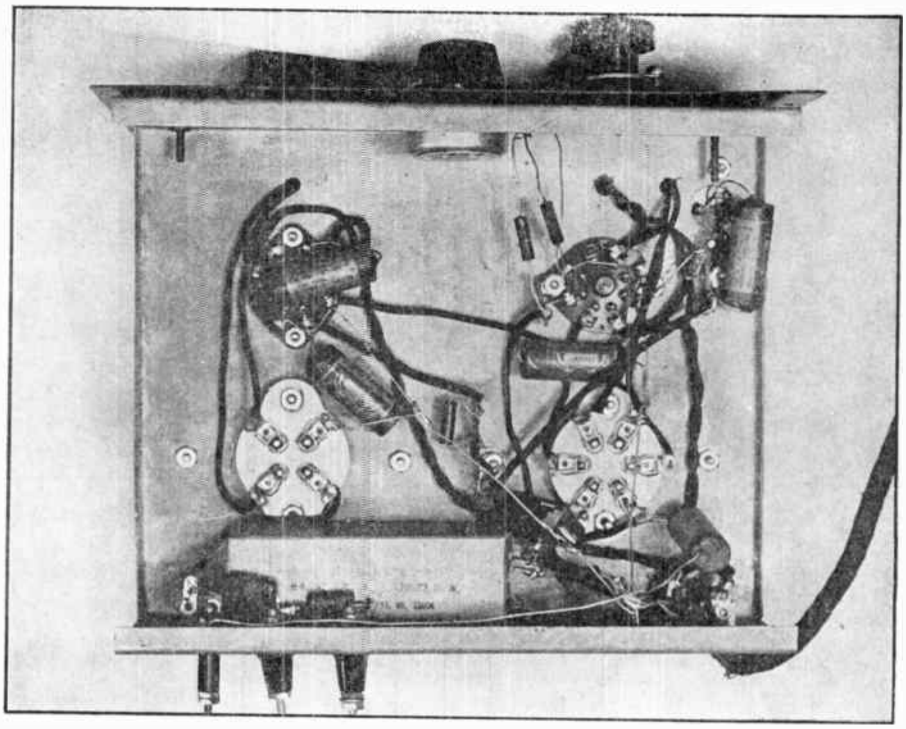


Figure 57—Bottom view of tuned R. F. receiver.

The *"mutual conductance"* of a tube is the ratio between a small increase in plate current and the increase in grid voltage producing it. For instance, increasing the grid voltage by 1 volt may result in an increase of 2 ma. in plate current. The mutual conductance is then $\frac{.002}{1} = .002$ mho. or 2000 micromhos.

The three quantities are related as follows: Mutual conductance in micromhos × plate resistance = amplification factor × 1,000,000.

When a tube has an amplification factor of 100 it does not necessarily mean that it will amplify 100 times. It does mean that one might think of the tube as a generator with 100 times the applied grid-voltage with an internal resistance equal to the a.c. plate resistance. This increased voltage divides across the generator and the plate load in proportion to their resistance. In order to realize a great part of the amplification, the plate load resistance must be very much higher than the a.c. resistance and that is not always practical. Tubes with the highest amplification factor generally have the highest a.c. resistance. So, the 6J7 with a mu of 1500, generally cannot give a gain greater than 200 at radio frequencies and not more than 100 at audio frequencies.

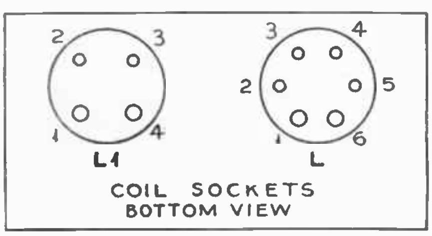
LESSON EIGHTEEN

Simple Tuned R. F. Receiver

THE present lesson will provide constructional information on changing the untuned r.f. stage of the all-wave tuner described in Lesson Fifteen to a tuned r.f. stage.

Figure 59 shows the untuned input section of the receiver as it was shown in Figure 49, before the transformation. Figure 56 shows the complete circuit after converting the r.f. stage to the tuned type. All the necessary holes for mounting the added parts were shown in Figures 54 and 55. The coil socket with its shield as well as the tuning condenser are to be mounted as shown in the photographs. The resistor R1 is removed and the primary winding of the plug-in coil connected in its place. The grid circuit of the 6K7 is hooked up as shown in the diagram. The dial of the original diode receiver, described in Lesson Five, can be used here. Of course, those who so desire may use any other kind of dial.

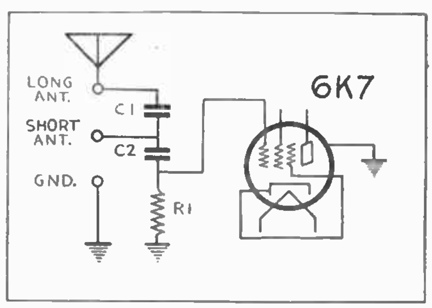
Figure 58



Simple Operation

The reader may think that now he needs three hands to tune the set, but actually operation is very simple. The best procedure is to set the left-hand dial somewhere near the point where one wishes to tune and then concentrate on the right-hand dial and regeneration control. After the station has been found, readjust the left-hand dial for best results. It should be remembered that only the detector is ever supposed to oscillate and then only when receiving c.w. signals, or in searching for weak 'phone signals. If the first tube oscillates, no results can be obtained. One can detect the condition with the finger test, as described previously. If this happens, an

Figure 59



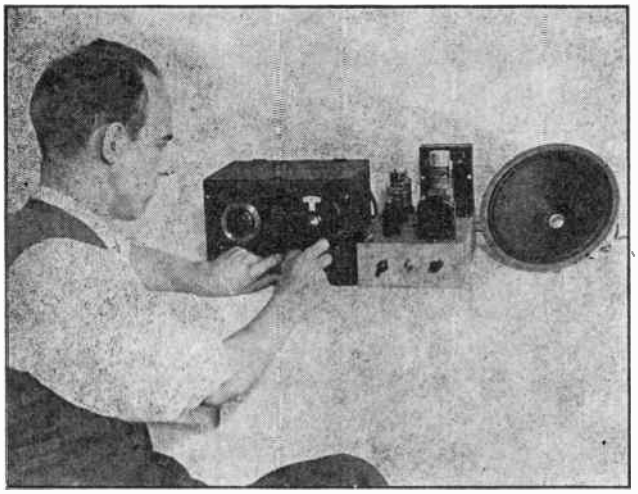


Figure 60, at left, the complete tuned R. F. receiver.

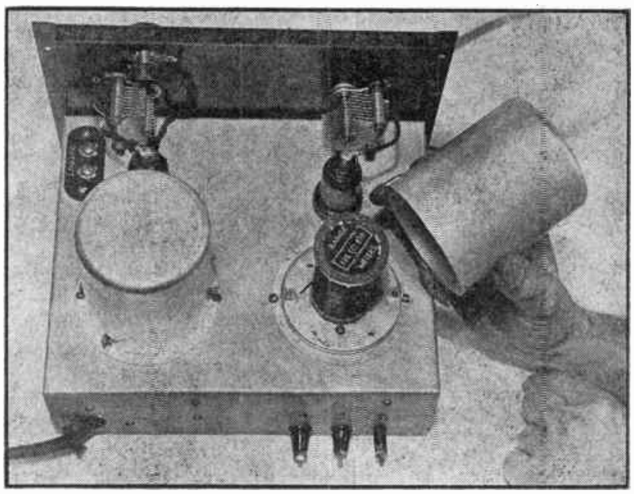


Figure 61, at right, a top view showing the various parts.

increase in the resistance values of R2 and R3 should help. The model receiver was stable with the recommended values.

The antenna can be the usual inverted L type with a total length of 75 to 100 feet. A good ground is essential to stable operation.

Parts List

(in addition to those listed in Lesson 15)

C14 Hammarlund "Star" midget variable condenser, 140 mmfd.

One set of Hammarlund plug-in coils, type SWK-4 (covering from 16-270 meters) (L1).

One Hammarlund broadcast hand coil, type BCB4 (L1).

One Bud 2¾-inch dial.

LESSON NINETEEN

Discussion Of T. R. F. And Superhets

THE earlier articles of this series acquainted the reader with the theory of operation of detectors, amplifiers and power supplies. and with the actual construction of typical equipment. We now proceed to a study of more advanced receivers and an introduction to the practical fundamentals of the tuned-radio-frequency and superheterodyne types.

The tuned radio-frequency receiver, also referred to as the t.r.f. type, consists of a radio-frequency amplifier, a detector and an audio-amplifier. The all-wave receiver, which was described in Lessons Fifteen and Eighteen, was a tuned radio-frequency receiver. However, modern t.r.f. receivers usually cover the broadcast band only, seldom employ regeneration, and include two or more tuned stages with all stages tuned by a single control knob This means that all stages must be made sufficiently alike electrically so that they will be in tune with the signal and with each other at every position of the dial.

This involves some complications since it requires that the condensers, coils and capacities between wires be exactly alike. There is bound to be some difference, however, and even though there are small trimmer condensers to compensate for such differences it is usually not possible to have the set exactly in line at all frequencies throughout the range. Therefore, at points where the circuits are not in line, the selectivity and the sensitivity will suffer.

Varying Selectivity

It is a characteristic of radio circuits that the selectivity varies with the resonant frequency. For instance, if a circuit has a selectivity of 10 kc. when it is tuned to 500 kc., this selectivity is likely to be 20 kc. when that same circuit is tuned to 1,000 kc. So we see that a tuned-radio-frequency receiver varies in selectivity over the band. Some form of compensation is usually employed which partially offsets these variations. Similarly, the sensitivity varies with frequency. Compensating methods are again employed but it is uneconomical to try to obtain even sensitivity and selectivity all over the range.

Another difficulty in the design of tuned-radio-frequency receivers is the avoidance of undesired oscillations. There is always some coupling between the leads of the input and output circuits which results in a tendency toward "feedback" or regeneration. This regeneration again is a function of frequency and become worse at high frequencies. The tuned-radio-frequency receiver, therefore, is limited to relatively low sensitivity (unless unusual pains are taken in the design) with a proportionate increase in design and production costs.

The Superheterodyne

The superheterodyne differs from other receivers in that it changes the signal frequency to another frequency which is fixed for that particular receiver. Thereafter, the signal is amplified in an "intermediate-frequency amplifier" which is tuned to a fixed frequency and is never changed by the listener.

This process is illustrated by the block diagram in Figure 62, which is a diagram of a typical superheterodyne receiver. The signal comes in at the antenna and first passes through the t.r.f. amplifier stage which is usually included in this type of receiver The reason for this stage will be explained later. Then the signal is applied to the grid of a "mixer" tube. A local signal is generated by an oscillator and this signal is also applied to the same mixer tube. The process of mixing consists of the creation of new frequencies which are equal to the sums and differences of all the frequencies applied to the mixer. The result is that in the plate circuit of the mixer tube several frequencies will be present as follows: The original signal frequency, the oscillator frequency and the sum of the two and the difference of the two. Moreover, the audio-frequency signal which was already modulated on the signal frequency when it came in, has now been transferred to the sum and difference frequencies, also.

The intermediate-frequency amplifier now picks out the difference frequency and amplifies it. After the signal has been sufficiently amplified, it passes through the usual detector and audio amplifier.

The major amplification takes place in the i.f. amplifier and, because its tuning is fixed, its sensitivity and selectivity also remain fixed. Furthermore, since the intermediate frequency is generally low, the inherent selectivity is greater and it is possible to obtain more amplification without running into difficulties of oscillation; also, the selectivity can be further improved by the use of more tuned circuits, all of which can be aligned exactly in the factory.

The r.f. stage, the detector and also the oscillator must be tuned by the same control knob and they have to be so designed that the oscillator is always maintained at a fixed difference between its resonant frequency and that of the incoming frequency.

Repeat Points—Images

The superheterodyne is subject to some special troubles, however. There are what are called "repeat points" or "images." As an illustration, suppose the intermediate frequency was 175 kc. and a station operating on 1,000 kc. is tuned in. The oscillator will normally be tuned to 1175 kc. in order to receive that station. However, if

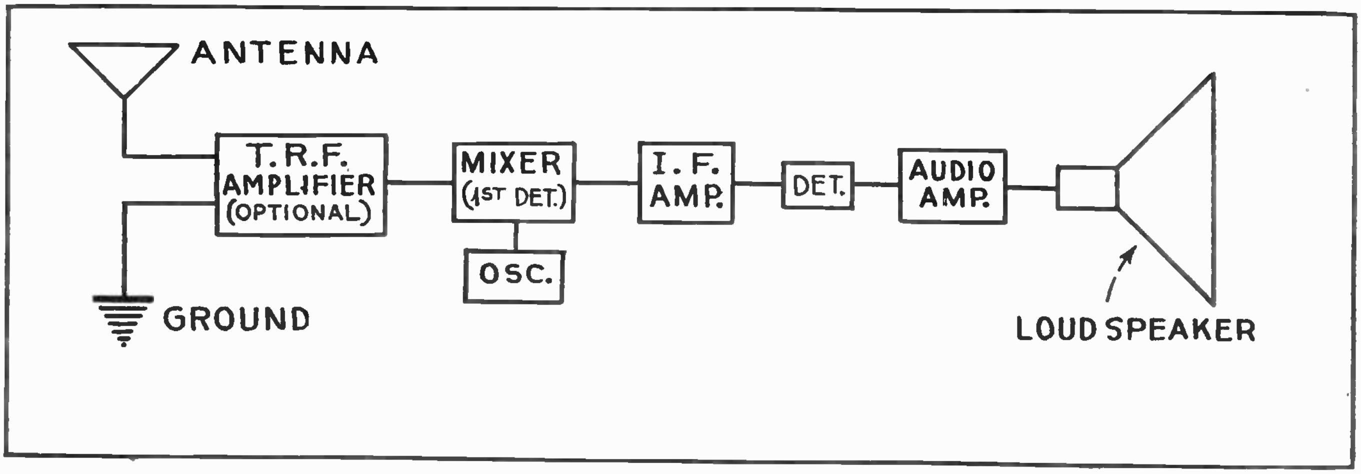


Figure 62—A block diagram of a typical superheterodyne receiver.

the oscillator is tuned to 825 kc., it will also create a beat of 175 kc. with the incoming signal. This is known as the "image." Therefore, there are two positions of the oscillator dial which would bring in one station. It is a function of the tuned r.f. and the mixer circuits to reduce the two points to one by cutting out one of them. For instance, in the above example, the signal-frequency circuits will be tuned to 1,000 kc. when the oscillator is tuned to 1175 kc., since they are ganged on the same tuning control shaft. When adjusting the oscillator to 825 kc., however, the radio-frequency circuits will be tuned to 650 kc. Now it all depends on how selective these r.f. circuits are. If the 1,000 kc. signal is very strong and the r.f. circuits are insufficiently selective, it may be that the 1,000 kc station will pass through the r.f. amplifier. If it reaches the mixer tube, it will interfere with another station working on 650 kc. It is for this reason that a good sharp tuned-radio-frequency stage is almost essential.

There are also possibilities that harmonics of the oscillator will fall in the broadcast band or may be equal to the fundamental or harmonic of the signal frequency. In both cases, this may result in a squeal or "birdie" at a critical point of the dial. The remedy is, of course, to shield the oscillator so well that there will be no opportunity for the oscillator frequency to enter the antenna circuit.

Reducing "Image" Effects

From the standpoint of reducing "image" effects, it is best to make the intermediate frequency fairly high. For instance, if in the above example, the intermediate frequency had not been 175 kc. but 465 kc., the 1000 kc. image would be outside of the broadcast band. The choice of a high intermediate frequency reduces the requirements for high selectivity in the r.f. circuits. In fact, in many cases, the t.r.f. stage is omitted when intermediate frequencies of 465 kc are employed.

It was stated above, that selectivity varies with the frequency. Therefore, the lower the frequency, the better the selectivity in the intermediate-frequency amplifier. Furthermore, the selectivity of the whole receiver will be the same throughout its tuning range.

Another point to keep in mind when choosing the intermediate frequency is that it should not be within the band to be covered by the receiver and it should not be a frequency where a powerful station is working. For instance, if the intermediate frequency is 456 kc. and a local station (commercial code stations are sometimes encountered around these frequencies) were to transmit on this frequency, its signal might pass through the r.f. stages even though these were not tuned for that signal and when it reaches the mixer stage, it will keep on traveling through the intermediate-frequency amplifier, mixing with any signals present in this amplifier and causing "birdie" whistles. It is thus seen that the choice of an intermediate frequency is a compromise and there are now several standard frequencies employed which have been found to be satisfactory; 175 kc., 262 kc. and 456 kc. are some of the most popular ones.

Advantages and Limitations

The advantages and limitations of each type of circuit can be summed up as follows: the tuned-radio-frequency receiver is simpler in construction and therefore more economical to make than a super. On the other hand, it is limited both in sensitivity and selectivity with the result that it will generally not be a long-distance receiver. This has its advantages because sharpness of tuning is the natural enemy of good quality reception. Therefore, a broad-tuning set may deliver better quality and the tuned-radio-frequency type is an economical high-quality receiver. The sensitivity being dependent on the frequency, it generally becomes impractical to employ the t.r.f. type as an all-wave receiver especially so if a switch has to be employed for more than three circuits.

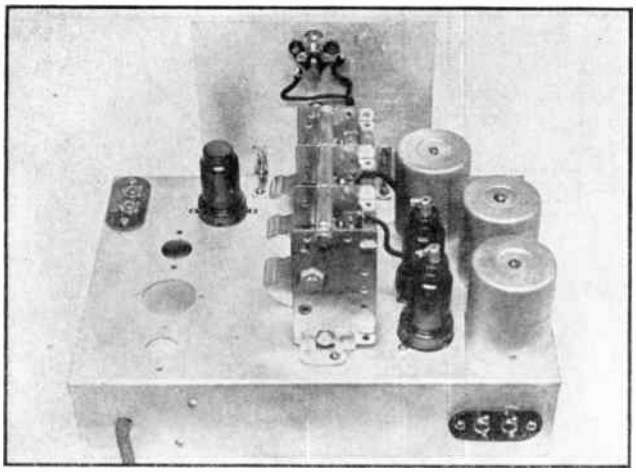
The superheterodyne can be made much more sensitive, partly due to the fact that the amplification is divided into two amplifiers at different frequencies, and partly that the intermediate frequency is low and it is easier to obtain more gain at low frequencies. The selectivity will be high even in the smaller receivers. At the present time, superheterodynes have advanced so far that they are available with variable selectivity so that high selectivity can be used for distant stations and relatively broad tuning for local high-quality reception. The same could be done with the tuned-radio-frequency receiver but it would be much more difficult. Since the intermediate-frequency amplifier provides nearly all the sensitivity and selectivity, such a receiver lends itself readily for use as an all-wave receiver.

The drawbacks of superheterodynes consist in the possibility of the presence of repeat points, and some birdies and whistles which are due to the presence of oscillator harmonics and signal harmonics. Improperly designed superheterodynes also may cause interference in your neighbor's receiver. In such cases, the oscillator frequency is being radiated and may interfere with the reception of another receiver in the house which is tuned to the same frequency as that on which the oscillator is working. In general, however, none of these troubles is likely to be present in the best supers.

LESSON TWENTY

High-Quality Broadcast Receiver

THE t.r.f. tuner described here, the circuit of which appears in Figure 69, when used in conjunction with the universal power pack and audio amplifier described in Lesson Thirteen, provides reception of excellent quality from local and medium-distant stations. The tuner has been constructed with a view towards later changing it into a super. Therefore, the chassis is not only drilled for the present layout but also for this later use. Also, the change-over to a super



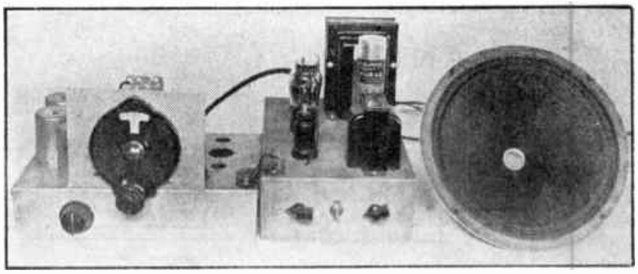


Figure 63, left, shows the layout of parts on the top of the chassis. Figure 64, right, shows the new tuner with the power supply-amplifier.

has been worked out so as to employ the present parts and require the minimum of new ones.

For the sake of stable operation, it was thought inadvisable to use more than two r.f. stages. On the other hand, sufficient selectivity had to be obtained. So the coils are of the "low-impedance" type, which means that they have primaries of only a few turns, increasing the selectivity. The detector circuit is tuned, too, making, in all, three tuned circuits.

In such cases one must be very careful to obtain the greatest benefit from the tuned circuits. Besides the variable condenser in the secondary, the tuning is affected by the primary circuit and also by the tube following the transformer. For instance, the coil L2 (Figure 69) has its secondary tuned by C2, but there is also the slight capacity between grid and cathode of the second 6K7, and the primary adds its influence which depends on the tube's plate resistance. Coil L1 is connected to the antenna, which may react on the circuit in such a way as to bring this circuit out of tune.

No matter how much trimming is done, it is usually impossible to get this first circuit in exact line all over the range. The condition may be helped by placing a small series condenser in the antenna circuit. To obtain the best value for the antenna used it is well to experiment with sizes between .001 and .0001 mfd.

Inasmuch as the antenna circuit is probably not going to track throughout the range, we must be sure that the third circuit, L3-C3, is not going to be out of line. This brings us to the choice of detector circuits. From the standpoint of best reproduction, the diode detector is preferred. But the diode detector, when connected across L3-C3 in the normal manner, as in Figure 68, would result in added capacity across C3 and this would tend to unbalance the alignment. Furthermore, the relatively low diode resistance makes tuning broad. To avoid these drawbacks it is an advantage to use a type of detector which does not "load" the circuit; one which does not draw any current from the tuned circuit. The only type which will do that is the "biased detector."

New Detector Circuit

The one employed here (see the 6C5 circuit in Figure 69) is a relatively new circuit, suggested by engineers of Sylvania. It is a biased detector with the load resistance in the cathode circuit, combining good fidelity with sensitivity, yet permitting the circuit L3-C3 to remain in tune with L2-C2. In fact, the circuits lined up so well that it was decided to omit the usual trimmers, since good enough results were obtained without them. The constructor may add these if he so desires.

The use of variable-mu pentodes for tuned radio-frequency stages is already familiar to the reader. Resistance-capacity filters are placed in all screen and plate leads to prevent instability.

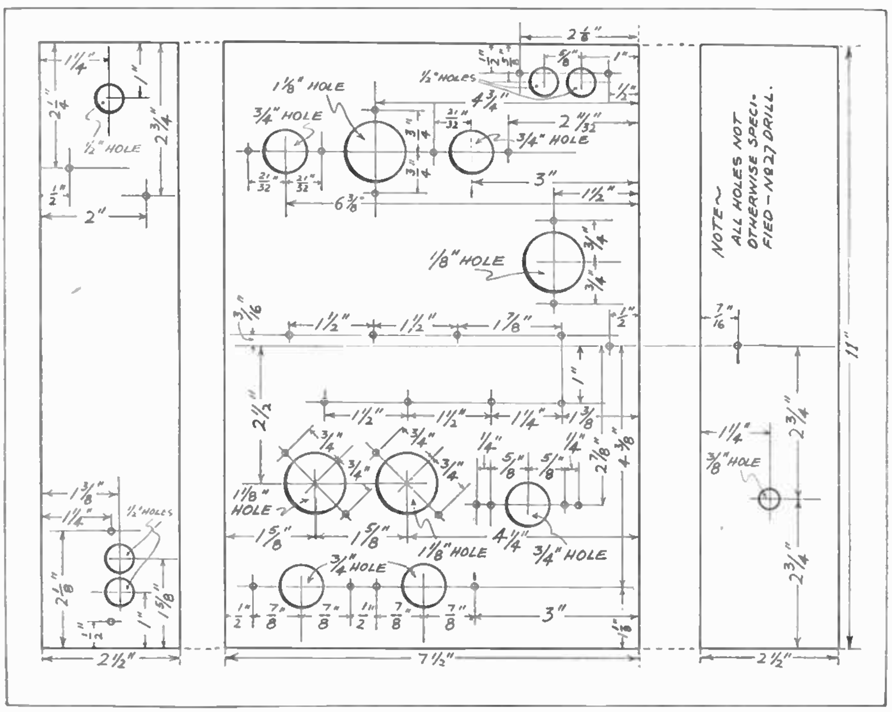
The filter C12-R9 is included to prevent any tendency toward motorboating. The sensitivity control is in the cathode circuit to adjust the sensitivity according to requirements; this is *not* a volume control. Best results will usually be obtained with the sensitivity control at the lower settings in order not to overload the tubes.

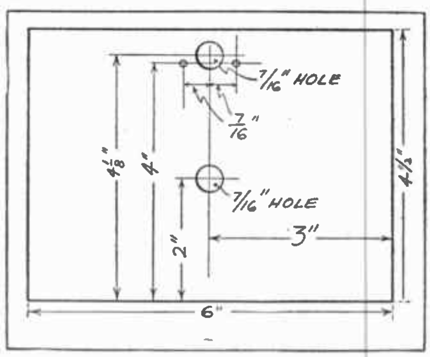
Construction

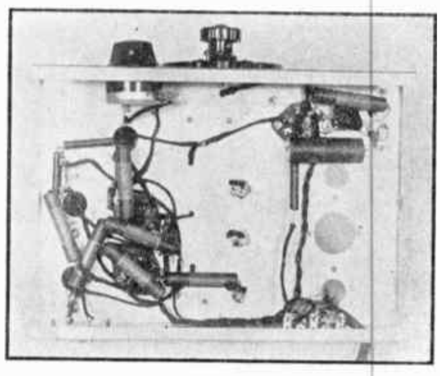
The tuner is constructed on a chassis which will fit the Insuline type 3828 cabinet. This cabinet has dimensions 12 x 8 x 7 inches. The chassis used in this lesson can also be obtained from the same company with the large holes already drilled, or it can be had without holes.

After completing all the holes in the chassis and panel according to Figures 65 and 66, mount the coils, the sockets and the terminal strips. First make all the connections to the coils; the antenna coil can be distinguished from the others by

Figure 65, below, chassis drilling plans; Figure 66, upper right, panel drilling plans; Figure 67, lower right, below the deck.







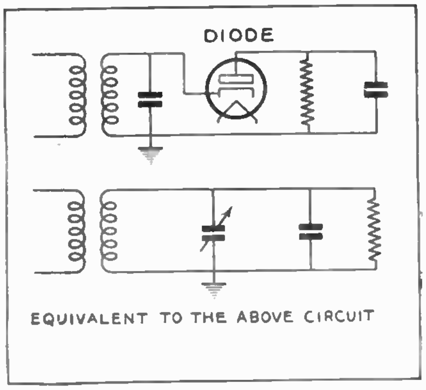


Figure 68

the type number and it is also marked "antenna coil." The terminals are identified by referring to Figure 69. Before mounting the coils, solder long enough leads to the terminals and bend the lugs so as to prevent them from touching the chassis. All wires from the coils should be run close against the chassis.

Mounting Tuning Condenser

Now solder leads to all the rotor lugs of the condenser gang and another lead to the front stator lug (on the bottom). Thread the leads through the holes, place the condenser and bring up the grid leads from the coils through the proper holes, then cut these leads to correct length and solder them to the remaining stator lugs. The condenser can now be bolted down. The leads from the rotors should be soldered to the chassis close to the hole through which they pass. It is very important to individually ground each of the three sections. Depending on the frame of the condenser for a ground causes a common path to be used in all three circuits and oscillation may result.

Next mount the insulated terminal strips and finish all wiring possible without putting in any resistors and condensers. Then connect the resistors in place and finally the condensers. Doing the last job, the grounded foil should always be connected to the ground side and the leads kept as short as possible. Finally connect the cable, sensitivity control and pilot light and mount the dial. The dial, most of the bypass condensers and some other parts can be salvaged from the previous construction job.

Before trying out the unit, plug the cable into the power pack and measure the resistance from B+ (at the cable terminal in the tuner) to ground. This should be about 22,000 ohms. If it is found to be zero there is an error in the connections to the plug.

Testing The Tuner

When it is established that there can be no short circuit, complete the connections between the units and connect the antenna.

In case there is no response, check the tuner stage by stage. Connect a condenser of .00025 mfd. to the antenna and touch the free end of the condenser to the stator of C3. If there is no station coming in, the defect is in the detector stage. After obtaining results there, move the antenna to the stator of C2 and so on. The defect can thus be isolated. Watch for shorts between leads and chassis at places where the leads pass through holes. You should be able to receive all the local stations and many distant ones. The original model brought in stations in Philadelphia in the daytime without any difficulty and that was in a noisy New York City location.

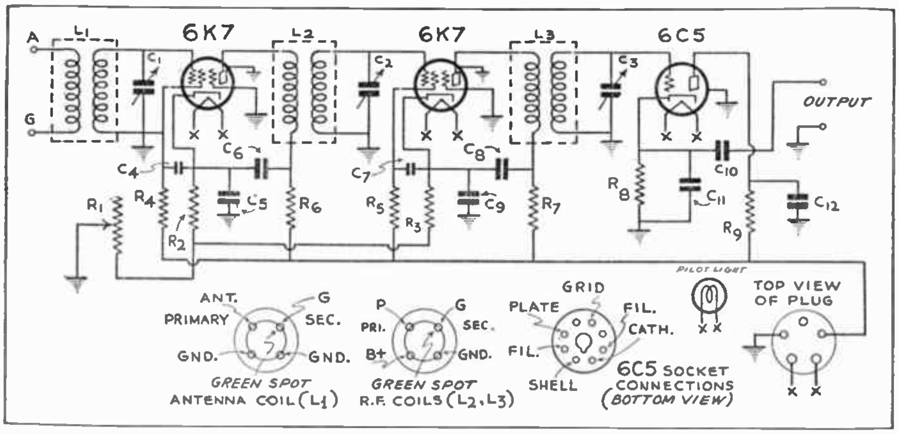


Figure 69—The circuit diagram.

Parts List

R1—Electrad, type 280, potentiometer, 25,000 ohms.
R2, R3—500 ohms
R4, R5—100,000 ohms } I.R.C. carbon resistors, ½ watt.
R6, R7—1,000 ohms
R8, R9—¼ megohm
C1, C2, C3—Meissner, 3-gang variable condenser type, 15122, .00035 mfd.
C4, C5, C6, C7, C8, C9, C10—Cornell-Dubilier, type BA-4P1 tubular paper condensers, .1 mfd., 400 volts.
C11—Cornell-Dubilier, type 2W-5T25 mica condenser, .00025 mfd.
C12—Cornell-Dubilier, type BB-4P25 tubular paper condenser, .25 mfd., 400 volts.
L1—Meissner, type 1085 low impedance antenna coil.
L2, L3—Meissner, type 1084 low impedance r.f. coil.
1—National, type C., dual-range velvet-vernier dial with illuminator and 6.3 volt pilot light.
3—octal sockets, wafer type, mounting centers spaced 1½ inch.
1—I.C.A. chassis, type 1531, cadmium plated steel, 11x7½x2½, with large holes punched.
1—alumiuum panel, 4½x6 inches, 1/16-inch thick.
1—I.C.A. terminal strip, type 2419, marked "A. & G."
1—I.C.A. terminal strip, type 2418, marked "output."
4—insulated terminal strips, two terminals each.
1—insulated terminal strip, three terminals.
1—shaft reducer, ⅜ inch hole, ¼ inch shaft.
2—angle brackets.
2 feet 5 wire battery cable.
1—five-prong plug.
1—grommet for ½ inch hole.
1—knob for sensitivity control.
2—grid clips for metal tubes.
2—6K7 tubes.
1—6C5 tube.

LESSON TWENTY-ONE

Automatic Volume Control

THIS lesson is devoted to an explanation of automatic volume control circuits and the newly acquired knowledge is put to work at once by changing the t.r.f. receiver of Lesson Twenty so as to include this new feature.

The so-called "automatic volume control" circuit is a scheme for obtaining approximately the same carrier amplitude at the detector tube on all signals, weak and strong. In other words, the strength of the signal *when it is unmodulated* is kept approximately the same. The actual volume coming from the loudspeaker depends on the audio amplification after the detector, the setting of the manual volume control and the percentage of modulation at the transmitter.

A receiver equipped with perfect "automatic volume control" would still not give equal volume on all stations at all times, even if the manual volume control were not moved, because the station may send out loud or soft audio signals, and the average may vary between stations. We would not want to eliminate these volume variations, since they are a part of the program. Therefore "automatic volume control" is not really the correct name; it should be "automatic sensitivity control." However, the wrong name has caught the public's fancy and it is now too late for a change.

It has been explained in Lesson Sixteen that the sensitivity of a radio-frequency amplifier stage can be reduced in the case of a variable-mu tube by increasing the negative voltage at the control grid. In fact, this is being done manually in the receiver described in Lesson 20. It can be done automatically when a detector is employed which develops a negative voltage (d.c.) with respect to the chassis when a signal comes in. This negative voltage should be proportional to the strength of the signal.

Choice of Detector

The detector of Lesson Twenty is not suitable for the purpose, but the diode detector will do the work nicely. Figure 71 shows the diode detector circuit with the a.v.c. circuit incorporated in the t.r.f. receiver. The same tube is used as a diode by connecting plate and grid together. During the positive half of each cycle, the plate and grid become positive and some

Figure 70 shows how A.V.C. is added to the receiver. A half hour's work and the t.r.f. receiver is provided with automatic volume (sensitivity) control.

current flows through the circuit in the direction indicated by the arrows. This is pulsating d.c. and it is of such a direction as to make point A negative with respect to the chassis. Across resistor R8, then, there are several voltages: d.c., radio frequency and audio frequency. The radio-frequency current is by-passed by the condenser C11 and the audio-frequency current is fed to the audio amplifier through C10. The negative voltage at A must now be fed back to the grid returns of the amplifier stages, but we must take care that the audio-frequency fluctuations are filtered out because they would cause distortion. Precautions should also be taken to insure against feedback between stages, as this would cause oscillation. The network of resistors and condensers fulfills all these requirements.

Special Filters

As soon as a negative voltage appears across the diode load resistor R8, the condenser C13 is charged through the resistor R10; it takes considerable time to charge this condenser, because the resistor limits the rate of charge. After C13 is charged, the condensers C14 and C15 are charged through the other resistors. This delays the action still more. The result is that the current is too slow to follow the audio-frequency variations at A and the steady voltage across C14 and C15 which is applied to the grids is free from audio-frequency variations.

The speed of such resistance-capacity filters is indicated by their "time constant." This is the time in seconds it would take to charge the condenser completely if it kept on charging at the initial rate. The rate varies and the condenser charges to 63 percent of its full charge in the time indicated. The time constant in seconds is equal to the product of R in megohms and C in microfarads. In this case, where there are several sections, we must first take the sum of the resistors and the sum of the capacitances. The total capacity of $C13 + C14 + C15 = .04$ mfd. and the sum of the resistors $R10 + R11 + R12 = 1.2$ megohm. Thus the time constant is $0.04 \times 1.2 = 0.048$ seconds (approximately 1/20 of a second).

How A.V.C. Works

The condensers C14 and C15 also serve the purpose of closing the tuned grid circuits of the amplifier tubes. They are in series with the tuning condenser.

The automatic volume control now works as follows. When no station is coming in there is no voltage across R8 and the grids of the 6K7 tubes are at ground potential. The tubes then have the bias determined by the resistors R2, R3 and R1. When a strong signal comes in, the point A will become negative and this negative voltage is applied to the grids, reducing the sensitivity. The circuit immediately adjusts itself for any change in signal strength, cutting down the strongest signals. It should not be expected that the action is perfect. Theoretically it can never be made so but a close approach is possible. Note also that the circuit can only reduce the sensitivity but cannot increase it. Therefore on weak signals there is nearly no a.v.c. action.

In large receivers when many stages can be controlled it is actually possible to regulate the signal strength at the detector very closely. The t.r.f. circuit is usually not so well adapted to it because it is hard to get enough control. The model used in the Radio News laboratory worked well enough to prevent overloading of the r.f. stages and to make adjustment of the sensitivity control unnecessary.

It was pointed out in Lesson Twenty that the use of a diode detector will broaden the last circuit and less selectivity will be obtained. On the other hand the quality should be better.

Tuning Meter

One important by-product of a.v.c. circuits is the tuning meter. If a milliammeter is placed in the plate circuit of one 6K7 tube (range 0-10 ma.) or in series with the plate circuits of both tubes (range 0-15 ma.), the correct point of resonance can be easily determined. The meter will show about 7 ma. per tube with no signal. As a signal is tuned in the meter reading goes down and the correct dial setting is indicated by the minimum meter reading. The meter reading is also an indication of the signal strength of the station and the merit of your antenna. The lower the meter reads on a given station the better it is coming in.

Automatic volume control has peculiarities which are common to all receivers in which it is employed. For instance, when the receiver is suddenly tuned from a strong station to a weak one, the background noise appears to increase. The reason for this is that the sensitivity is brought up to maximum as soon as one tunes off a carrier, and this brings in all the noise. The manual sensitivity control may be used to limit the maximum sensitivity and the maximum noise level.

For convenience, the circuit of Figure 71 shows the wiring changes in heavy lines. First the detector circuit is to be changed from the biased detector to the diode type. A special diode tube for this purpose is the 6H6 but the 6C5 will do the work as well if the grid and plate are joined. This makes the purchase of a new tube unnecessary.

Locate the grid return or grounded terminal of the secondary in all three coils. Disconnect it from the chassis, mount the terminal strips and wire as shown in the diagram. The wires should be kept as short as possible, especially those running from C14 and C15 to the chassis and to the coil.

A test to show that the automatic volume control circuit is working can be made by connecting a milliammeter in the plate circuit of a 6K7 tube. The current should decrease when a strong signal is tuned in.

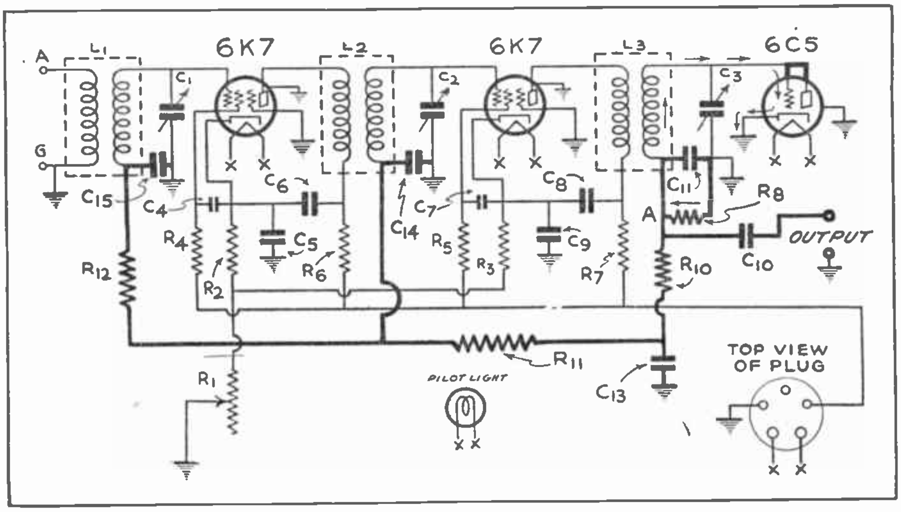
Parts List

The following additional parts are required.

C13—Cornell Dubilier, type DT-4S2 tubular paper condenser, .02 mfd., 400 volts.
C14, C15—Cornell Dubilier, type DT-4S1 tubular paper condensers, .01 mfd., 400 volts.
R10—IRC carbon resistor, 1 megohm, ½ watt.
R11, R12—IRC carbon resistors, 0.1 megohm, ½ watt.
2 insulated terminal strips; one 2-terminal, one 3-terminal.

For further lessons on the construction of modern radio receivers read the supplement on Page 47 of this book and "The Radio Beginner" in the July 1937 and subsequent issues of RADIO NEWS.

Figure 71—The revised circuit diagram.



LESSON TWENTY-TWO

Facts About Antennas

AN aerial or antenna is a wire or a system of wires, elevated some distance above ground and suspended in different forms, so that it is insulated or free from surrounding objects. A simple, easily erected antenna is the inverted "L" type shown in Figure 72.

No matter what type of antenna is used its purpose is the same—to intercept a small amount of the radio-frequency power radiated through the ether from the broadcasting stations. The antenna used at the broadcast transmitting station must send out through the ether thousands of watts of power—the antenna connected to your receiver must intercept but microwatts of power. A broadcasting station antenna might transmit, for example, say 25,000 watts and the antenna on the set intercepts but millionths of a watt of power! The broadcast station antenna is suspended by means of insulators, and when the station is "on the air" the voltage across these insulators may be 10,000 or 50,000 volts. The voltage across the insulators of the receiving antenna is only millionths of a volt. These figures give some idea of the differences between antennas for transmitting and receiving. In this lesson let us consider some of the characteristics of the receiving antenna.

Electrical Characteristics

As we look at an antenna it appears to be a simple sort of thing—just a long piece of wire—but electrically it is far more complicated. Electrically the antenna can be represented as in Figure 73. Here we see a number of coils, all marked L, a number of condensers, all marked C, and a number of resistances, all marked R. These coils, condensers and resistances are the same as the coils, condensers and resistances we use in a receiver—although their values may of course be quite different.

The effect of the coils, L, is produced by the fact that any piece of wire has the property known as "inductance." This is why we sometimes refer to the r.f. transformers in a set as having an inductance of so many henries or millihenries—the henry being the unit inductance, and the millihenry being equal to one-thousandth of a henry. The effect of the condensers, C, is produced by the fact that the antenna wire and the ground under the antenna act like two plates of a condenser. The effect of the resistances, R, is due to a number of factors, including the resistance of the wire, the resistance of the ground and what might be called the "useful resistance," because the antenna must pick up energy from the ether and transfer it to the set. The power actually transmitted to the set can be represented by a resistance and a technical term for this useful resistance is "radiation resistance."

The Fundamental Wavelength

When we tune a receiver what we do actually is to adjust the capacity of the tuning condenser so that the circuit will be in "tune" with the desired signal. Now since the antenna has all the characteristics of a coil-condenser combination in a receiver it follows that the antenna will tune

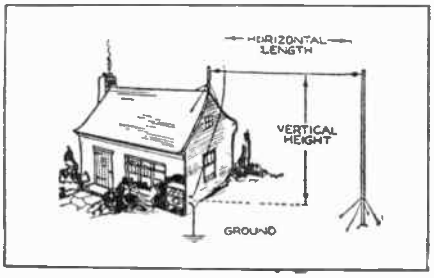


Figure 72

to some particular frequency or wavelength. And the frequency or wavelength to which an antenna naturally tunes is known as its *fundamental wavelength*—just as for a 200-meter wave greatest current will flow through them if we tune the coil-condensed circuits in a receiver to 200 meters.

Antenna Problems

In no instance can one take full advantage of the possibilities inherent in any receiver—from the elementary types to the elaborate multi-tube super-heterodynes—unless the antenna is pretty well what it should be.

In the case of the simple receiver—the one- and two-tube affairs—a great deal necessarily depends on the character of the signal input, which in turn is an antenna problem. And the greater efficiency engineered into complicated receivers, as the number of tubes increases, cannot be touched unless the signal well overrides the noise pick-up—which again is a function of the aerial system.

A good broadcast antenna will, in many instances, give entirely satisfactory operation with a short-wave set. Such an aerial, however, will almost invariably be a reasonably long outside antenna—75 to 150 feet—swung high and clear, well insulated, soldered joints—a clean job from tip through lead-in. If you believe your antenna falls into this class—or that such an aerial can be easily erected—by all means try it before experimenting with the somewhat more complicated types. An exception to this advice is in apartment houses, where, regardless of how well the lead-in may be installed, it will be practically certain to run through a noise-infested area.

Some broadcast antennas will not give good short-wave results, such as those employing noise-reduction systems designed for operation between 200 and 600 meters and, in most cases, indoor aerials. (Again, an exception. Indoor aerials sometimes give good results in rural districts. But in such cases, an outdoor antenna is easily erected, and advantage should be taken of the superior results accompanying an open installation.)

Indoor antennas are unsatisfactory from the point of view of noise. This is because the entire system is located within a noise area. These noises are caused by radiations from vacuum cleaners, violet ray machines, elevators, electrical refrigeration, incinerators, oil furnaces, dial telephones, etc. Such appliances need not necessarily be used in the apartment or home where the short-wave set is installed. The interference they cause is often conducted, like "wired wireless," by telephone and electric light wires, and radiated all along the route. Noise interference is much more noticeable on short waves, due to the fact that the disturbance is of a very high frequency. The broadcast receiver does not tune down to it efficiently.

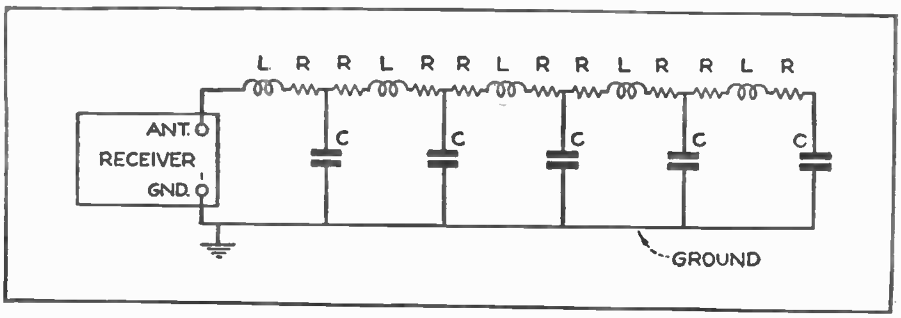
Using a broadcast antenna for short-wave reception, the background noise can be reduced somewhat by lengthening the aerial. Always assuming that the antenna is out of the noise area, this will increase your signal pick-up more than the noise pick-up. Adding more feet to the aerial will of course, increase the capacity between aerial and ground. This capacity acts as a small condenser across the antenna primary in the receiver which may boost its natural wavelength to an undesirable degree. In such cases it is necessary to put a small condenser in the lead-in, close to the set. This should be preferably of the variable air-dielectric type—the so-called midget or trimming condenser—having a maximum capacity of from 35 to 90 microfarads. If the complaint of poor reception on the broadcast antenna is other than noise, the trouble probably is with the short-wave set itself—not the antenna. However, if background noise is excessive, the only cure is recourse to a noise-reduction antenna system.

Increasing Signal-to-Noise Ratio

What we really mean by noise reduction is the increase in the signal-to-noise ratio. As implied above, this can be accomplished in either one or a combination of two ways—by increasing the signal pick-up and by decreasing the noise pick-up. This may be illustrated by an ideal problem.

We assume that our antenna picks up only signal and the lead-in picks up both signal and noise. (The ordinary lead-in picks up quite a bit of signal.) If we sub-

Figure 73—Electrical characteristics of an antenna.



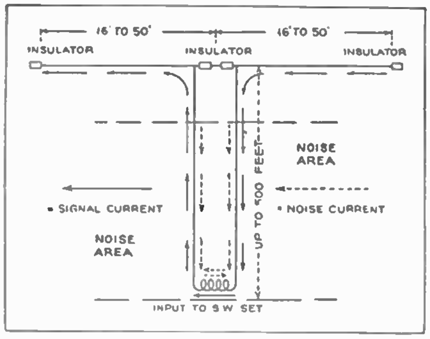


Figure 74

stitute a lead-in which picks up nothing at all, we shall have increased our signal-to-noise ratio enormously! Of course we shall have lost a bit of signal strength, due to the elimination of lead-in pick-ups, but the volume control can now be turned up to compensate this. However, if the sensitivity of the set is insufficient to make up for this loss, we can increase the length of the antenna—which is usually a good idea, unless a particular length is desired.

As predicated, the problem just considered is an ideal one. In actual practice the situation is as follows: The antenna pick-up on a given signal may have a signal-to-noise ratio of say fifteen to one, while the lead-in has a *noise-to-signal* ratio of perhaps thirty to one. The combination may well result in the noise being much louder than the signal, and reception is impossible. We now install a lead-in which picks up practically no noise, nor signal, and the result is we have a signal-to-noise ratio of fifteen to one. If we wish, we may lengthen the aerial, compensating the loss in signal pick-up by the lead-in—probably without material change in the signal-to-noise ratio. However, if the aerial is extended toward a noise area, the signal-to-noise ratio will naturally be lowered, and if away from a noise area, the ratio will be increased.

The transmission line provides a form of lead-in which picks up neither signal nor noise, which is economical, easy to install and widely used for short- and all-wave reception. Its noise-reduction qualities are effective as high as 600 meters.

A "Doublet" Antenna

Inspection of Figure 74, will indicate the manner in which the transmission line functions. This illustrates the "doublet" antenna—so named because of the two equal stretches of aerial on each side of the double lead-in. We shall assume that at a given instant a signal current is induced in the antenna which follows the direction of the arrows drawn in solid lines. This current goes *down* one lead-in, through the antenna primary of the receiver, and *up* the other lead-in, following along its original direction on the left-hand portion of the horizontal wire. Noise pick-up by the antenna will follow a similar course and be heard in the receiver. If the antenna is well located, the noise impulses will be very weak in comparison with the signal. In other words, we have a high signal-to-noise ratio.

The very powerful noise impulses in the section indicated as "noise area," through which the lead-in passes, will take the same direction, *in both lead-ins,* as indicated by the dotted arrows. Meeting in the antenna primary, they neutralize (buck each other) and become non-existent as far as the receiver is concerned. Similarly, any signals picked up by the lead-ins will have no effect on reception.

The parallel leads are placed close together so that they receive impulses of identical strength. If one wire were to pick-up a stronger impulse than the other, it would force itself through the primary against the bucking action of the weaker impulse picked up by the other wire, and noise would be heard. The leads must not be placed too close together, or the capacity will be increased to the extent where losses will occur, as mentioned in the case of long wave noise reduction systems used for high frequency work. The leads are usually spaced about three inches.

In practice, parallel lead-in wires must be separated by spacing insulators (one about every 18 inches) in order to keep the feeders the proper distance apart.

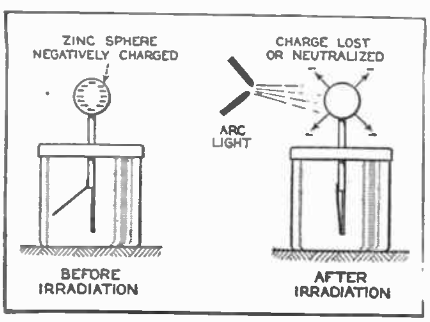
There is no ground used with the transmission line but this should not be a problem with the new sets, as their antenna input circuit is generally designed for use with noise reducing antenna systems.

LESSON TWENTY-THREE

Photocells

THE wide technical application of light-sensitive devices in the fields of radio, television, sound film, for controlling industrial processes and chemical actions and finally the creation of electric energy directly from light, have brought about the development of many forms of photo-sensitive apparatus. When Heinrich Hertz, as early as 1887, discovered that the length of electrical discharges as produced by an electrical inductor could be increased when the electrodes between which the spark passed were illuminated by the light of a mercury interrupter, he probably did not dream of the wide industrial and scientific possibilities opened by his discovery and the modern light-sensitive cells which are several hundred times more efficient than the crude device in which he recognized the physical fundamentals of the photo-electric effect.

Figure 75



What does this wonder tool of the electronic magician of today consist of? The theory of all types of light-sensitive devices—and there are today quite a number of widely different types—goes back to the common source: the photo-electric effect. Under the influence of electromagnetic radiation, preferably of a frequency which can be seen with the human eye, certain reactions take place in the irradiated material. This law, however, is more general than just for the range of human visibility.

Photo-electric Effect

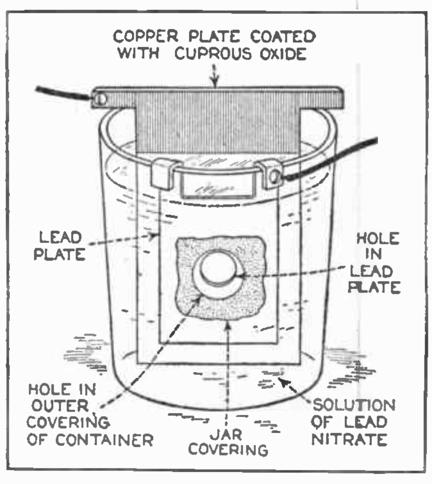
Light and other electromagnetic waves beyond the range of light have an effect upon almost everything in the universe. Light colors the leaves of the trees green, by developing chlorophyll particles in them; it influences the emulsions of our photographic films.

It was William Hallwachs who took the essential parts of Hertz's arrangements and simplified his experimental set-up so far that he was able, in 1888, to clarify the problem of photo-electric reaction. This was the thought of Hallwachs: if the light of the mercury interrupter, shining upon the electrodes, could seemingly effect the distance between the electrodes, then probably something was going out from the electrodes which reduced the resistance of the space between them. From where could this something originate, if not from the electrodes themselves?

Electrodes, at that time, were made of zinc. So, for isolating this phenomenon, Hallwachs put a polished zinc sphere upon a sensitive gold-leaf electroscope which he charged negatively. The leaves, ordinarily showing a wide divergence, under these circumstances touched each other almost instantly when the electroscope was irradiated with an arc-light. The negative charge had disappeared, or a positive charge had been acquired, thus neutralizing the system. See Figure 75.

In Stoletow's experiment a polished zinc plate Z (see Figure 77) was exposed to an intensive light source which included

Figure 76



the shorter wavelengths. Outgoing negative charges were collected upon a grid G, thus diminishing the space resistance between Z and G and allowing a small current to pass through the sensitive galvanometer G under the influence of the electromotive force delivered by the battery.

Early Experiments

This circuit of Stoletow actually disclosed the principles used in many modern photo-electric circuits. However, the energy output of his polished zinc plate, with relation to the light falling upon it, was a small one and inconstant.

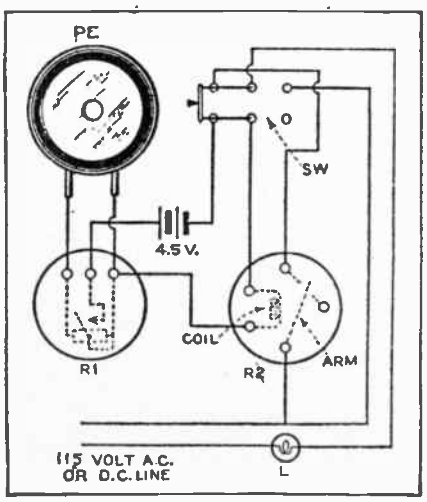
Elster and Geitel used, instead of the pure zinc, an amalgamation of zinc and alkaline compounds. Their sodium amalgam, which was enclosed in a glass vessel to prevent oxidation, may be considered as the first photo-cell in use, although it tarnished badly and had to be cleaned by a magnetic scraper. Finally, by discovering that colloidal suspension of the cathode increased the sensitivity by two decimal points, they were able to build a cell which in many ways, has not been changed considerably in its fundamentals until recently. The increase of sensitivity was produced mainly by passing a glow discharge in a photo-cell filled with hydrogen gas, to evacuate the cell after the sensibilization and to fill it with an inert gas as argon or helium of low pressure.

Types of Light-Sensitive Devices

There are today widely different types of light-sensitive devices which, though they go back to the same fundamental principles, are widely different in their action and appearance. From the various developments along the lines of light-sensitive cells, the following are of practical interest:

1. *Photo-electronic Cells.* These are the cells most widely used, although for many purposes other types of cells seem to be promising.
2. *Wet Photo-voltaic Cells,* using the Becquerel effect, who discovered (in 1839) that a potential difference is created between two electrodes in an electrolyte from which one was irradiated and the other kept in the dark for a period of time.
3. *Dry Photo-voltaic Cells* ("Light batteries," disc cells with copper oxide, silver selenide, etc.)
4. *Photo-conductive Cells* (selenium bridges, for instance). These have been neglected for some time, but their improved types are now most promising.
5. *Crystal Photo-cells* (effects between minerals, as, for instance, argentite, and their metal contacts.)

Figure 79



In this lesson special attention is given to the types of dry and wet photo-voltaic cells.

Photo-voltaic cells are found in nature. Every leaf, if irradiated, indicates minute voltage changes. These, however, are too low to be measured without special amplification. But certain chemical compounds have been developed with which it is possible to make a photo-voltaic cell (Becquerel cell) for a few cents.

How to Make Photo-Voltaic Cells

Figure 76 shows a diagrammatic sketch of such a *light-battery.* A beaker of clear glass is filled with a solution of lead nitrate. In this lead solution is immersed a copper plate which has been uniformly coated with cuprous oxide. At the front of the beaker a lead plate is hung into the solution. The lead plate has a hole in the middle through which the light can enter the cell. The outside of the cell is covered with black paper or coated with a dark lacquer with the exception of a hole at the same place where the hole in the lead plate is. The cell is protected at all sides from light with the exception of that one opening.

If the copper disc is irradiated through this hole, a voltage difference is produced between the lead and the copper electrode. If the two poles are connected in an electric circuit, currents as high as several milliamperes can be produced when the cell is exposed to daylight or sufficient artificial illumination is brought into the cell, for instance, by concentrating the light of an incandescent lamp by a lens before the hole. The amount of current output for a given intensity of light depends to a large extent upon the electrode surface, larger surfaces giving stronger currents.

Dry disc cells have also been developed in the Westinghouse laboratories. They use a copper-oxide disc about the size of a silver dollar. Another disc cell is produced by the Weston Company. Its output is sufficient to operate a highly sensitive relay of the contact-galvanometer type or to read on a microammeter. By calibrating this ammeter in light intensity, it is possible to read illumination (in foot candles) directly.

Photo-Cell Applications

Some of the most interesting applications are those where the cell is used as watch-dog. Ordinary burglar alarms, consisting of wires along doors and windows do the job only half-way. A photo-electric cell can be set up in a room with a light source shining upon it. If desired this light is made invisible (infra-red or ultra-violet). Any person interrupting the light beam will then set off the alarm, unknown to himself.

The work can be done still better than this, however. If a cell is set up so as to detect anyone entering a door or passing through a narrow passageway, a camera can be focused at that point. The relay is then arranged to open the shutter and ignite a flashlight, taking a picture of the intruder.

2-Stage P. E. Amplifier

The following circuit, Figure 78, shows a photocell two-stage amplifier, capable of

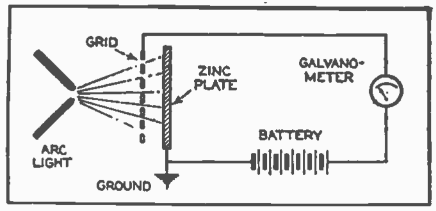


Figure 77

developing a current of about 30 milliamperes. This amplifier uses the Loftin-White principle. All of the voltage dividing equipment has been abandoned and "hum-balancing" resistors have been eliminated. The only condenser shown in the diagram is not really essential, but seems to eliminate any tendency on the part of the relay to chatter when acting at high speeds.

A "B" power unit capable of supplying 300 volts was used in place of the batteries shown in the diagram. The filament return from the -45 and lower end of the 10,000-ohm resistor in the -27 plate circuit were returned to the 180-volt tap. This is not a very critical adjustment, as any voltage from 150 to 200 will give good results. The only control necessary for the operation of this amplifier is the resistance, R. which controls the grid bias on the first tube and hence the current through this tube. This in turn controls the grid bias of the second stage and the current through the -45.

How It Works

In operation, a value of light slightly below the maximum is allowed to fall on the photo-cell. This increases the current through the first tube and increases the grid bias of the second stage until the current through the relay becomes a minimum. The resistance, R, is adjusted until the relay almost trips. The light source is then cut off and the effect noted on the relay. This should allow the relay current to return to normal and close the relay. If it does not, the adjustment should be repeated with a stronger light.

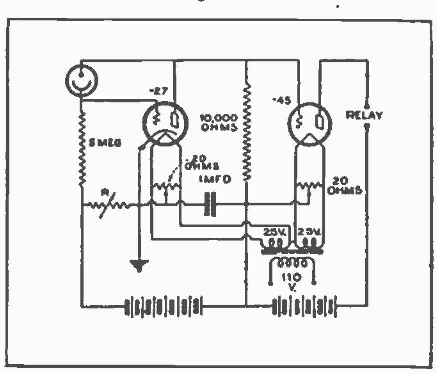
A resistance of 200 ohms for R will generally be sufficient to allow for any adjustments which may have to be made. It is to be understood that this amplifier was intended to produce large currents in the power stage.

Another photocell application that offers extensive possibilities is found in using a photo-electric cell to operate a light switch to automatically turn on lights at sundown and turn them off again at sunrise.

Equipment of this nature can be readily constructed by following the circuit of Figure 79.

The photo-electric cell, PE, is the Weston Model 594 Photronic Cell, and works

Figure 78



into a Weston Model 634 relay (R1). This relay is of the very sensitive type required to operate directly out of the cell. The relay, R2, is of the power type and is capable of breaking a one-ampere circuit, thus permitting the control of electric lamps totaling up to 100 watts in power (L). The switch, SW, may be an ordinary double pole, double throw knife switch.

With this equipment, wired as shown, the cell is placed in such a position as to be fully exposed to daylight, yet protected from the light of the lamp it is to control. While the day remains bright the coil of R1 is energized, holding the circuit open. But when dusk falls the cell becomes inactive, the coil of R1 is no longer energized, and the armature is released, allowing the circuit to close. This energizes the coil of R2, closing the a.c. circuit through the armature and causing the lamp to light. At the break of day the action is reversed, thus turning off the lamp. If it is desired to turn off the lamp manually at any time it is accomplished by simply opening switch SW. Or the lamp can be turned on by throwing this switch to the right.

When the system is first put into operation, the relay R1 is adjusted at dusk so that the arm just makes positive contact and the lamp lights.

LESSON TWENTY-FOUR

Breaking Into The Amateur Game

THERE are very few young men who at some time during their life have not been fascinated by the mysterious dots and dashes of the telegraph code. And it is far from the mark that only boys are interested in code. Many of our wealthiest men, holding enormously responsible positions, have their own radio shacks where they spend many fascinating hours communicating with ordinary "hams" in all parts of the globe. But it is equally true that every growing boy, and especially the Boy Scout, should learn the code; it may be useful and even save life at some time in the future.

In the beginning, Morse signals were sent over the land-line and recorded by embossing them on a strip of paper. It was purely accidental that the art of receiving the signal by sound was discovered. Some of the old-time operators, after watching the recording for many years, found that they could read the signals by the sound of the electromagnet. That was the beginning of "reading" by sound.

In radio, the sound is somewhat different from the signals over the land-line, since the receiving operator hears a sustained musical tone which has the duration of the dots and dashes. In the land-line system there is a click at the beginning and end of each dot or dash.

Code Offers Entertainment

Those of us who possess short-wave or dual-wave receivers are missing many an evening of good solid entertainment if we do not know the International Morse code. There are new and recurrent thrills; radio signals from merchant and naval vessels in all parts of the world, weather bulletins, news flashes, time signals and oceanic services competing with the world's cable system; there are the thousands and thousands of amateur radio operators to whom most of the credit must be given for developing and opening up the shorter waves. All of these stations communicate by Morse code. Messages, some bearing on world affairs, tragedy and comedy, love and simple fellowship are buzzing out from radio stations all over the world; they are there for those of us who know the code. Though we are bound to secrecy in what we intercept (it is a serious offense and there are severe penalties for *divulging* the contents of radio messages) we are at liberty to "eavesdrop" all we want.

"But," you say, "it takes a lot of study and it's hard to learn the code. I could never do it." And that is where you are wrong. During the war, Great Britain turned out high-speed operators in less than a month's training. There is a right and wrong way, a pleasant and an unpleasant way, to learn the code.

Easy Instruction Method

Most of us make the mistake of thinking of the code in terms of "dots and dashes"; unknowingly we separate the dots from the dashes, we break into its component parts a character that should be thought of as a whole. Forget the dots and dashes, and in their place think of dits and dahs; think of the sound of each character as one complete unit—*a*, for instance, becomes *dit dah*.

Each letter of the alphabet has a separate and distinct sound of its own. Very good code can be produced by whistling, or on any wind instrument of the orchestra. As a novelty, it is often the practice at radio operators' conventions to pass out wooden whistles with which it is possible to blow good code, readable blocks away. So, with this simple music lesson we start out to learn the code.

The International Morse code shown herewith is the accepted radio code. Now, we'll make a copy of the code, but instead of putting down dot-dash for *a* we'll draw two little tents, one short and one long (Figure 81); and every time we see this group in our future study of the code, we'll think of its as *dit dah*, repeating it in our minds and verbally droning the signal out on our lips. A sharp staccato dit is followed by a longer dah (about 3 times as long as the dit), These sounds can be made distinctly with the tongue and lips, and hummed over a few times it doesn't take long for us to know without a doubt that the familiar little tune of dit dah can be nothing but the letter *a*.

Next comes *b*, which we put on paper as one long tent and three short ones, *dahhh-dit-dit-dit*. The writing of the characters as short and long tents help to prevent us from learning the groups as dots and dashes; instead, it gives us the impression of sound.

Each character follows with equal ease and simplicity. Practice each letter from A to Z just as you like; let the numerals go until you have mastered the alphabet. Hand the printed dit dahs over to some fellow sufferer and have him skip around and call out characters for you to respond to in song. It's pleasant, like doing a crossword puzzle, and you'll find yourself repeating the signals over and over, whether you be president of Amalgamated Mushrooms or Johnny Clerk; and you both can expect and get just as much ultimate pleasure out of knowing the code as the rest of us.

Figure 80

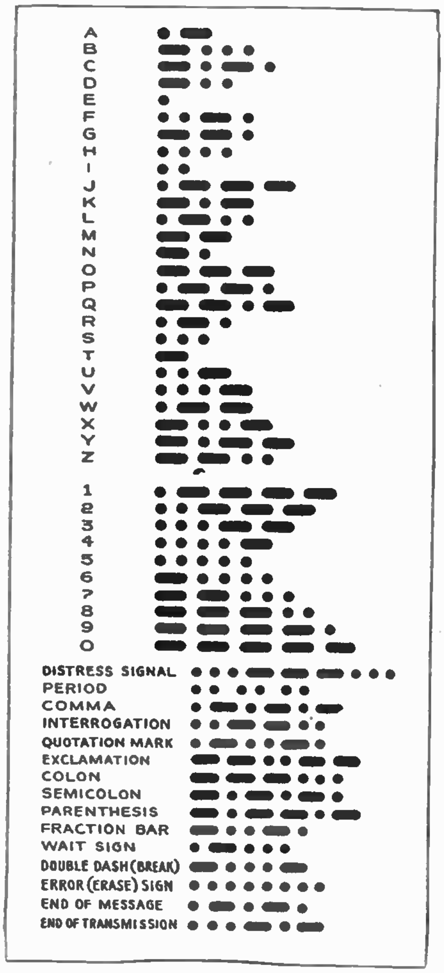
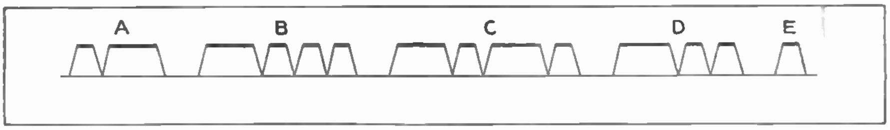


Figure 81—A pictorial representation of dit dahs.



Start Today!

You don't have to have telegraph keys, buzzers, oscillators and batteries to learn the code. Start today and make your voice the buzzer and your lips and tongue the key. In this manner the characters, dits and dahs, are more quickly and lastingly impressed on the brain and the sound is conveyed with directness and realism to the ears. Later on if you like, you can equip yourself with a telegraph key and buzzer or oscillator. If you use the dot-and-dash method you'll find yourself counting the number of dots and dashes to make the characters, and if you have to hesitate, see it in your mind's eye, take your mental pencil and point out each dot and dash, you'll find yourself greatly hampered and soon you'll give up in disgust at your slow progress.

Perhaps by now you are settling down to copy all the code you hear. All right, good, but tune until you can find some slow signal. They're there, especially between 8000 and 9000 kilocycles on your receiver dial. Just listen without trying to put anything on paper. After a moment you'll single out individual characters. Try listening for some predetermined letter and confine your efforts to recognition of that particular sound. You'll find that in a remarkably short time you can recognize that selected character without any trouble at all. Just watch the individual characters; never mind the words and sentences, they'll come later.

It's not work, it's fun; get a group together—father, son, and all the youngsters and oldsters in the neighborhood, a boy scout troop—it doesn't matter, but do get in line for the fun you can get out of such little and pleasant effort.

Getting An Amateur License

For the benefit of those who wish to build a transmitter and actually go on the air, here are some of the questions asked by prospective "hams." The answers are brief but contain pertinent information.

1—Q. Is there any charge for the license and where are the examinations held? Must these examinations be taken every so often or are they for an unlimited time? Where would one get the information asked for in the examinations?

A. There is no charge for an amateur license other than a notary fee of 25c for attesting to the validity of answers on a station and operator's application blank. Licenses are issued by the Federal Communications Commission, which has branch offices in the principal cities of the country. Licenses are issued for a period of three years. After an examination is taken and passed, no further examination is necessary providing the station is kept in operation. Lack of activity after a license expires makes it necessary to take a new examination unless it can be shown to the satisfaction of the examining authority that the failure to apply for renewal was due to something beyond the control of the applicant. Information contained in examinations is available in several handbooks published for the amateur. Most radio stores keep these in stock.

2—Q. What is the very cheapest station one would be able to build and which would be able to compete with other amateurs? Do these stations operate on 60-cycle a.c. current? What is the cost of upkeep per hour? Must one operate them daily or may they use them only about three times weekly?

A. The cost of an amateur station varies tremendously. However, it should be possible to construct an efficient telegraph transmitter for between twenty and thirty dollars. Telephone equipment costs considerably more as expensive speech equipment is necessary to supplement the apparatus normally used for telegraph transmission. Practically all amateur stations are operated from 60 cycle alternating current, as this type of power is available in more than 90 per cent of the homes in the United States. Some sections of the country have 25 and 40 cycle a.c. and direct current, which it is possible to use providing the apparatus is designed for such mains. An amateur may operate his station at any time he chooses. There are no operating requirements other than the station must have had communication with at least three other amateur stations within ninety days before the expiration of term of license in order to qualify for renewal of license at the end of the three-year period without having to take another examination.

Space Needed For Station

3—Q. About how much space is needed for an amateur station? Are two separate units necessary; one for sending and one for receiving?

A. Space needed for an amateur transmitter is governed entirely by the facilities available and the operator who constructs it. It is possible to mount a complete station in a secretary type of desk with a transmitter consuming no more space than the average size receiving set. On the other hand some amateurs have a whole room for their radio equipment. A separate unit is necessary for transmitting as a transmitter always functions independent of the receiving set. Any receiving set that is capable of tuning the amateur frequencies may be used. Practically all all-wave sets fulfill this requirement. Amateur frequencies are: 1715 to 2000 kc.; 3500 to 4000 kc.; 7000 to 7300; 14000 to 14400 kc., and in addition channels in the vicinity of 28000 kc., 56000 kilocycles and other higher frequencies. For frequencies above 14000 it is necessary to use a specially designed receiver, designed for ultra-high frequencies.

4—Q. Is there any branch of the government which trains young men for work in radio in exchange for labor? Is it possible to secure ordinary work in any of the large broadcasting stations and thereby come in contact with the mechanism and be able to learn a great deal about radio?

A. The military branches of the government train enlisted men in radio communication. It usually is necessary to have some knowledge of radio before obtaining a position with a broadcasting station. If in the operating division, a commercial operator's license is required which of course, requires more advanced training than an amateur's license.

5—Q. Is the amateur field filled or are there still more needed?

A. There is no fixed limit to the number of amateurs that may be licensed.

Time Needed For Preparation

6—Q. About how much preparation and how many hours of study are necessary before one may operate a station?

A. The amount of time necessary for preparation to pass an amateur examination depends entirely upon the ability of the individual. Some persons have been known to start from "scratch" and qualify for license within three months. The most difficult part of obtaining a license is learning the telegraph code. A copying speed of thirteen words a minute (computed on the basis of five letters to the average word) is required.

7—Q. Do you know of any amateurs who would be willing to work with a newcomer to the field in this territory?

A. We suggest you consult a call book for the location of amateurs in your vicinity. You will find most of them willing to help a newcomer.

8—Q. Is the amateur's work of any benefit to the radio world in general? Will his work as an amateur aid him in getting into other fields of radio? Will it be of any assistance to him in the field of television?

A. Amateurs have contributed a tremendous amount to the development of radio. To cover their achievements would fill a large volume. One of their achievements was the development of short-wave communication which today is the backbone of international radio communication. Most of the prominent radio inventors and engineers are, or were at some time or another, amateurs. The prestige of being an amateur usually is helpful in obtaining employment in the radio industry. The knowledge gleaned by being an amateur undoubtedly will be helpful in understanding the intricacies of the television of the future.

9—Q. Is it necessary to learn code to be an operator?

A. It is necessary to learn the code to become an amateur. A receiving speed of thirteen words a minute is required. (See answer to 6.)

10—Q. Is amateur radio usually followed as a hobby or do many people give their full time to it?

A. Amateur radio is essentially a hobby.

LESSON TWENTY-FIVE

Homemade Code Practice Oscillators

HERE is a simple code test set with which you can tap out messages or have a friend do the sending while you receive the message he transmits.

In Figure 82 is shown an arrangement of the apparatus which is employed in code instruction. Note that in this diagram we show, to the left, the actual circuit arrangement, while to its right is a picture diagram of the connections. All that the device consists of is a high-pitched buzzer (B), a key (K) and a battery (C). By pressing the key the electric circuit is closed, making the current from the battery operate the buzzer so as to produce a high-pitched buzzing noise. As the key contacts are opened and closed to form the code characters conforming to the letters which are being transmitted, the operator is able to listen to the buzzes and read the signals as they are sent.

At first, it is well to memorize the code characters by repeatedly tapping them out with the key.

When two radio beginners get together to learn the code the job is somewhat simplified because then, after each has memorized the code by hearing the sounds, the wires which connect the key to the circuit may be lengthened, say, to 30 or 50 feet, with the key in one room and the buzzer in another.

Figure 82

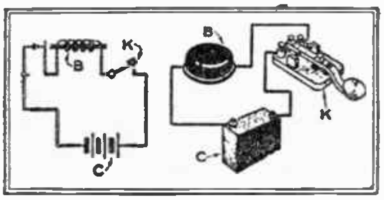
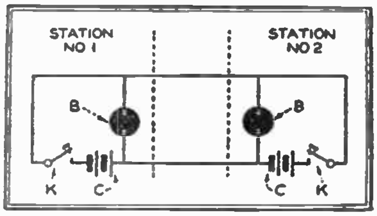
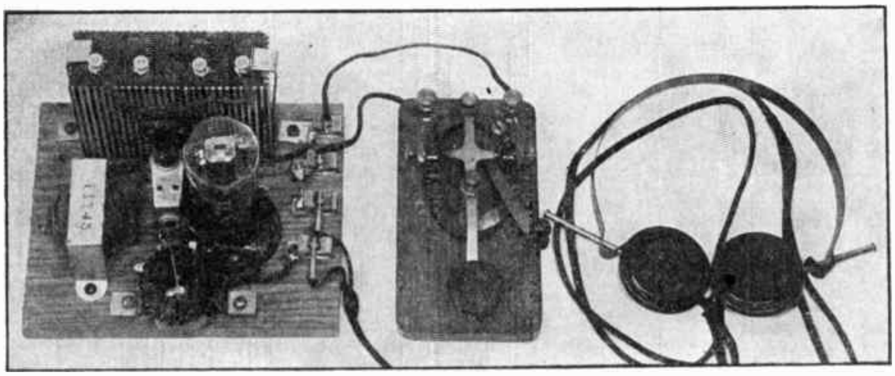


Figure 83





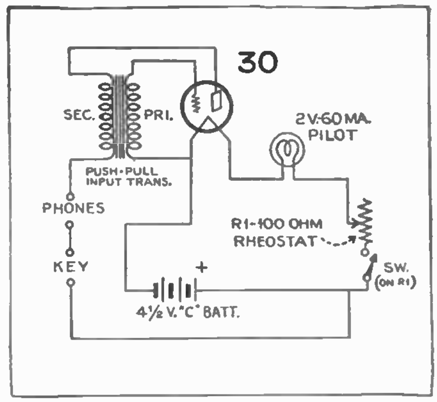


Figure 84—right; Figure 85—left.

In this way the effect of nearness of the fellow who's doing the transmitting is dispelled and you really have the feel of listening in on regular code reception.

After this stunt has been tried, each of the operators alternating at the key, a second key and buzzer may be added to the circuit as shown in Figure 83.

With such an arrangement you can actually transmit and receive messages as you would do if you were operating a regular radio transmitter and receiver.

A Vacuum Tube Oscillator

The little code practice oscillator shown in Figures 84 and 85, has several features that recommend it to the attention of the code student. First of all, the parts are few, simple and standard and most of them will probably be found in the proverbial "junk box." Second, the only battery used is a standard 4½-volt C battery. Third, the pitch or tone of the oscillator can be continuously varied over a wide range by rotating the rheostat knob.

This variable tone is an advantage for two reasons. It permits the listener to obtain a pitch that is pleasing to him and it permits the use of almost any type of audio coupling transformer. Normally a large transformer is likely to result in a very low pitch whereas the small, cheaper transformers provide a high pitch. With the circuit employed in the oscillator shown here a transformer which is normally unsuitable for this work will be found to function very satisfactorily.

The circuit and construction is so simple that a detailed description is unnecessary. The illustrations make the construction of this particular model quite clear, although there is, of course, no necessity for following this particular layout.

The variable pitch is obtained by varying the filament voltage and therefore the emission of the type 30 tube. It will be noted that the tube is connected in series with the rheostat and a pilot light. But the full 4½ volts could be applied across this circuit without seriously overloading the filaments even with a fresh battery. The rheostat is therefore inserted primarily for the purpose of tone variation. The plate return is made to the plus 4½-volt tap of the battery. This voltage is adequate for the plate supply and will provide a good loud signal in the headphones.

The pilot light is an almost essential feature of a gadget of this type, because without one it is the easiest matter in the world to forget to turn the oscillator off when practice is finished with the result that battery mortality runs high. With the pilot light to act as a reminder to turn the oscillator off when not in use, the single 4½-volt C battery should last from one to three months, depending on the amount of use.

This little oscillator is also excellent for i.c.w. when used in conjunction with a transmitter operating on the 5-meter band. The oscillator can be coupled direct to the grid of the first speech-amplifier tube by simply connecting a .1 mfd. condenser between the oscillator plate and the grid of this speech amplifier tube.

LESSON TWENTY-SIX

History Of Television

THE first practical electrical picture-transmitting system, strange as it may seem to us, was actually set up and transmitting recognizable facsimiles between Brighton and London (a distance of fifty miles) before the middle of the nineteenth century! This system, strikingly similar in principle to those which flash news photographs about the world today, was invented by Frederick C. Bakewell, an English teacher of electricity, in 1847. "The copying telegraph," wrote Bakewell, "transmits copies of the handwriting of correspondents. . . . Every letter and mark made with the pen are transferred exactly to the other instrument, however distant."

The invention, as shown in Figure 86, included two metal cylinders about six inches in diameter, one at the transmitter and the other at the receiver. The message (or the picture) to be transmitted was drawn on a sheet of tinfoil with insulating varnish, the tinfoil being wrapped on the transmitting cylinder. As the cylinder rotated, a steel wire bore against its surface and was moved along by a screw. The surface of the cylinder was therefore "scanned" by one continuous spiral line. When the steel wire touched a part of the picture represented by insulating varnish, the line current was cut off until the wire again touched the unvarnished tinfoil.

At the receivers, a similar cylinder rotated in synchronism with that at the transmitter. The receiving cylinder, however, was wrapped with paper soaked in a chemical solution. On this paper pressed another steel wire connected to the line, staining the paper under it *blue* whenever line current was flowing. The blank tinfoil at the transmitter was therefore reproduced as a blue background at the receiver, on which appeared white lines corresponding exactly to the varnish lines on the tinfoil.

Keeping the two cylinders exactly in step was of course a problem. Bakewell used the principle of the pendulum in some of his experiments, but he also devised an electromagnetic method, similar in principle to those used in modern television, which made use of a separate wire to transmit synchronizing impulses simultaneously to both the transmitting and receiving cylinders. In fact, so complete and well designed was his apparatus that one can scarcely believe it was actually demonstrated long before the outbreak of the Civil War.

The next forward step in television (or its slowed-down beginnings) had to wait on the discovery that selenium changed its electrical resistance in accordance with the amount of light falling upon it. When the Society of Telegraph Engineers and Electricians met at Paris in 1881, Shelford Bidwell, another Englishman, read before it a paper on some "apparatus . . . merely of an experimental nature." Bidwell's receiving apparatus was exactly like Bakewell's, except for a considerably smaller cylinder giving a picture about two inches square.

Bidwell's Transmitter

The transmitter, however, as shown in Figure 87, was radically different. The picture or scene to be transmitted was projected upon a ground-glass screen, behind which a selenium cell moved slowly up and quickly down, gathering light through a pinhole from successive portions of the picture in turn. For each upward motion, the selenium cell moved across the image 1/64 of an inch, and on the receiving cylinder a screw thread moved the platinum recording point across an equal traverse at each revolution. Bidwell pointed out that "the pictures to be transmitted are not mere artificial drawings upon tinfoil or some other substance, but the projected images of actual objects. . . ." The system thus might be

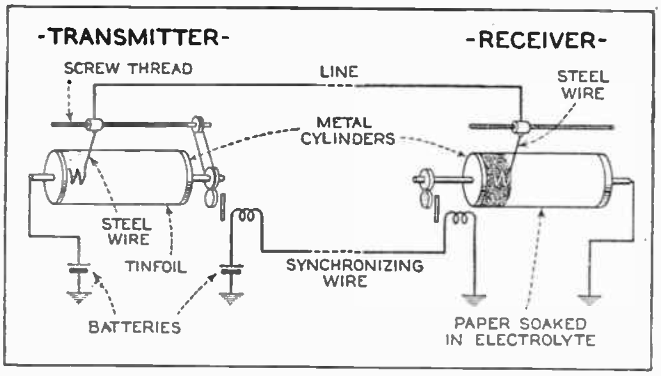


Figure 86—Bakewell's Facsimile System.

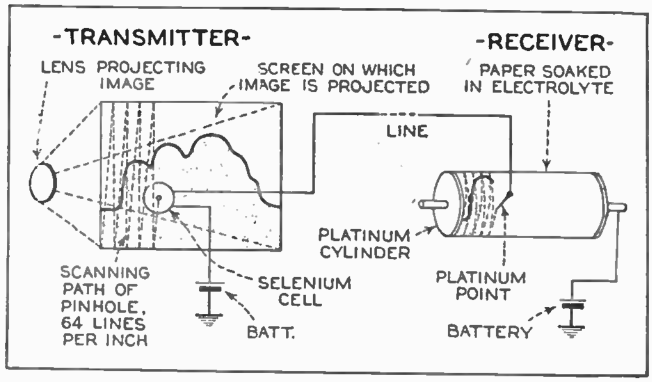


Figure 87—Bidwell's "Still" Television.

termed "still television," as the subject would have to hold a given pose several minutes before a picture could be formed at the receiver.

The Nipkow System

Undoubtedly one of the greatest names so far recorded in television history is that of Paul Nipkow, a German. In 1884 the German Patent Office issued to him Deutschesreichspatent No. 30105, setting forth all the details of a complete and workable television system. Figure 88 is based on one of his drawings. At the transmitter and receiver are two disks, perforated with small holes along similar spiral curves, which rotate in synchronism. The small holes, sweeping by the picture along successive horizontal lines, vertically displaced, trace each element of the picture in turn, or "scan" it. This scanning disk was the heart of Nipkow's system in 1884, and it was the heart of most television transmitters and receivers until recently.

At the transmitter an image of the subject was focused directly on the disk. There followed a condensing lens which converged the rays from this image on a selenium cell, the output of which was led over wires to the receiver.

At the receiver an arc light passed through a condensing lens and through a polarizer. Next the polarized light passed through sulphureted carbon gas or some substance which would modulate the light in accordance with the magnetic field changes caused by the changing "picture" currents in the coil. The modulated light then passed through the receiving disk which, in order to save light, was viewed directly by the eye. This electric modulation of polarized light, proposed by Nipkow in 1884 was applied (as widely heralded Kerr cell) to the theatre television projection of several years ago.

Among other things, Nipkow proposed stereoscopic television and the employment of infra-red rays at the transmitter. Both of these ideas were put into practice in England a few years ago, the latter attaining world-wide prominence as Baird's "noctovision." No greater compliment can be paid the great pioneer Nipkow than this simple truth: the method of his invention still remains, nearly fifty years later, the basic method of mechanical scanning, and practically all of his various devices are used in one or other of the systems of today.

Nevertheless, full practical exploitation of Nipkow's suggestions had to wait on three developments in other fields of science. The selenium cell follows light changes too slowly for efficient television use. Something quite inertialess was needed, and it appeared as the photoelectric cell of Elster and Geitel in 1890. Similarly, the weak picture currents at the receiving end balked the early experimenters. This difficulty was removed by De Forest's invention, in 1907, of the triode amplifier.

Later Progress

In the meantime there occurred other events, removed from the main current of television progress but nevertheless notable because they paved the way for modern developments. In 1891 Amstutz, an American, sent the first half-tone picture over a twenty-five mile line, using celluloid sheets etched in relief. In 1898 Szczepanik proposed color television, later staged as a practical demonstration. In 1902 Korn sent the first photograph by wire, using at the transmitter a powerful Nernst lamp as the source of a narrow beam of light, which was directed through successive elements of the "negative" to a compensated selenium cell. In 1909 Knudsen sent the first line drawing by radio, using one metal plate at the spark transmitter, and at the receiver a second plate, covered with lampblack, on which the drawing was scratched by a coherer relay.

Not until after the World War did Nipkow's television principle bear actual fruit in the work of C. Francis Jenkins in America and John L. Baird in England. Even so, at first the images were very crude; they appeared only as outlines, showing no detail. In April, 1925, Baird transmitted vision of this sort over the distance of a few feet before the patrons of a London department store. The subject was a ventriloquist's doll. In most of Baird's laboratory work a similar doll sat before the transmitter.

Progress continued. One cloudy Saturday in June, 1925, a distinguished group of Washingtonians, assembled in the Jenkins laboratory on Connecticut Avenue, watched the flickering image of a toy windmill which was seen to revolve. The windmill itself was turning in Anacostia, five miles away, and radio was bridging the visual gap. During the following January, Baird demonstrated an improved television system before members of the Royal Institution assembled in London. They saw recognizable faces and were much impressed. Single faces have been prominent in many television experiments since that time, because they reproduce satisfactorily where a larger or more comprehensive scene would be hopelessly blurred.

In 1927 television *in the grand manner* was demonstrated in New York by the Bell Laboratories. This great research organization quite naturally eclipsed the best efforts of the two pioneers. The Bell screen was about two feet square; the faces and speech came in twenty miles by radio and three hundred by wire. The hundreds of able men who planned and built the Bell equipment made vast improvements in existing technique, but they discovered no new principles.

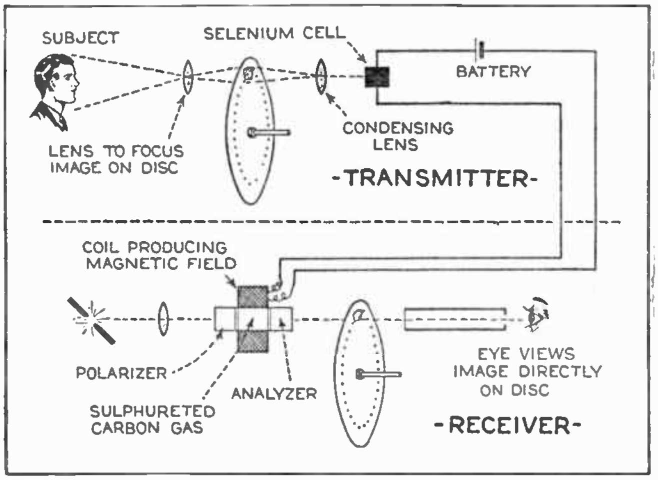
LESSON TWENTY-SEVEN

Application Of The Kerr Cell

THE problem of transmitting television images successfully, can be resolved into several separate and dintinct problems. In the transmission of sound, we have always been very fortunate in that a single fluctuating current and a single vibrating diaphram can be made to reproduce sound of any complexity, no matter how many instruments are used.

This is not the case with the reproduction of images. An image, when in motion, represents a myriad of points which vary in brilliance. In normal vision, an exact replica of this picture is projected on the retina of the eye, and numerous light-sensitive nerves carry the impression to the brain. This would lead us to the conclusion that numerous transmitting systems are necessary for just one image.

The solution is to divide the image into small squares and to telegraph the brilliance of each little square in turn. The squares must be "sent over" in a definite order and put together again at the other



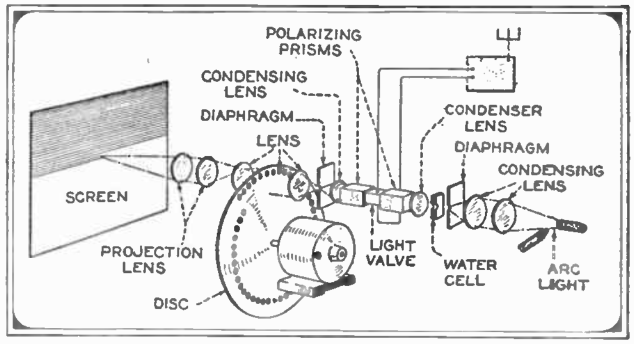


Figure 88, left, shows Nipkow's disk television system; Figure 89, right, illustrates the optical system employed in the scanning section of the televisor.

end, and this must be done so fast that the eye will receive the impression of a steady picture.

The light of each section in turn is made to fall on a photocell, which translates it into an electric current of varying strength. At the receiving end, this electric current has to find a light source which is powerful enough and can follow the fast fluctuations of light required in television.

The Neon Tube

Heretofore the only practical method of converting television signals to light depended upon bringing a rarified atmosphere of neon gas to luminosity by means of the two-element neon tube, the invention of Dr. D. McFarland Moore. The neon tube is amazingly rapid in its action and fully capable of handling picture signals representative of great detail. At the two-way wire television demonstration conducted by the Bell System in New York, using 72-line scanning (double the number of picture elements of 48-line scanning), the reproduction was an optically enlarged view of a reproduction about two inches square. To produce this image, a somewhat larger neon tube than had been used heretofore was developed, capable of handling 200 milliamperes. It was necessary to employ water cooling, so large was the energy dissipated in heat. Yet this was still "peep hole" television, limited to a single observer. Hence, when we consider the requirements of projection on the screen with the neon tube, it rises to the impractical proportions of a power device.

If a neon tube could be made to produce a maximum light as intense as the arc, it would be a simple matter to project its ray upon a screen through a scanning disc by merely reversing the scanning process at the transmitter. But such a powerful neon tube has not appeared.

The G. E. Light Valve

General Electric has developed a light valve controlling a powerful illumination source from a radio signal. Projection is accomplished by passing an intensely powerful beam of a standard 175-ampere motion picture arc through a high-frequency light valve through a scanning disc to a translucent screen to the eyes of the observers. The operation of the light valve is analogous to that of the grid of the vacuum tube by means of which a small incoming impulse controls a relatively large space current obtained from a local plate battery. The light valve, like the grid, has no apparent inertia and can handle picture signals of any conceivable frequency.

The apparatus, which was built under the direction of Dr. E. F. W. Alexanderson, was expected to be as effective in handling television signals having frequencies up to a million cycles as it proved to be with light changes with a maximum rate of change of a twenty thousandth of a second, involved in 48-line television.

A principle long known to science is applied in this light valve. It is the discovery of a Scotchman, John Kerr, whose interest in physics was developed as a student and protegé of William Thomson, the great English physicist. Kerr observed that the direction of polarization of a beam of polarized light can be altered by passing it through an electrostatic field. Faraday had previously observed a similar phenomenon in connection with intense magnetic fields and the pioneer, Nipkow, who evolved the working fundamentals still used in present-day television systems, suggested the use of that phenomenon for projecting television. Kerr's electrostatic bending of polarized light was embodied in a practical light control device by Dr. August Karolus of Leipsig, Germany. The General Electric Company obtained American rights to Dr. Karolus' inventions, which Dr. Alexanderson built into a practical television projector.

The Nature of Polarized Light

It is difficult for the layman to understand the difference between a beam of polarized light and an ordinary ray. The distinction is indeed subtle, but worth understanding, because polarized light exhibits properties of great prospective importance in television. A beam of polarized light can be deflected by magnetic and electrostatic fields in the same way that a stream of electrons in a vacuum can be controlled. Small changes in the direction of the beam of polarized light projected through certain crystals produces great changes in their intensity. The angle of maximum projection is determined by the structure of the crystal. By rotating the crystal about the angle of maximum light projection, that is, the axis of the crystal, or by varying the direction of the beam itself in relation to that angle, the intensity of the resulting light projected beyond the crystal is readily controlled.

If we project a powerful light beam through a shutter with only a pinhole aperture, a tiny spot of light can be projected to a screen. The spot, however, is not perfect. There is always slight diffusion. The cut-off from black to white is not as sharp as might be expected. Apparently, in the motion of an ordinary beam of light, there is not only motion in the direction of projection, but a component of transverse motion.

Passing light through a crystal of proper construction, it is possible to divert the transverse component in a ray separate from that moving forward as a plane. A Nicol prism is a crystal device of special construction which completely isolates the component of transverse motion from that of forward motion, producing a beam of polarized light.

Crystal structure comprises a rigid arrangement of electrons. Their orbits of motion are restricted to very definitely limited directions. The atoms of crystals are arranged in perfectly orderly array so that the entire crystal structure has the characteristics of a single crystal atom. When a source of energy, such as a light beam, is projected through a crystal, only that component of energy coinciding with the crystal structure is successfully projected through it.

The sun, rising upon a city of tall buildings, projects light through it only in the proportion that the light energy coincides with the direction of the streets. Obviously slight alterations in the direction of a ray of light projected through a street will make significant differences in the amount of light reaching the other end.

Application of the Kerr Effect

The light of the arc passed through the Karolus projector is first formed into parallel rays by means of a lens system. It then passes through a Nicol prism, which disposes of all of the transverse energy in the light ray, leaving only a plane polarized ray to be projected through the light valve. The polarized ray then passes through a transparent nitrobenzol solution which forms the di-electric of a condenser. The television signal is impressed on the plates of the condenser, rotating the polarized ray according to the intensity of the television signal which, in turn, corresponds to the light value being scanned at each instant. This rotating is only a minute angle, but is sufficient to produce a substantial effect upon the total light passing beyond a second Nicol prism, to which it is then directed. Thus we obtain a powerful ray of light varying in proportion tc the television signal.

The rest of the projection process is easy to visualize. (see Figure 89.) The intensely powerful ray is projected to the screen through a scanning disc revolving in synchrony with the transmitting disc. It covers the entire surface of the screen with sufficient rapidity so that the eye, through its property of persistance of visions, collates the separate impressions into a single picture. A new revised scene is flashed on the screen in so short an interval that motion is blended smoothly, without the jumpy action of the early moving picture films.

LESSON TWENTY-EIGHT

Television With The Scanning Disk

SCANNING is the process of dividing the picture into a large number of strips, which are to be transmitted as a continuously varying light source. At the receiving end, a similar device puts the picture together again.

The Nipkow disk was one of the first scanning devices. Figure 88 shows its application in the simplest form. The disk is made of paper, bakelite or metal. In this particular application, lenses are arranged so that an image falls on the disk and the light passing through the holes of the disk can fall upon the photocell.

By close examination of the diagram, it will be seen that the upper hole of the disk first passes over the picture and lets the light from the top of the image reach the photocell, yet only one point at a time. As soon as this hole has moved beyond the limits of the picture, the second hole traces a second strip immediately below the first strip. So the entire picture is "scanned" in one complete revolution of the disk. The more holes in the disk, the finer the lines and the greater the detail that can be transmitted. It is seen that the disk soon becomes unwieldy, so that high definition is hard to obtain.

The process can also be reversed, instead of placing the photocell back of the disk the light source is located there. The subject is then shut off from the light except for the beams passing through the holes, which illuminate the subject point by point. The photocells are thus focussed directly on the image.

Such a system was used by Sanabria in a theatre in New York City in October, 1931. He was able to throw the pictures on the motion picture screen, but the brilliance of the image was low.

The Sanabria system was unique in its method of scanning. The disc had only 45 holes, but these were arranged in three spirals of 15 each, each spiral covering 120 degrees of the disc, as shown in Figure 90. The first hole of spiral 1 swept across the very top of the subject, and the fifteenth swept across the bottom, not the very bottom, but a distance above it equal to the height of two holes. The concentric scanning sweeps did not overlap exactly, as in ordinary disc scanning, but were separated a distance again equal to the height of two scanning holes. Thus one-third of the entire surface of the subject was scanned in one-third of a revolution of the disc, which rotated at 900 r.p.m. This was really an early example of "interlaced" scanning.

Scanning System

As the disc continued to rotate, the first hole of spiral 2 traveled across the subject, starting directly under the arc traversed by the first hole of spiral 1. The second hole of spiral 2 started just under the second hole of spiral 1, and so on down the surface of the subject until the fifteenth hole of spiral 2 had passed under the path cut by the fifteenth hole of spiral 1. Two-thirds of the subject's area had now been covered.

The first hole of spiral 3 then scanned the remaining space left blank between the first and second holes of spiral 1. Progressively down the subject the holes of spiral 3 scanned the last third of the surface, until the fifteenth hole swept across the very bottom limit.

At the receiving or reproducing end the process was the same, the scanning disc recreating the image in the same manner that it was broken down.

Since all three scannings took place in the total time of 1/15 of a second, they impressed the eye as a single composite action. The eye's well-known characteristic of persistence of vision made this possible.

The Transmitter

The successful operation of the Sanabria system, as demonstrated on the stage, was due to the precision of the mechanical members, and also to the sensitivity and power, respectively, of the photo-electric cells and the projector lamp. The arc light and disc mechanism of the transmitter were set up on a massive cast-iron stand about four feet high. The base was fitted with leveling and locking screws so that the whole unit would stay put in any desired position. The transmitting disc was small, being only about sixteen inches in diameter. The rays of scanning light that came through it were not thrown directly on the subject, but came reflected by a 45-degree mirror through a square opening in a seven-foot-high frame holding eight photo-electric cells. This arrangement was very convenient for the operator, as it allowed him to see the subject at all times and to make any necessary focusing adjustments on the scanning rays.

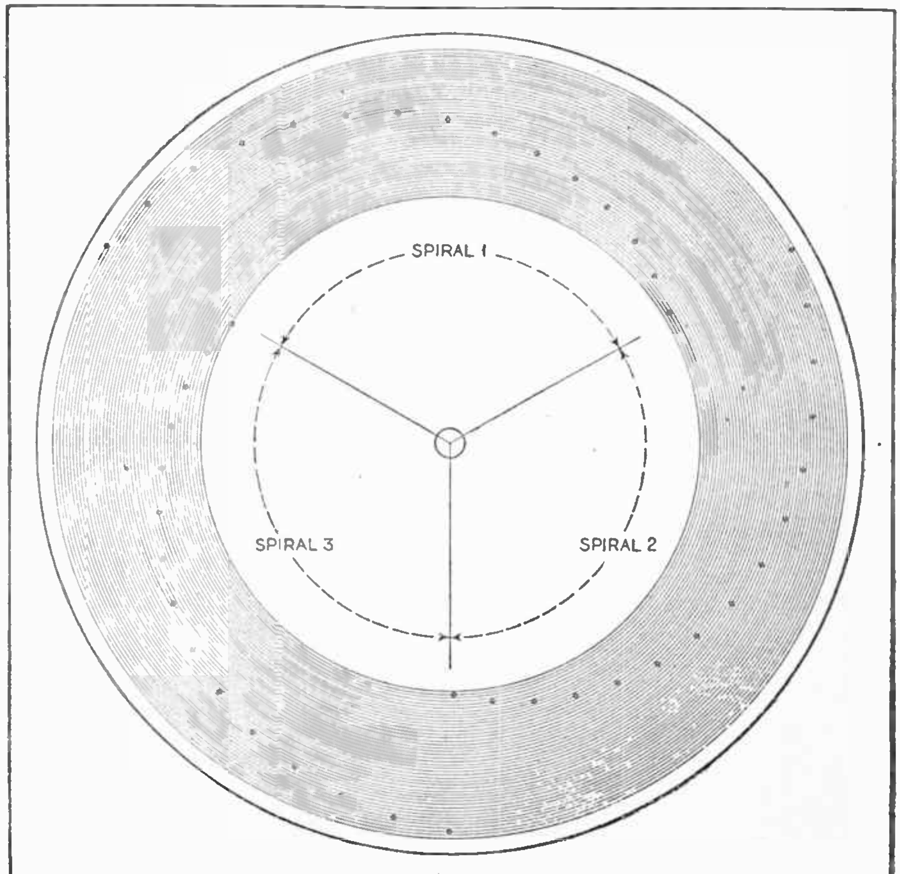
The side of the disc facing the reflecting mirror was fitted with a revolving turret carrying four different lenses. The operator selected the best lens for the particular subject being televised.

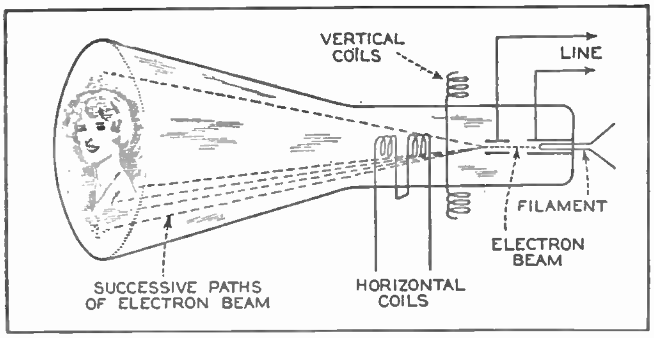
The photo-electric cells were about the same size as ordinary receiving tubes, but they were given a formidable appearance by the highly polished reflectors in which they were mounted. The active sides of the cells did not face the subject, as most people seem to think, but were turned inward and were placed at the exact foci of the reflectors. Thus the scanning rays from the arc and the disc fell upon the subject, were reflected in varying degrees, there was no radio transmission problem, and the images were free of the phantom snowstorms and other ghostly effects produced by stray bits of radio interference. A frequency band about 50 kilocycles wide was covered by the transmission.

The Projector

The projector was a piece of machinery worth seeing. The disc was *three and a half feet in diameter,* and was driven by a five-horsepower synchronous motor. It was fully enclosed for the protection of everyone concerned. Instead of having mere holes, it was fitted with 45 lenses, each *two inches* in diameter. Directly behind the disc was a Taylor projector lamp. The exact construction of this lamp was something of a secret, but it was known to

Figure 90—The scanning disk.





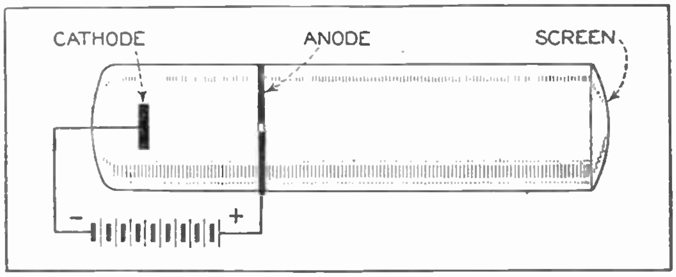


Figure 91, left, shows the Campbell-Swinton cathode-ray receiver. Figure 92, right, shows the earliest type of cathode-ray tube.

contain a mixture of helium and carbon dioxied and drew an energizing current of one ampere at 100 volts from the audio amplifier.

The whole projector unit stood about six feet high and was raised on a wooden image on the back of a translucent glass platform so that it projected an even screen ten feet square. The distance between projector and screen was about eighteen feet. The projector was not visible to the audience, although the flickering light of the lamp could be discerned faintly through the screen.

Besides using a disk, other workers in television have used mechanical systems which would make a concentrated beam of light pass over the picture in horizontal lines. Such devices were the drum scanner, and several arrangements involving rotating mirrors and lenses.

With the limitations of Nipkow's disk and other mechanical scanning methods ever more apparent, it was not strange that someone should have thought of using, in preference to mechanically directed light rays, the inertialess electron beam of a Braun cathode-ray oscillograph tube. Here again the idea roots in the past. It was familiar to the Germans Lux and Dieckmann in 1906, and came to the attention of the English-speaking world in 1908 through a letter to *Nature*. In June of that year Mr. Campbell-Swinton wrote: " . . . may I point out that . . . this part of the problem of distant electric vision can probably be solved by the employment of two beams of cathode rays (one at the transmitting and one at the receiving station) synchronously deflected by the varying fields of two electromagnets placed at right angles to one another and energised by two alternating currents of widely different frequencies so that the moving extremities of the two beams are caused to sweep synchronously over the whole of the required surfaces within the one-tenth of a second necessary to take advantage of visual persistence. Indeed, so far as the receiving apparatus is concerned, the moving cathode beam has only to be impinged on a sufficiently sensitive fluorescent screen, and given suitable variations in its intensity, to obtain the desired result." (See Figure 91). Cathode-ray receivers, now widely hailed as the last word in television, are thus in principle over twenty years old.

LESSON TWENTY-NINE

Cathode Ray Tubes

CATHODE-ray tubes are essentially devices indicating by means of the movement of a spot of light on a screen, the value of a voltage or current applied to the proper terminals. Unlike the usual meter, the only moving part is a beam of electrons, which has such little inertia that there is practically no time lag between application of a voltage and the movement of the spot of light. The power consumed in moving the beam is practically negligible.

The cathode-ray tube may also be used as an ammeter by causing the unknown current to flow through coils, and applying the resulting magnetic field to the cathode-ray tube; the power required to move the spot of light will then be of about the same value as that required by the ordinary ammeter, but unlike the ordinary instrument, a change in the flow of current will be indicated instanteously by the movement of the spot.

These characteristic features have made cathode-ray tubes exceedingly useful for many purposes, and now that relatively inexpensive tubes which give very good performance are commercially available, the use of this instrument by all persons interested in electrical measurements is increasing rapidly.

Early Types

The electrode structure of the first cathode-ray tubes was similar to that illustrated in Figure 92. In these tubes, the electrons were attracted from the cathode to the anode, which was pierced by a small hole. Some of the electrons, now moving with high velocity, would pass through this hole and impinge upon the glass wall (screen) of the tube, where a fluorescent light was produced. It was found that the electrons moved in straight lines unless deflected by a magnetic or electric field.

Until recently, in almost all cathode-ray tubes the electron beam was focused to a spot on the screen by introducing a small amount of an inert gas into the tube. Heavy positive ions would be formed and collect along the beam, neutralizing the space charge of the electrons and condensing the beam into a thin line. This method had many objections. To focus the spot, the gas pressure had to be regulated by varying the cathode temperature; and as the tube became older some of the gas would become absorbed so that the cathode temperature had to be raised to dangerous limits, shortening its life. Positive ion bombardment of the cathode also cut short its life.

When deflecting plates were inserted in the tube, to which a voltage could be connected so that the electron beam would be sent in proportion to the voltage, the ionized gas would cause leakage currents to flow between the plates so that the instrument could not be used as a very high resistance voltmeter. Also, the gas caused non-linearity, that is, the deflection was not proportional to the applied voltage. If high frequencies were applied, the heavy positive ions along the beam could not move rapidly enough to keep the beam focused, and the spot would be blurred. And in addition, gas would cause the screen material to become "burnt" or darkened if a high intensity spot were kept too long in one place.

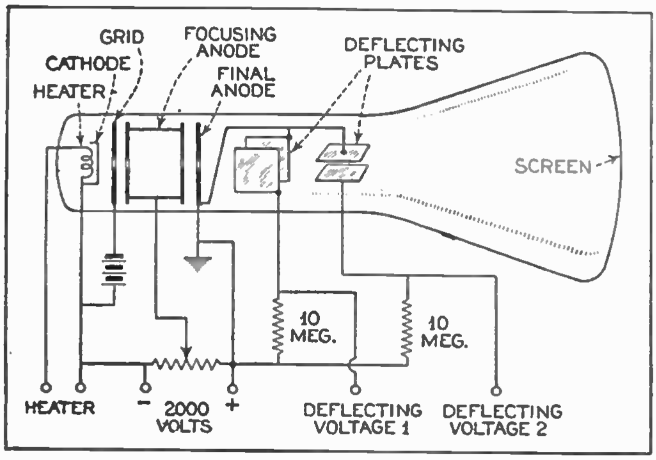
The Rogowski Tube

Rogowski of Germany was the next to improve the tube. He added a second anode; a truncated cone the apex of which pointed toward the cathode. For the first time the beam could be focused electrostatically in a high vacuum. The voltages on the two anodes had to be in a definite ratio, which suggested the probability of a general theory of optics for electrons, paralleling light optics.

After much research work had been carried on, charts were made from which one may determine the voltages and spacing for lenses of any desired focal length.

Static Focusing

All good camera objectives as well as microscope and projection lenses consist of a series of lenses of different shapes and different kinds of glass, the combination resulting effectively in a simple lens of one focal strength with most of the errors of the corresponding single lens corrected. The same is true in the design of electron lenses. A four-lens combination was the result of much work along this line and proved, from the viewpoint of simplicity as regards mathematical calculation and focusing potentials to be



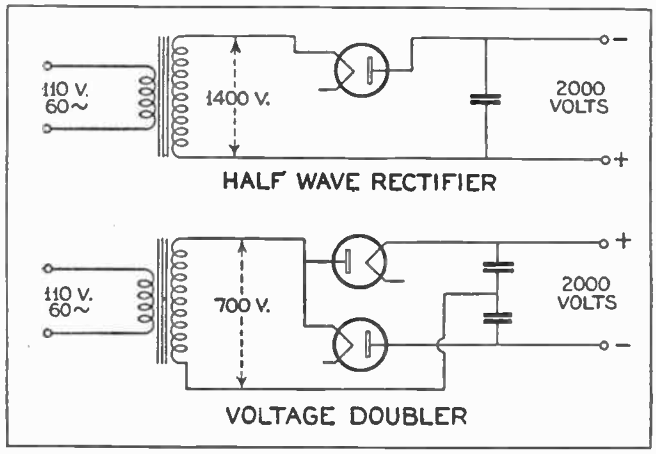


Figure 93, at left, the inside parts of a cathode-ray tube. Figure 94, right, power-pack circuits.

the most effective. This arrangement, incorporated in a tube, is shown in Figure 93.

The electrons fall upon a fluorescent screen and cause a greenish or bluish light. This screen is a coating of "willemite" or some other luminescent material which is coated over the inside of the glass.

Cathode-ray tubes of this type have been available for some time and are used for observing wave patterns of alternating voltages or currents. They are made in different sizes, with screen diameters of 3 inches, 5 inches, and 9 inches. Special television tubes are made at the present time, some having a screen diameter of 12 inches.

LESSON THIRTY

The Sweep Circuit And Power Supply

THE cathode-ray tube requires a special power pack to deliver the necessary voltages to its elements. Certain power pack assemblies are particularly recommended, such as the half wave rectifier and the voltage doubler types, illustrated in Figure 94. The former is simple and effective, and the latter is better for obtaining high voltages without using special transformers and condensers. Voltage doublers have the drawback that two rectifier tubes must be used with a separate filament winding for each tube. The current drawn from the power supply is so small that little filtering is required.

Operating Cathode-Ray Tubes

In operating these cathode-ray tubes, the maximum voltage recommended may be as high as 2,000 volts or more, to be applied between cathode and anode. A lower voltage, as specified by the manufacturers, should be applied between the cathode and the focusing electrode, and this should be variable in order to obtain exact focusing. Since some purposes require great brilliance but not much voltage sensitivity, and other purposes demand much sensitivity but not much brilliance, it should be possible to change the anode voltage and focusing voltage simultaneously over a sufficient range to meet both purposes. Also, in a power supply for the tube, there should be provision for supplying the heater current.

Since the current drawn by the anode and focusing electrode is a fraction of a milliampere, the components of the power supply need not be built for much power, and a small filter will be sufficient.

In studying wave forms of periodic voltages or currents, the wave form studied is connected so as to move the spot of light vertically, while some additional means should be provided for moving it across the screen horizontally at a constant rate of speed. If this is done, the wave form of the voltage or current as a function of time will be obtained; but if the horizontal movement is not at a constant speed, the wave form will be distorted; for example, the peaks of a sine wave might be too close together on one end of the screen and too far apart on the other. Also, in order to have the wave pattern stand still on the screen, it is necessary to have the horizontal movement snap back to the start always at the same part of a cycle of the wave form.

The "Sweep" Circuit

Such a "linear time axis" can be provided by means of a "sweep" circuit in which the voltage across a condenser is applied to the horizontal deflecting plates of the cathode-ray tube. A controllable constant current is sent through the condenser, charging it so that the voltage is proportional to the time; the plate current of screen grid or pentode tubes is quite constant over a wide voltage range and may be used for this purpose. A thyratron, which is nothing but a hot-cathode, mercury-vapor rectifier with a control grid, is connected across the condenser, and when the voltage reaches a certain value, the thyratron discharges the condenser almost instantly, allowing the cycle to repeat itself. The voltage at which the thyratron discharges is controlled by the grid bias of the thyratron. Such a circuit is shown in Figure 95.

This circuit is really a sort of oscillator, in which the voltage across the condenser has a "saw-tooth" wave form as shown in Figure 96. The amplitude of the voltage can be controlled by the thyratron grid bias, since a negative bias will not permit the condenser to discharge until a high voltage is reached. Increasing the amplitude in this way will also decrease the frequency, since the condenser will take more time to accumulate enough voltage to discharge through the thyratron.

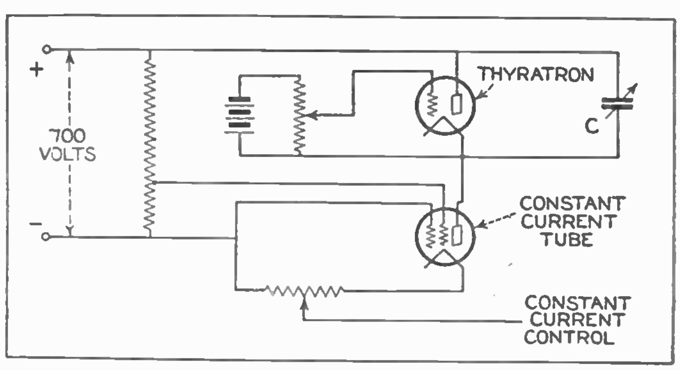
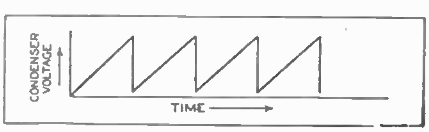


Figure 95, at right, shows a highly effective sweep circuit. Figure 96 at left, the "saw-tooth" wave form of the sweep.



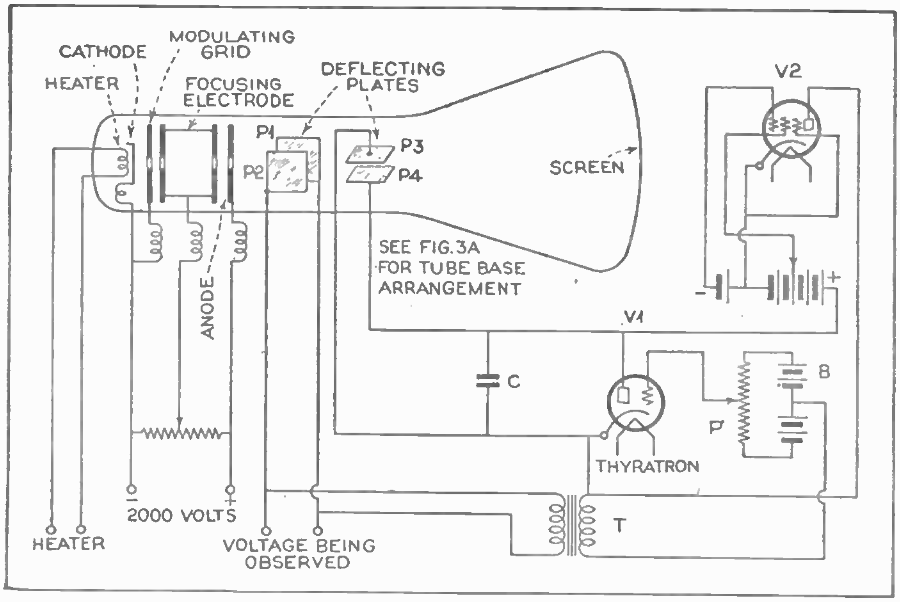


Figure 97—An elementary cathode-ray circuit.

The frequency can be controlled independently, though, by changing the constant current or the capacity of the condenser. A smaller condenser will charge faster and increase the frequency; a larger current will charge the condenser faster and increase the frequency. For best results, all three controls should be used in the "linear time axis" or "sweep circuit." A transformer with the secondary in series with the thyratron grid should be used to permit synchronizing the saw-tooth frequency with the wave form being observed, by connecting the observed wave form to the transformer primary. Such a circuit is shown in elementary form, in Figure 97.

How It Works

The electron gun structure in the cathode-ray tube shoots a narrow beam of electrons from the anode to the fluorescent screen. On passing through plates P1-P2 it is deflected vertically according to the voltage being observed. On passing through plates P3-P4 it is deflected horizontally in proportion to the time. The wave-form curve produced is seen on the screen.

The tube V2 is a pentode, such as a -57 or -58, for which the plate current is almost constant regardless of plate voltage. This constant current flows through condenser C, charging it so that its voltage is proportional to time. This voltage is then impressed on plates P3-P4, where the time deflection is produced.

When condenser C reaches a certain voltage, the Thyratron V1 ionizes and discharges the condenser instantly. The condenser can then charge again and repeat the cycle of sweeping out the time axis. The voltage at which the Thyratron discharges is controlled by its grid bias. The transformer T is also in series with the grid bias, and delivers voltage corresponding to the voltage being observed. This causes the Thyratron to discharge the condenser when the voltage observed is at its peak value, so that the discharge always occurs at the same part of the cycle of the observed voltage, and the image seen is apparently a solid, stationary curve.

Figure 98 illustrates a complete circuit for the power supply and a sweep circuit.

Great caution is necessary with the high-voltage circuits. It should be made impossible to come in contact with the high voltage, which is dangerous to life. This is especially important in regard to connections coming directly from the high-voltage transformer. The positive high voltage terminal should be grounded as shown, and if this is done the connections to the deflecting plates will be near ground potential and can be touched without receiving the high voltage. The *heater and cathode* connections will be at high voltage with respect to ground and *should not be touched* with the high voltage on.

LESSON THIRTY-ONE

Application Of Cathode-Ray Tubes To Television

CATHODE-ray tube reception of television pictures will become important in the future, because they can be made suitable for pictures of any number of lines and degree of definition, up up to 400 lines at least. It is difficult to make mechanical scanners to handle such high scanning speeds, but there are no moving parts in the cathode-ray tube and no limit as to its scanning speed. The degree of detail in pictures that can be obtained, depends upon the size of the spot of light produced on the screen as compared to the size of the screen. Apart from this, picture detail in cathode-ray television is limited more by the apparatus associated with the tube than by the tube itself.

Confining ourselves to the receiver, the alternating voltages of the received signal are applied to the modulating grid of the cathode-ray tube, while the spot is made to travel across the screen by voltages applied to the deflecting plates.

The power supply and sweep circuit can be similar to that shown in Figures 94 and 97. Instead of one sweep circuit, however, two must be used, one for deflecting the spot of light horizontally across the screen about 2400 times a second, and the other for deflecting the spot vertically about 20 times a second. The combination of the two linear deflections causes the spot to trace out scanning patterns of about 120 lines. The pattern will be repeated 20 times a second, which will not give much flicker. Figure 98 shows a diagram of a power supply with a double sweep circuit.

The general light intensity level of the picture can be regulated by varying the grid bias voltage with potentiometer P5 of Figure 98. This should have an insulating shaft, and it and other apparatus connected to the grid should not be touched, because such points are at high d.c. potential with respect to ground. The degree of contrast in the picture can then be regulated by varying the volume control of the amplifier. If the largest possible output is small, the light intensity will have to be reduced by potentiometer P5 to obtain good contrast. In any case, the average light intensity should not be made over half the maximum possible value, so that it can increase when a positive voltage is applied to the grid from the television signal.

In television by radio, certain problems are met that do not enter into transmission by wire. At the transmitter there are many difficulties that will not be considered here. In reception, use of cathode-ray tubes has eliminated many difficulties, but there are still four main difficulties found in television reception but not in sound reception. The first is that of obtaining high picture frequency amplification without loss of details. (The term "picture frequency" is used here in the same way that "audio frequency" is used in speaking of sound reception.) By using low gain per stage and many stages, it is possible to make picture frequency amplifiers of high gain that will handle the details of pictures at any number of lines likely to be used.

A second difficulty is that of making a detector circuit which will detect the high frequency modulation components as well as the low frequency ones. The radio-frequency carrier is modulated by frequencies of over 200 kilocycles in the case of a 120 line picture. In order not to discriminate against the higher modulation frequencies, all coupling resistors in the detector, which couple the picture frequency to any circuit in any way, must be small compared to the impedances of the capacitances by-passing them. Simple grid leak and condenser detection is impossible because of the large by-pass condenser across the grid leak, which acts as

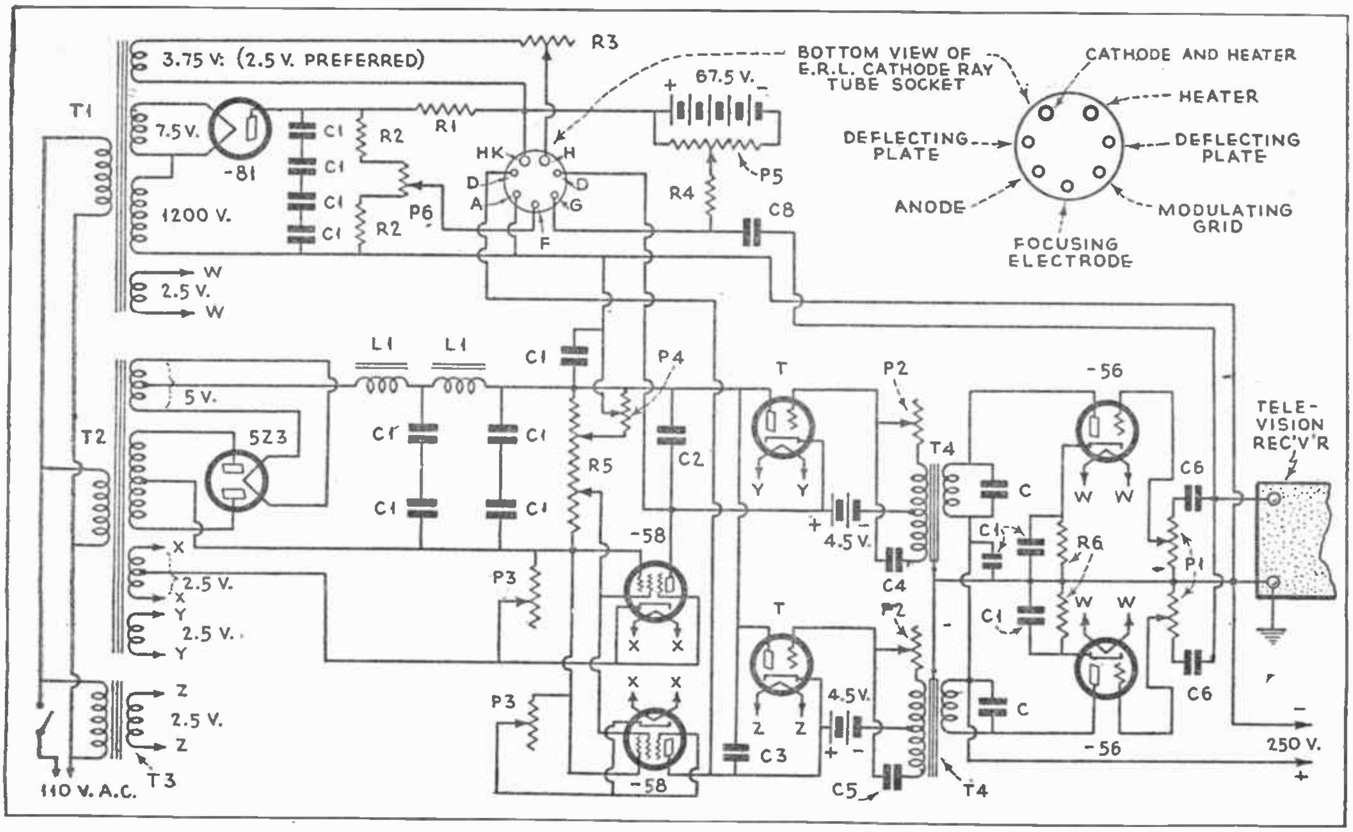


Figure 98—"Sweep" circuit and power supply.

a sort of coupling resistor. Plate detectors, duo-diode detectors, and simple rectifier detectors are satisfactory if the coupling resistors for the picture frequency and the capacitance across them are kept small, for instance 30,000 ohms and 20 mmfd. For example, Figure 99 shows a suitable plate detector circuit and its coupling to the following amplifier.

In detectors for sound reception, simple filters are often used to prevent radio-frequency detector output from being fed into the audio amplifier. These must be made very small or omitted entirely for television reception, because they by-pass too much of the higher picture frequencies.

A third difficulty is that of making a high-gain radio-frequency amplifier that does not cut off the higher side-band frequencies. To preserve the details of a 120 line picture the radio-frequency amplifier must pass a band width of about 450 kilocycles. The simplest way to obtain such broad tuning is to use ordinary tuned, coupled circuits with resistance in series or parallel to broaden the tuning. Unfortunately, this reduces the amplification per stage greatly. The solution to this problem probably lies in the use of some sort of band pass filter circuits.

Scanning Synchronization

The fourth problem, and one which is particularly important in cathode-ray tube reception, is that of scanning synchronization at the receiver and transmitter. Where the receiver and transmitter are operated on the same a.c. power system, it is possible to use two sweep circuits, one for vertical scanning and one for horizontal scanning, and synchronize both circuits by "locking" the frequencies in step with a multiple or sub-multiple of the power line frequency. For example, if the number of pictures per second is 20, the number of lines 60, and the power line frequency 60 cycles, one sweep can be locked at one third of the 60 cycle frequency, and the other at twenty times this frequency. If the a.c. locking voltage is fed into the grid of the gas-filled discharge-tube or "thyratron" in the sweep circuit simply through a transformer, locking will be successful but the picture obtained may appear in the wrong position on the screen. This may be corrected by shifting the phase of the a.c. locking voltage, which is easily done by shunting a condenser of about .05 mfd. with a 250,000 ohm variable resistance, and connecting the combination in series with the transformer primary to which locking voltage is applied, if this is an ordinary audio transformer. This synchronizing system is simple, but is suitable only where sending and receiving equipment are served by the same power system and even then requires much manipulation and frequent readjustment if reception is mainly through reflection from the Heavyside layer.

A better method of synchronizing is to obtain synchronizing frequencies from the received signal itself. There are several methods of doing this, but some of them require receiving apparatus made only for special types of transmission and will not be discussed here. The system shown in Figures 98 and 100, is not as good as some of these special methods, but works quite well on any television signal. Practically all television pictures are sent with "frame lines," black borders on the edges of the picture. These lines give strong

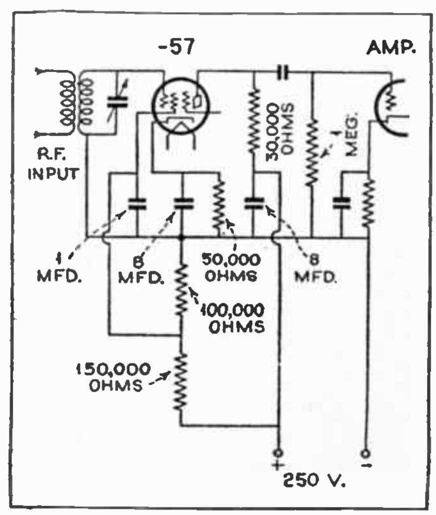
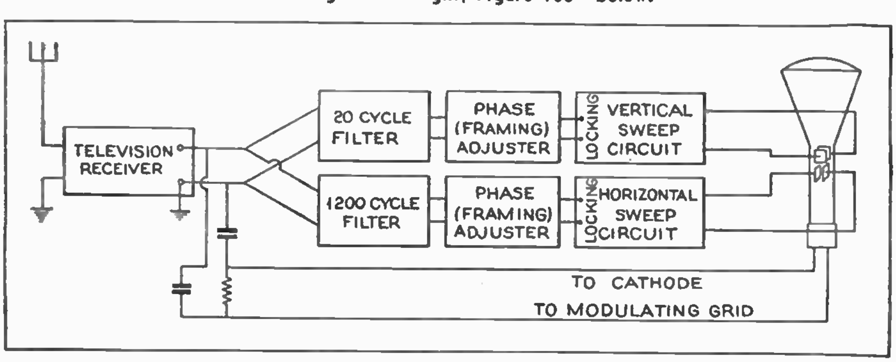


Figure 99—right; Figure 100—below.



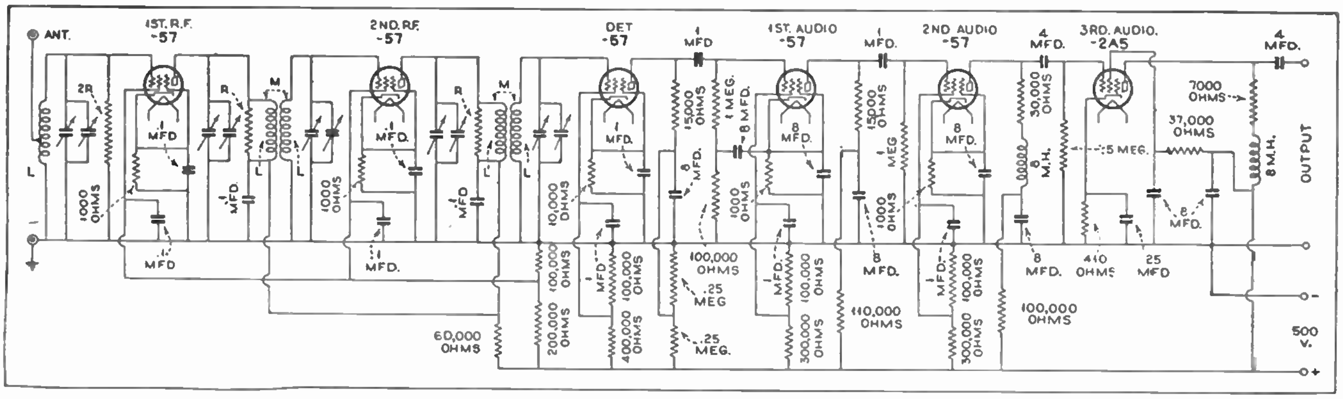


Figure 101—A television receiver circuit.

frequency components in the resulting signal, of 20 and 1200 cycles in the case of a 20 frame, 60 line picture. By means of filter circuits, these frequencies can be picked out of the combined picture frequencies and used for locking the two sweep circuits at 20 and 1200 cycles. The phase of the locking voltage can be adjusted to give correct framing.

Such a system, is shown in block diagram form in Figure 100, and the complete circuit in Figure 98. This circuit is intended to show the principles discussed and is not to be interpreted as a "how to build" diagram.

LESSON THIRTY-TWO

Principles Of Television Receiver Design

SINCE many are not familiar with the radio receiver proper as used in television either for cathode-ray tube reception or mechanical scanning methods, it was thought desirable to add a lesson on that subject.

An ordinary broadcast receiver has three main functions. One is to convert modulated radio-frequency current into direct current, varying in accordance with the sound picked up by the microphone at the transmitting station; this is the process of detection. The second is to provide enough amplification so that the small amount of energy picked up by the aerial can operate a loudspeaker. The third is to provide radio-frequency selectivity such that the desired signal can be separated from others. The loudspeaker then serves a fourth function of converting electrical energy into a reproduction of the original sound.

This is not much different from the process in television reception. There the loudspeaker is replaced by apparatus which converts electrical variations into light variations, together with scanning apparatus which makes a point of light trace out a whole picture. For cathode-ray tube reception, this apparatus was described in previous lessons.

Functions of the Receiver

The television receiver proper has the same functions as a broadcast receiver: namely, detection, amplification, and frequency selection. The difference between the two classes of receivers lies in the fact that a broadcast receiver must cover a range of modulation frequencies from 20 to 5000 cycles, and separate stations 10 kc. apart in frequency; but a television receiver must cover a range of modulation frequencies from a fraction of a cycle to 100,000 cycles or so, and separate stations over 200 kc. apart in frequency, for good 60-line pictures.

This means that in television receivers the radio-frequency tuning must be much broader, the "audio" frequency amplifier must have a much flatter frequency response curve, and the detector must have much better output for high modulation frequencies than in the case of a broadcast receiver.

A Typical Circuit

The circuit diagram of Figure 101 shows a receiver that fulfills these conditions. This circuit does not differ at first glance from that of a tuned r.f. broadcast receiver using a resistance-coupled audio amplifier. The difference lies in the choice of values for the circuit elements. In the audio amplifier, for example, the coupling resistances are much smaller than usual, to reduce the relative effect of the stray capacities by-passing the coupling resistors. This makes the frequency response flat to very high modulation frequencies, at the cost of reduced gain per tube. The audio amplifier shown uses two type -57 tubes for voltage amplification and a 2A5 power tube.

The 2A5 power tube is used, not because of the power delivered, but because the small load resistance required reduces the by-passing effect of the stray capacity of the lead to the cathode-ray tube grid, which may therefore be moderately long. This lead should not run through a cable, but as much in the open as possible, and should not be over five feet long. If the cathode-ray tube is to be used far from the receiver, it would be better to use a 2A3 instead of a 2A5, and use a load resistance in its plate circuit of 2500 ohms instead of 7000 ohms.

With three audio stages and a plate detector, an increase in radio-frequency input will cause the ungrounded output terminal to become more positive. If this terminal is used to apply voltage to the modulating grid of a cathode-ray tube, a positive picture will result for most television signals. The transmitting station generally increases its output on the bright parts of the picture, but if it does the opposite, the phase of the cathode-ray tube grid voltage at the receiver must be reversed or a negative picture will result. This reversal is best accomplished by adding an extra resistance-coupled audio stage with little or no amplification; for instance, a -56 or a -57 tube with a 1000-ohm coupling resistor.

Any type of detector can be used, but resistors across which audio-frequency voltage is to be developed must not be by-passed seriously by any capacitance, or if they are, the resistance must be reduced accordingly. The product of resistance in ohms and capacitance in mfds. should be kept under one-half. For grid leak and condenser detection, the grid leak must be so small that this method is not very practical. Plate detection may be used, with plate circuit resistance values similar to those used in the audio amplifier. Diode or duo-diode detection is also good, if the condenser by-passing the diode load resistor is under 20 mmfd. and the resistor about 25,000 ohms. Incidentally, if grid leak or duo-diode-triode, etc., detection is used instead of plate detection, the phase of the "audio" voltage is reversed. Plate detection was chosen for the diagram given, because it is simple and reliable. No radio-frequency filters are used in the detector output, because they bypass the higher modulation frequencies too badly.

The R. F. Amplifier

The most striking difference between a television receiver and a sound receiver lies in the radio-frequency amplifier. Modulation frequencies up to 100,000 cycles must be passed, requiring a radio-frequency bandwidth of 200 kc. for good 60-line pictures.

For the modern 441 line pictures, a band width of 2 megacycles is required. In the diagram of Figure 101 such a wide band is obtained by means of tuned, coupled

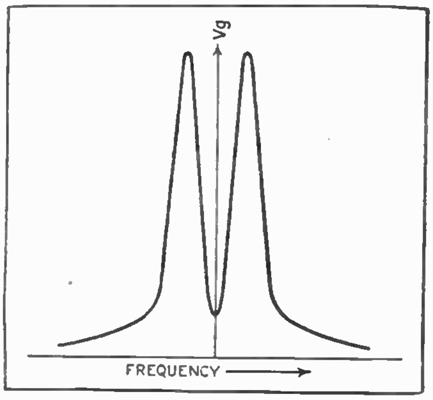


Figure 102

circuits which act much like band-pass filters.

The theory of the effects obtained from coupled circuits is as follows: When two tuned circuits without resistance are coupled together as the coupling agent between two tubes, the voltage delivered is not a maximum at resonance, but instead the resonance curve shows two large peaks, occurring at frequencies on each side of the resonant frequency, separated from it by a frequency proportional to the degree of coupling and to the resonant frequency.

Figure 102 illustrates such a case. That is to say, the ratio of frequency separation between the two peaks to the average frequency is proportional to the coupling coefficient. The separation will in a way determine the band width obtained; the ratio above is small for a broadcast receiver and the coupling is loose, but it is larger for television work and rather tight coupling is used.

It is clear, of course, that such a sharp, double-peaked resonance curve would be totally unsuited for band-pass action, which in the ideal case would give constant output over a 400 kc. range and zero at all other frequencies. (When a 400 kc. band width is used in a receiver, it should give good pictures of 60 lines.) However, when resistance is added to the circuit—for example, by the shunt resistors R in the diagram—the resonance curve is changed. The peaks are greatly reduced in size, but the response at the resonant frequency is not much reduced, so that the resonance curve can be made such as to give an almost constant output over the desired frequency range. The value of shunt resistance that will accomplish this becomes smaller as the desired frequency range and the coupling are made larger. It also becomes smaller as the tuning capacity is made larger. Since the amplification will depend largely on the size of this resistance, much more amplification can be obtained if the tuning capacity is kept small and the shunt resistor made correspondingly large. It can be seen that the gain per stage must be reduced as the modulation-frequency range is made greater, which was also the case for the audio amplifier. Figure 103 shows the effect of varying the shunt resistance on the shape of the resonance curve; Figure 104 shows the effect of changing the coupling.

Good Receiver Design

The tuned radio-frequency receiver shown was selected for this lesson because it is simple and yet illustrates the essential points in good television receiver design. It suffers from one notable defect;

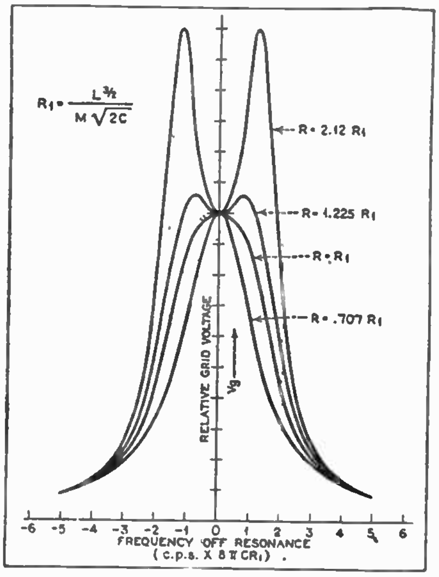


Figure 103

that is, if the tuned coupled circuits are designed for band-pass operation at one carrier frequency, the resonance curve will not be very good when a different carrier frequency is to be tuned in. It would therefore be advisable to use a superheterodyne instead of a t.r.f. receiver, because the band-pass action could then be confined chiefly to the intermediate-frequency amplifier, which could be adjusted carefully for best results and left alone. The superheterodyne also has the advantage that with a coil-switching arrangement it could be made suitable for either the 1500 to 3000 kc. television signals or the experimental transmissions sent on something like 60,000 kc. However, those readers who are sufficiently familiar with receiver construction to make a successful superheterodyne will probably be able to apply the principles involved in the t.r.f. receiver to the superheterodyne.

No new problem is involved, except that the oscillator and first detector should be suitable for use where the carrier frequency and oscillator frequency are widely separated. A pentagrid converter (2A7, for example) would be quite satisfactory. A good choice of intermediate frequency would be 6000 kc. For the signals between 1500 and 3000 kc., the oscillator frequency could be 7500 to 9000 kc. and for the signals around 60,000 kc. the oscillator frequency can be about 54,000 kc.

The Circuit Constants

Suitable values of the circuit constants for a carrier frequency of 2800 kc., with the t.r.f. receiver shown in Figure 101, are as follows: All tuning condensers are to be of 100 mmfd. capacity, ganged, with small trimmers. The inductances L should tune to 2800 kc. with about 10 mmfd. of the condenser capacity in use. Assuming 10 mmfd. of stray capacity or a total of 20 mmfd., L should be .16 millihenry. The coupling coefficient should be .143, and M .023 millihenry. R should be 10,000 ohms. Amplification per stage will be about 24 times. The band width should be 400 kc. The circuit will tune to about 1500 kc. minimum, but the resonance curve will be rather badly peaked on the lower carrier frequencies.

To cover the same range of carrier frequencies, but with best operation on 2100 kc., make L .16 millihenry as before, to tune to 2100 kc. with about 26 mfd. of

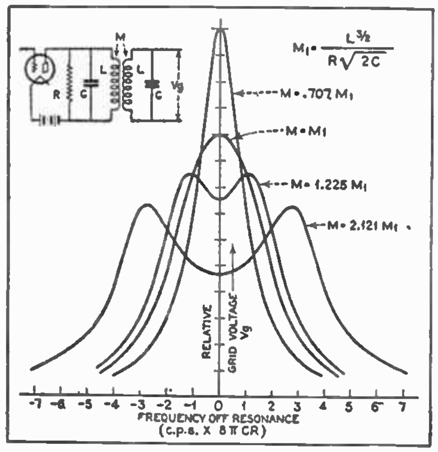


Figure 104

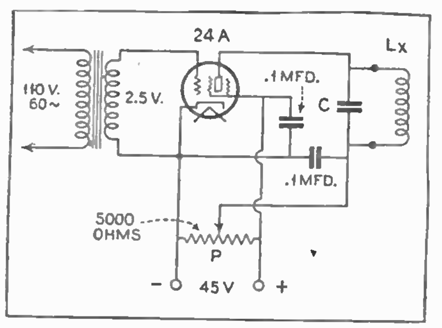
the tuning condenser in use (assuming 10 mmfd. stray capacity). Make the coupling coefficient .191, and M .031 millihenry. R should be 6000 ohms. The gain per stage will be about 14 times.

For the intermediate frequency amplifier of a superheterodyne operating at 6000 kc., use 20 mmfd. adjustable condensers for the permanent tuning. Make L .035 millihenry, the coupling coefficient .094, and M .0032 millihenry. R should be 10,000 ohms and the gain per stage about 17 times.

Dynatron Test Oscillator

A good way of measuring the values of L and M, so that they may be adjusted by the cut-and-try method, is to use a dynatron oscillator, a calibrated broadcast receiver, and an accurately known capacitance. The dynatron oscillator circuit is given in Figure 105. The potentiometer P is adjusted for maximum oscillation. The capacitance C can be a 150 or 250 mfd. variable or fixed condenser for which the capacity is fairly accurately known. The frequency determined by Lx and C can be found by turning the dial of the broadcast receiver, with the dynatron in its vicinity and the aerial disconnected. A hum will be heard at one or more points on the dial, unless the coil Lx is too small to give an oscillation frequency below 1500 kc. The frequencies at which the hum is heard will be the fundamental frequency or that frequency multiplied by an integral number. Note all frequencies at which the hum is heard; the average frequency separation between them will be the fundamental frequency, or if only one point occurs, it should be the fundamental, except where between 1100 and 1000 kc., in which case it may be a second harmonic. For example, 375 kc. oscillations would be heard at 750, 1125 and 1500 kc., and 800 kc. oscillations would be heard

Figure 105



only at 800 kc. on the usual broadcast receiver. The value of Lx in millihenries is given by

$$\left(\frac{25{,}300{,}000}{f^2 \times C}\right)$$

where f is the frequency in kc. and C the capacity in micromicrofarads.

To measure L, M and the coupling coefficient k most easily, connect the two coils of the r.f. or i.f. transformer in series, first in opposition and then so as to aid each other, using the combination as Lx in the dynatron oscillator. Lx will then be first 2(L—M) and then 2(L+M). Measure the frequencies obtained; call them f_1 and f_2. Then the values of L, M and the coupling coefficient k will be given by the following formulas:

$$L = \frac{25{,}300{,}000}{4C}\left(\frac{1}{f_2^2} + \frac{1}{f_1^2}\right)$$

$$M = \frac{25{,}300{,}000}{4C}\left(\frac{1}{f_2^2} - \frac{1}{f_1^2}\right)$$

$$k = 2\left(\frac{f_1 - f_2}{f_1 + f_2}\right) \text{ approximately.}$$

The formula for the coefficient of coupling does not require knowledge of the condenser capacity. The inductance values above are in millihenries when C is in mmfd. and frequency kilocycles.

Antenna Coupling System

One other matter worth mentioning is the antenna coupling system. The method shown in Figure 101 allows ganging of all tuning condensers without having too much detuning effect from the aerial, and the shunt resistance (2R) can be made accurately twice the value of that used on the double tuned circuits, which will give proper results. Since damping is introduced artificially by the shunt resistance, the same damping effect and more output could be obtained by using more antenna coupling and omitting the resistor. This is not recommended, because the damping and tuning will change whenever the aerial used is changed, and ganged tuning will not be possible.

LESSON THIRTY-THREE

Present-Day Television In The U. S.

TRANSMISSION of television signals in the United States is now exclusively on the ultra-short waves, the 3000-2800 kc. band is now being used for other purposes. Also, the number of lines used in scanning now varies from 300 to 441 while some are employing interlaced scanning.

THE RCA SYSTEM

A series of RCA television demonstrations have already been given to various branches of the industry. They revealed several important features. A press showing was the first under practical working conditions. It included a complete program built for entertainment value as well as a demonstration of transmission. It also featured the initial exhibition of a new 12-inch cathode-ray tube yielding a 7½ by 10-inch screen—claimed by RCA to be the largest yet employed which is capable of commercializing.

The program embraced a balanced assortment of live and filmed subjects. One highlight was a tour of the television studios and the Empire State Building transmitter by the transmission of a film especially made for the occasion. Lenox R. Rohr, president of NBC, and Mr. Sarnoff were also seen and heard over the sight-and-sound transmitter.

The images were clear and commercially acceptable. There was a bit of interference, but at no time did it materially mar the program. In all, the forty-minute program was satisfactory enough for commercial home reception!

A long line of television receivers were installed on the sixty-second floor of the RCA Building for the press demonstration. The programs, originating in the television studios in the NBC section of the structure, were conveyed by coaxial cable to the transmitter atop the Empire State Building—about three-quarters of a mile away—and received through the air.

Definition of 343 lines was used in the test. This, however, has since been stepped up to 441 lines.

The programs are transmitted to the Empire State tower either by cable or by ultra-short-waves on a frequency of 177 megacycles. The "band-width" employed in this transmission is 3 mc.

The signals are then retransmitted by the equipment (shown in Figure 106) in the Empire State tower. The frequency for the picture signal is 49.75 mc. and for the sound 52 mc.

Interlaced scanning is being used, employing a picture frequency of 30 per second and a "frame-frequency" of 60 per second. This means that the scanning is arranged so that the vertical scanning takes place twice per picture and therefore, since the number of lines is *odd,* the second set of scanning lines falls between the first scanning lines. This arrangement reduces flicker.

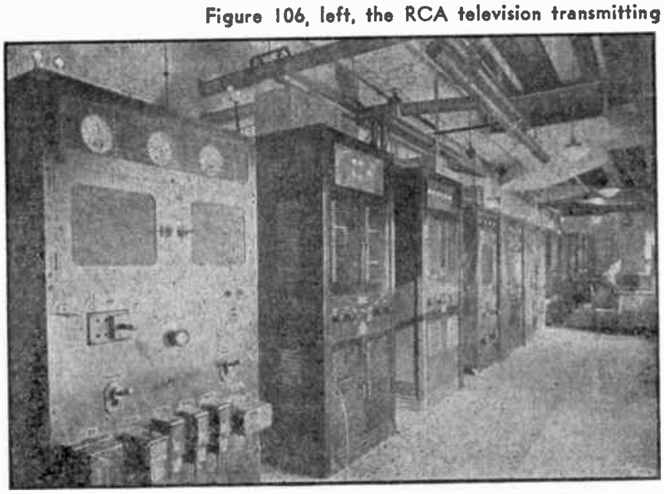
THE FARNSWORTH SYSTEM

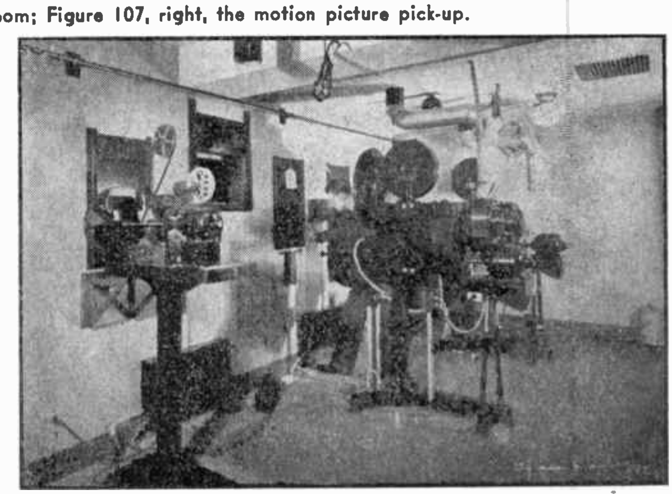
The Farnsworth transmitting and receiving systems depend entirely on the cathode-ray method. Two types of tubes most in use at the Philadelphia Laboratories include a 15-inch diameter tube, yielding a 10 by 12 picture, and a 9-inch tube with a 6 by 7 image. Electro-magnetic focussing is employed exclusively, with the coils outside the tube.

Image size of 12 by 14 is considered ideal for home reception, but the Farnsworth technicians declare that, for home use, a small type high intensity, cathode-ray tube must be used in conjunction with optical projection. This method, has already been completed. The new Farnsworth transmitter also uses over 400-line scanning.

Figure 108 gives the basic schematic outline of the Farnsworth television transmitter and receiver circuits, virtually identical to the apparatus employed at the Philadelphia press demonstrations. The pick-up of the transmitter, designated on the diagram as A has been dubbed the "image dissector." The light intensities of an image focused upon its photo-sensitive

Figure 106, left, the RCA television transmitting room; Figure 107, right, the motion picture pick-up.





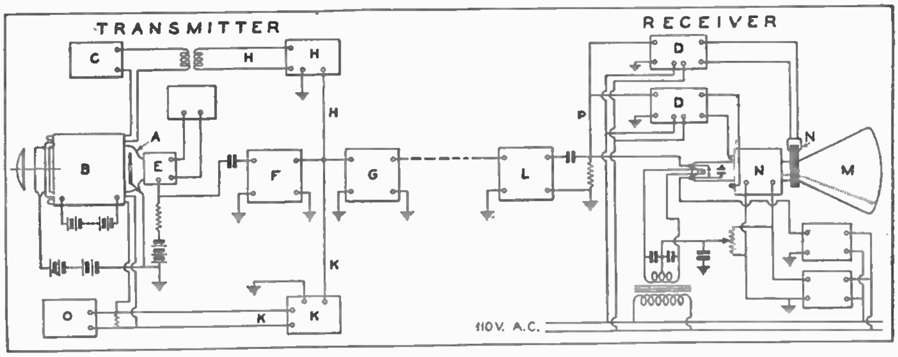


Figure 108—The Farnsworth dissector and recreator.

surface is converted by the dissector into fluctuations of an electric current. The scanning system also embraces its enveloping coil assembly (B) and the scanning oscillators (C) and (D). Their joint duty is to analyze the area of an image into a regular succession of space elements and convert them into corresponding signal currents adequate for routing over but one signal channel.

Current impulses are amplified by an electron multiplier (E) which is an integral part of the valve, and by vacuum tube amplifiers (F and G) to produce signal voltages great enough to modulate a radio carrier. The connections (H and K) between the scanning circuits and the amplifier, provide signal impulses which automatically synchronize reproducers tuned to the transmitter.

The Scanning System

The cathode-ray tube (M) is the heart of the reproducer. It converts the received electric impulses into corresponding light variations and arranges them in orderly space-sequence to reproduce the image at the receiver. This is done with the use of the scanning system comprised of the coils (N-N), the associated oscillators (O-O) and the tube (M) itself. Once more the scanning oscillators are joined to the signal channel as shown by P to make possible automatic control from the transmitter. Amplification compensates for the inefficiencies of the translation and transmission while the series of processes is completed by propagation of the signal.

The focused electron image in the dissector is scanned by displacing it in its own plane by means of transverse magnetic fields which sweep the image across a fixed aperture, thus allowing a small area of the picture element to produce a current in an electrical circuit where it may be amplified and transmitted over wire lines or by radio. A resultant field which is inclined to the axis of the tube is obtained by the addition of a transverse magnetic field to the focussing field. Electrons starting from given points on the cathode travel in spiral paths directed along the resultant magnetic field and come to focus at a point displaced by the transverse field.

Black and White Pictures

The pictures at the receiving end could be black-and-white, a fluorescent green and black or possibly other colors. It seems that there is a public objective toward black-and-white pictures. It is not because black-and-white images are more natural, but rather on account of the fact that the public has learned to accept black-and-white as natural through constant attendance at motion-picture shows. The color of the picture through the Farnsworth methods depends on material utilized to produce the fluorescence of the cathode-ray tube screen. In the Farnsworth tests, pictures with a greenish tone were obtained through the use of a zinc orthosilicate screen. To reproduce images in black-and-white, a combination of substances, including calcium tungstate, is employed.

The Transmitting Equipment

At Farnsworth's test transmitting point (for both wire and radio), the apparatus includes his cathode-ray "camera," or "dissector," an amplifier for the minute impulses and an ultra-short-wave transmitting outfit. Figure 110 shows the transmitting room. And, as noted, the receiver also embodies the cathode-ray tube and its allied equipment.

Experiments have reached the stage where home model receivers have been designed in attractive cabinets. The featured model seen at the Philadelphia demonstration for the RADIO NEWS staff has the screen end of the cathode-ray tube framed neatly at eye level from a sitting posture (Figure 109).

One of the chief things to be ironed out in television is "standardization." This must precede commercialization. Philco already is sanctioned to make Farnsworth-type receivers while Hentz and Kaufman has permission to make visual transmitters. Although the Farnsworth demonstrations were warmly received by the press, company engineers are already at work on improvements. Instead of the 24-frame-per-second image used at the demonstrations, a speed of 48-frames-per-second is now used, although this is actually an interlacing of two 24's.

THE PHILCO SYSTEM

Here are some of the details of the Philco television system. Some of this information will be important to those ama-

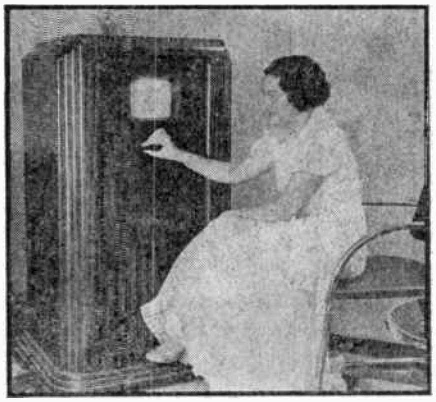


Figure 109—Farnsworth receiver.

teurs or experimenters who are thinking of building experimental types of television receivers and are trying to learn the fundamentals on which future broadcasts will be based. The electrical specifications for this system are as follows: The carrier frequency of the picture transmitter is 51 megacycles. The carrier frequency for the sound transmission is 54.25 mc. This makes a spacing, between the two carrier centers of 3.25 mc. approximately. The total space taken up in the ultra-short-wave spectrum is 6 mc. The number of scanning lines was 345, but this has now been changed to conform to the R.M.A. recommendations of 440—450 lines. The number of pictures-per-second transmitted is 60, 30 of them being interlaced. By "interlacing" is meant that the lines of each consecutive frame show in between the lines of the preceding one. This reduces the rather striped appearance of earlier methods. The polarity of the transmission is negative. The aspect ratio is 4.3. The percentage of television signal devoted to the synchronizing signal is 20 percent. The wave-form of the synchronizing signal is narrow and vertical.

The Television Camera

The focussing device for picking up the television signal actually looks somewhat like a camera on wheels. (See Figure 113). It contains a large tube, operating on photo-electric and cathode-ray principles combined. This tube generates, by an electrical scanning method, voltages corresponding to the light and shade of the television picture which is focussed by the lens onto the signal plate of the tube. A special amplifier in the control room strengthens these varying voltages about 10,000 times, to

Figure 110 — The Farnsworth transmitter panels installed in the new television transmitter house at Wyndmoor, Pa.

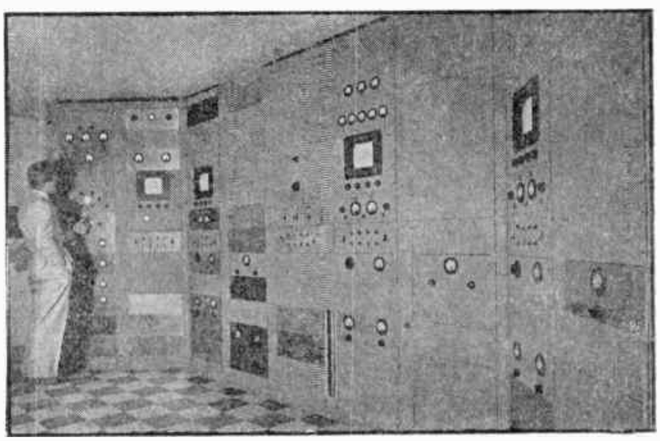


Figure 111 — An actual television picture "snapped" at a recent Philco television demonstration. It really suffers by being a photograph and also in being made into a cut for reproduction on this page, but at least it does give an idea of the smooth and natural pictures that were seen.

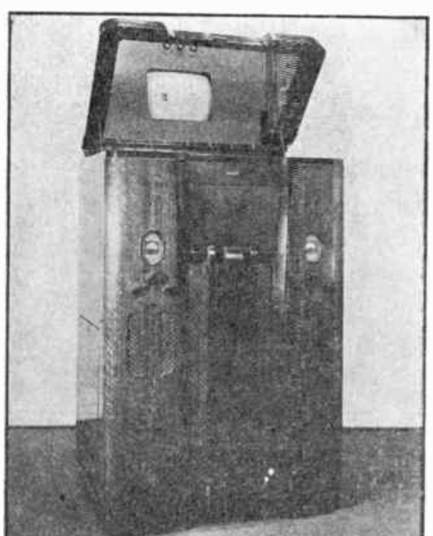
modulate the ultra-high-frequency transmitter. Also mixed with this television signal, as it is transmitted, are the synchronizing and blanking impulses. These impulses when received by the receiving set control the movement of the electron beam in the receiving cathode tube which rebuilds the picture.

In the studio there are, of course, accompanying the picture transmitting apparatus, microphones and audio-frequency amplifiers and another radio transmitter for sending the sounds to the receiving location.

A separate pick-up device consisting of a specially built projector, is used for transmitting the motion picture part of the program. This apparatus energizes the same radio transmitters that are used for televising the actual scenes.

Front and rear views of the Philco receiver are shown in Figure 112 and 114. Figure 111 shows the clarity of the pictures now being received.

Figure 112—The Philco receiver.



This picture was actually photographed, during a recent Philco demonstration, with a small hand camera directly from the screen of the television receiver, after the image had been sent through the air, by ultra-short-wave radio, a distance of 7½ miles. Do you think it good enough for commercial broadcasting?

THE DON LEE SYSTEM

Below are given the salient technical features of the system of cathode-ray television now in use at the Don Lee experimental television station W6XAO, Los Angeles. This is a system perfected by Harry R. Lubcke, Director of the Television Division of the Don Lee System. Figure 115 shows the Don Lee television transmitter and Figure 116 shows the type of image now being received daily.

Public demonstrations where experimenters can see and ask questions about the receiver, which is of the self-synchronized cathode-ray tube type, are being held daily, except Sundays and holidays, in the afternoons and evenings. Mr. Lubcke, who is interested in having experimenters build home-made television receivers for the reception of these television broadcasts, has furnished the following details to encourage the skilled amateur and to give him the essential information that will enable him to build such a receiver.

"The advantages of the television enthusiast today are far greater than were those of the amateur constructor of broadcasting's earlier days. Sufficient technical information to allow a moderately well-skilled person to construct a television receiver to receive the programs of W6XAO are given in the following paragraphs," said Mr. Lubcke as he handed them to our technical staff on a recent visit to the Editorial Offices.

"The Don Lee television transmitter W6XAO operates on the ultra high-frequency of 45,000 kilocycles (6 2/3 meters) daily except Sunday and holidays, from 3:00 to 5:00 p.m. and from 6:30 to 8:30 p.m. Voice announcements concerning the broadcast are made at the beginning and end of each transmission.

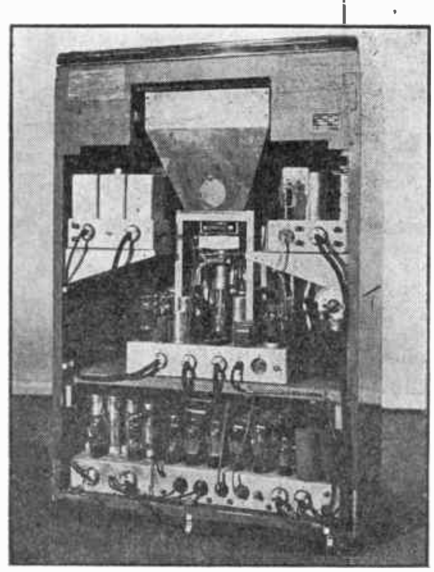
"For receiving the voice announcements of W6XAO and for preliminary experiments, any type of ultra short-wave receiver which will tune to 6 2/3 meters may be used. Receivers designed for 5-meter amateur work are suitable when provided with larger coils. Install coils with 50 percent more turns and remove one turn at a time while tuning for W6XAO. A simple line-image of constant intensity is broadcast for a short period of each schedule, and an appreciable change in its strength after a change in the circuit or operation of a receiver is a direct measure of the effect of the change.

"The image broadcast is a 300-line sequentially-scanned picture, with a frame frequency of 24 per second. For receiving these images the receiver must tune very broadly and should be one of the superheterodyne type, with band-pass intermediate-frequency transformers arranged to operate on an intermediate frequency of approximately 8,000 kilocycles. The RCA 954 or 955 "acorn" tubes are recommended for use in circuits carrying ultra high-frequency radio energy, except for the first detector of a superheterodyne receiver, where the metal tube 6L7 is recommended.

"The receiver 'audio' channel must be resistance-coupled and capable of substantially uniform response over a range of from 24 cycles to 800 kilocycles, in order to reproduce faithfully the high-definition picture that is broadcast. A cathode-ray tube must be used as the image reproduction device, since it is practically impossible to construct a scanning disc of sufficient accuracy. Data on cathode-ray tubes, and a gas triode for producing saw-tooth scanning waves are given in the booklet, "Cathode Ray Tubes and Allied Types,"

Figure 113—The Philco "camera."

Figure 114—Inside the receiver.



Technical Series TS-2, obtainable from the RCA Radiotron Company, 415 South Fifth Street, Harrison, New Jersey, and at large radio stores.

The Scanning Source

"The high-frequency receiver scanning source should produce a saw-tooth wave-shape of a frequency of 7,200 cycles. This is applied to the pair of deflection plates, in the cathode-ray tube, which produce a horizontal deflection. The low-frequency scanning source should also produce a saw-tooth wave-shape, and of a frequency of 24 cycles. This is applied to the pair of deflection plates which produce a vertical deflection. If the image appears upside-down, reverse the connections to the low-frequency deflection plates; if printing reads backwards, to the high-frequency deflection plates.

"A negative image is radiated from the transmitter. In the particular receiver constructed, if the image shown on the cathode-ray tube is a 'negative' (white objects reproduced black, and vice-versa) one more or less, stage of 'audio' frequency amplification (following the second detector) will give the proper 'positive'.

"Synchronizing pulses are transmitted at the end of each line and at the end of each complete image for keeping the receiver scanning sources in step at the 7200- and 24-cycle frequencies, respectively. A small amount of the image signal should be supplied to the grids of the gas triode tubes to synchronize the sources.

"Extensive data on television reception is given in the December 1933, November 1934 and March 1936, issues of the 'The Proceedings of the Institute of Radio Engineers'. This publication can be consulted at public libraries or obtained from the Institute of Radio Engineers, 35 West 39th Street, New York City.

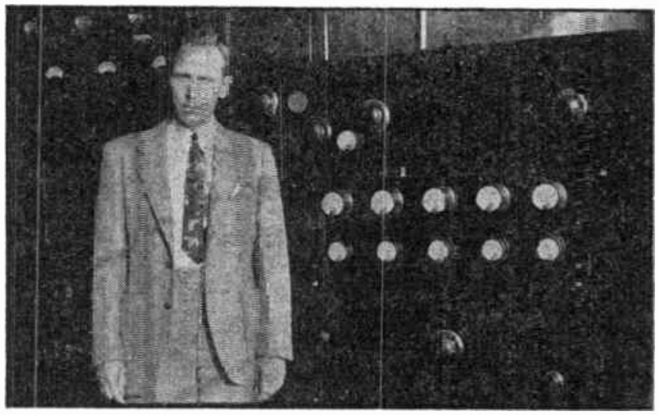


Figure 115 — The Don Lee television transmitter, station W6XAO in Los Angeles. Programs are transmitted daily, except Sundays and holidays.

Reception Reports Wanted

"Reports on reception results are requested. Please give the date, time, signal clarity and strength, amount and nature of interference, your address, location of nearby hills and large buildings, type of receiving antenna and its height above ground, type of receiver, and your signature. Standardized reception report forms may be had from the Television Division of the Don Lee Broadcasting System, Seventh and Bixel Streets, Los Angeles, upon the receipt of a stamped self-addressed envelope."

Complete constructional details for a "Don Lee" Television Receiver appear in the May 1937 issue of RADIO NEWS. This article includes a complete circuit diagram, list of parts, and all of the other information necessary to build a receiver with which you can tune in present day television broadcasts.

Figure 116—A television picture.

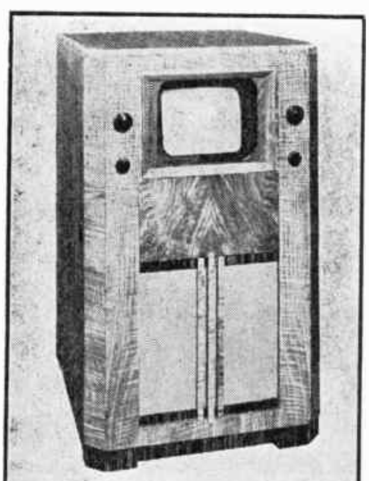
LESSON THIRTY-FOUR

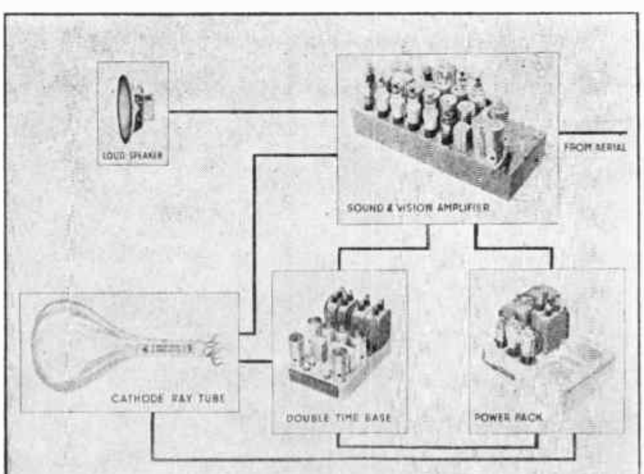
Television Abroad

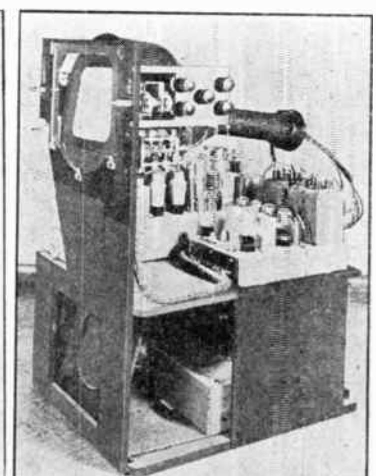
THE television studio and transmission set-up of the British Broadcasting Company is installed in the Alexandra Palace from which transmissions are now on the air. Let's see what a tour of the Palace discloses: The television station is on a hill 306 feet above sea level. Nearly all London can be seen from the antenna site —an important point where ultra-short waves are concerned. With the combination of mast and tower height, the summit of the aerials is actually more than 600 feet above sea level. Directly below is a separate antenna for the synchronized sound signals and voice transmissions.

There are alternate transmissions using, respectively, apparatus of the Baird Television Company and the Marconi-E.M.I. Television Company. The installations are separate. The sound transmitting equipment was supplied by Marconi's Wireless

Figure 117, left, a British television receiver; Figure 118, center, schematic circuit; Figure 119, right, inside view.









Figures 120, 121 and 122—Highlights of the new British equipment.

Telegraph Company according to specifications of the BBC. Such refinements as dressing rooms for artists, a restaurant, store rooms for scenery and props, and cinema projection, editing and cutting rooms are also provided.

The transmitters are all on the ground floor. This level also houses the projection theatre, restaurant and scenery productions shop. A large area has been set aside for televising such large objects as motor cars and animals which cannot be brought into the studio. Tackle and hoists for handling scenery can accommodate scenery weighing a ton.

The television camera can travel down a ramp to a concrete "apron" on the terrace for picking up outdoor programs. The main studios are on the upper story.

Marconi-E.M.I. pick-ups are made from a studio 30 by 70 feet in area and 25 feet high. Two stages have been built in this room with equipment for rapid interchanging. A steel lighting bridge runs across the center of the studio, providing variable illumination for both stages. Adjoining are the production and "telecine" rooms housing the production staff and television cameras. Incidentally, the British television cameras are built along virtually the same lines as those of RCA, Philco, Farnsworth, etc., of the U. S. A.

The Baird studio is the counterpart in size of the Marconi-E.M.I. studio. There are two stages here, too, but they are in different positions than the neighboring ones.

Five dressing rooms for men and five for women are close by, each suite having its own bath. Forty artists can be accommodated in a large chorus room. Just like the theatre, each dressing room is equipped with a call buzzer.

The Alexandra Palace Theatre has also been acquired by B. B. C., but the immediate use of the auditorium is planned for rehearsals and experiments. There is a separate band-room—the counterpart of an orchestra pit where accompanying music will originate.

All prominent radio manufacturers of the British Isles were quick to fall in line with receivers for the public demand. As anticipated, the cost of initial equipment is high, the average model costing about $500.

Marconiphone, Bush, Philips, Baird, H. M. V., General Electric, Pye, Ecko and other eminent brand names appeared on the lines immediately available to the public.

An additional move of manufacturers was to include the television band (7 to 16 meters) in standard sound receivers, permitting possible future adaptation of the instruments for television reception. As in the American sets demonstrated privately to the press, most British models use the cathode-ray tube mounted vertically with the picture reflected on tilted mirror-lined lids. Receivers use an average of 25 tubes.

Scophony has supplemented cathode-ray receivers with opto-mechanical instruments projecting images of 12 by 16 inches, for home use, to 9 by 12 feet for theatres.

Virtually all models on the market function on both 240 lines, at 25 frames per second, and 405 lines, at 50 frames per second. Initial transmissions were kept in the neighborhood of 6 to 8 meters.

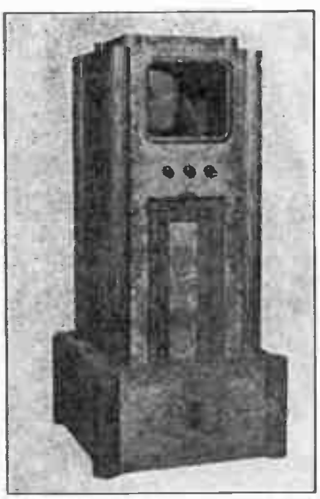
Visitors returning from London have remarked how television-minded the nation has become. A new era of industry prosperity is seen ahead in the introduction of visual transmissions.

Figures 117 and 119 show front and inside views of a television receiver made by the General Electric Company of England, with a screen and loudspeaker centered vertically and the controls for sight and sound at right and left. Figure 118 is a schematic representation of the various elements in the receiver.

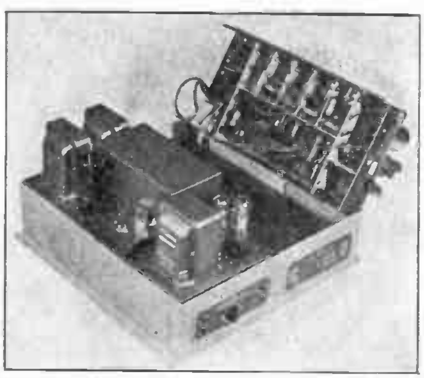
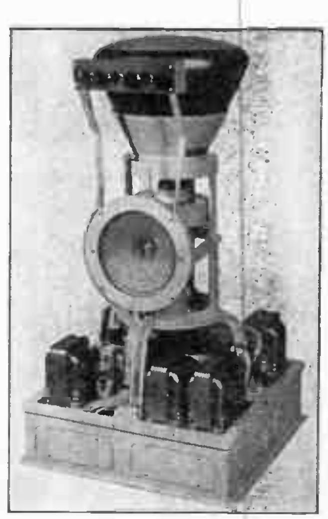
Figure 120 shows the two 240-line Telecine scanners in operation for the Alexandra Palace, Figure 121, the Baird control disk and amplifiers, and Figure 122 Baird "cathovisor" cathode-ray tubes now being used, showing the various size screens, in comparison to a small cathode-ray tube held by William Taynton, whose face was the first televised in England in 1926.

ITALIAN TELEVISION

Considerable activity and developmental improvement in Italy, in the "video" art, is now apparent after an examination of their latest television instruments. The manufacturer in that country producing this SAFAR organization, which is the only kind of equipment, has recently demonstrated a new 15-tube television receiver using a huge cathode-ray tube that gives high-definition television reception in actual black-and-white images. (See Figures 123, 124 and 125.) The system used is that of Arturo Castellani, head of the Italian Laboratory for Television Researches. The development of this new receiver and of the transmitting appartus, which uses wave-



Figures 123, 124 and 125, from left to right, show the external and internal appearances of the new Italian receiver that projects images in black and white.

lengths between 5 and 7 meters, follows a course somewhat parallel with those of Farnsworth, RCA and Philco in America, and Baird in England, Telefunken in Germany and other developments in France, Russia and Japan. The apparatus, however, has been worked out with such a regard to fidelity in reception and fineness of manufacture that it should be brought to the attention of television enthusiasts everywhere. This is evident from the illustrations accompanying this lesson.

SAFAR first started its television activities in 1930 and its first successful tests were carried out at Milan at the National Radio Show of that year. The first transmissions and receptions employed Nipkow disks with a synchronization system using impulses transmitted along with the signal. These first images were of 60 line and 25 frames per second.

In 1931 the company instigated the establishment of experimental laboratories for the development of luminous gas lamps and other types of tubes for television. In 1932 a new disk receiver with a mercury-vapor lamp was demonstrated and a rather successful experimental service was maintained through the period the show was held. This included an ultra-short-wave television transmitter working on 7 meters with 100 watts power.

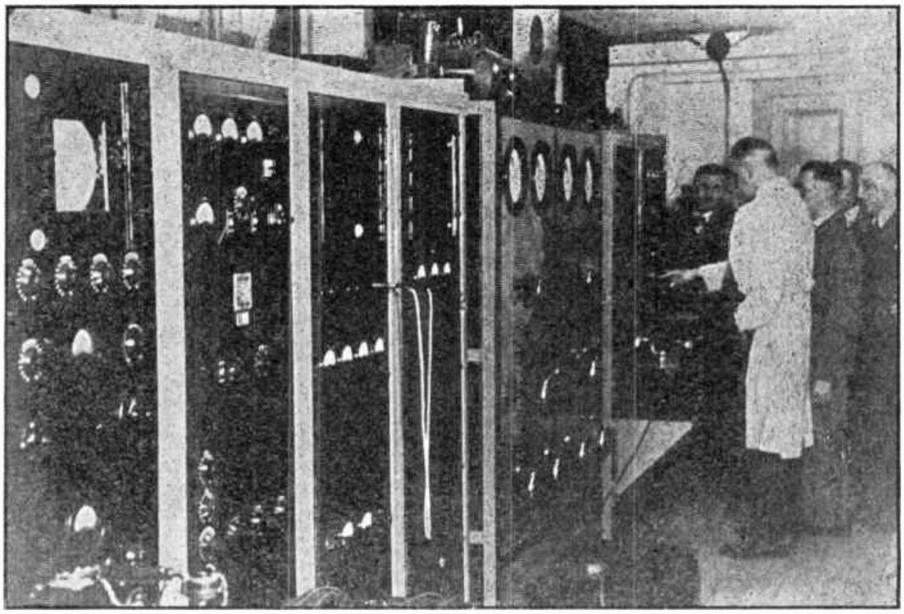


Figure 126—The Berlin television transmitter.

After that a 1 kw. transmitter was developed and installed and tests were made with various early types of cathode-ray tubes, including a whole series of experiments with different kinds of fluorescent substances. The first public demonstration of cathode-ray television in Italy was made with 130 and 240 line transmissions utilizing frequencies from 25 to 1,000,000 cycles wide. During 1933 and 1934 the researches were advanced and a 13-tube system was developed utilizing the SAFAR "Televisode" cathode-ray tube, with an image of 180 by 210 millimeters. In 1935 the development progressed to a point utilizing similar but improved equipment, with 240 lines and 25 frames per second.

This development was continued through 1936 and resulted in the present apparatus which transmits and receives scenes, in artificial or ordinary daylight and gives a dimensioned picture of 240 by 220 millimeters using 375 lines and 25 frames per second in a perfectly black-and-white picture. The system transmits and receives the television signals on 7 meters with the sound accompaniment on 6.7 meters.

In the newest receivers the large cathode-ray tube is mounted, as can be seen in the illustrations, on a rigid metal frame (duralumin) into which it sets, with the fluorescent screen at the top. A 45-degree mirror projects this image so that it can be seen through an opening in the upper-front portion of the cabinet. There are three controls used in this system, which are shown in the illustrations. The loudspeaker is also mounted on this frame.

The receiver itself is made in two parts, which are hinged so as to be easily serviced, each part folding down into one-half of the receiver chassis proper. One portion contains the power apparatus and the sweep circuits, etc., and the other contains the r.f. receiving circuits. This latest job uses a total of 15 tubes. The price of the complete receiver runs somewhere between $450 and $500 at the present rate of exchange. The cathode-ray tubes are priced at about $60 and are guaranteed to give 2500 hours of operation. The whole receiving apparatus weighs slightly over 120 pounds.

Further experimentation and development is being carried on with the idea of establishing a chain of television stations employing the Castellani system throughout the length of the Italian Peninsula, possibly connected by a coaxial cable, for transmission of both sight and sound programs. According to present plans, each station will have a practical working range of approximately 20 to 25 miles.

Special Supplement

LESSON 21-A

Oscillators And Mixers

BEFORE going over to the actual construction of the superheterodyne, it is necessary to understand the function of two devices which are new to followers of these lessons.

A superheterodyne receiver consists usually of one or more radio-frequency amplifier stages, an oscillator, a mixer, one or more intermediate-frequency amplifier stages, a detector, and an audio amplifier. Since the i.f. amplifier works on the same principle as the r.f. amplifier, all parts but the mixer and oscillator have been explained.

It was stated in Lesson 19 that the function of these two devices is to change the frequency of the incoming signal by the creation of beats between its carrier and a locally generated signal.

THIS supplement has been added to the original edition of "34 Lessons In Radio And Television" so that readers will have all installments of "The Radio Beginner" which appeared in RADIO NEWS from May 1936 to June 1937 inclusive. The lessons continue in the July 1937 and subsequent issues of RADIO NEWS.

Radio men find frequent use for oscillators, so beginners will find it worth while to learn as much as possible about them. It was explained in previous lessons how amplification of a tube can be increased by means of feedback. Now when the amount of feedback is above a critical value, the tube goes into oscillation. In Figure 132, a typical oscillator is shown. When the plate coil (the "tickler") is large enough and brought close enough to the grid coil, the tube will "oscillate"; that is, it will generate an alternating current at a frequency determined by the size of the condenser C and the coil L. By changing the coil and condenser, an oscillator can be made to generate currents of any frequency.

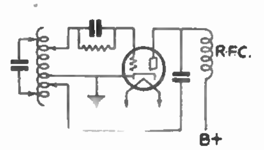


Figure 127

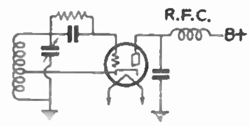


Figure 128

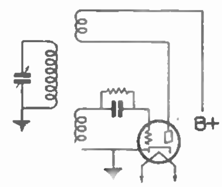


Figure 129

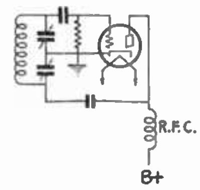


Figure 130

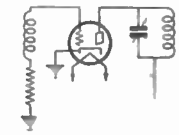


Figure 131

There are several different ways of obtaining the necessary feedback to make a tube oscillate and each has its advantages. It is not within the scope of this lesson to discuss the merits of all of them, but the most important types are shown in Figures 127 to 131. Most oscillator circuits are called by the name of a radio engineer who contributed to its development. Figure 127 shows the "Harley" circuit, which is generally recognized by the tapped coil. The location of the taps here regulates the feedback. A variation of this circuit, also known as the Dow circuit, is shown in Figure 128. The only difference is the ground connection, which has been moved to the plate tap. Figures 129 and 130 show the Meissner oscillator and the Colpitts oscillator, respectively.

There is no particular reason why the tuned circuit cannot be in the plate circuit and the tickler to the grid. Whenever considerable power is required, as in transmitters, this procedure is followed. Figure 131 shows a typical oscillator of this type, the so-called TNT oscillator. There is usually enough coupling between the grid and plate coil to keep the tube oscillating.

Besides getting a tube to oscillate, it is usually important to keep it working at the same frequency as long as the values of L and C are not changed by the operator. This means that the coil and condenser should be well constructed so as not to vary, and also that the tube voltages should be kept constant, since they too cause slight variations of the frequency.

The Mixer

A tube, working as an amplifier, should not generate sums and differences of the frequencies applied to its grid. This is a form of distortion which radio men try to avoid. Consequently, when the sums and differences are wanted, as in the mixer of a superheterodyne receiver, it should be operated on the curved portion of its characteristic; that is, as a detector. This is why the name "first detector" is often applied to the mixer. Any of the usual detector circuits can be employed.

Coupling the Mixer and Oscillator

It is necessary to apply the signal of the oscillator and the incoming signal to the grid of the mixer tube. Both of these signals are supplied by tuned circuits and so we have the problem of coupling the two circuits without making the tuning of one circuit affect the tuning of the other. Figure 133 shows the simplest arrangement, which used to be employed. The coils of the tuned circuits are in inductive relation. There is considerable interaction between the circuits if this arrangement is used and it has, therefore, been abandoned. The next improvement was to make the coupling less and therefore the interaction less by placing a small coupling coil in the cathode lead of the mixer and coupling this to the oscillator; or, there might be a small condenser between the oscillator plate and the mixer grid. There are, however, more improved ways.

Electron Coupling

When a multi-element tube is used as mixer, the incoming signal can be applied to the control grid and the oscillator to some other element such as the screen or suppressor grid. If this is done, the only link between the two circuits is the electron stream. In this condition, they do not influence each other's tuning. If the bias is correct and the oscillator voltage is large enough, the sums and difference frequencies will be obtained in the plate circuit. In this connection there is still a small capacity coupling between the circuits in addition to the electron coupling. This is caused by the small capacity between the grids.

The Pentagrid Tube

In recent years a special tube has been developed to perform the functions of both oscillator and mixer and provides electron coupling between the two circuits. At the same time it has a screen between the respective grids so as to minimize capacity coupling; furthermore, the designer does not have to worry about the strength of the oscillator signal.

This tube contains five grids, therefore the name "pentagrid." Its action is best understood by first considering the cathode and the first two grids as a regular triode. They can be made to oscillate by any of the usual oscillator circuits. When this is done, the combination of cathode and two grids, acts as a cathode emitting an interrupted or modulated electron stream.

The third and fifth grids form the electrostatic screen, while the fourth grid serves as "control grid" for the incoming signal. The circuit is shown in Figure 134. This is the arrangement to be used in the construction of the superheterodyne in this series.

The above described circuit works well, but at very high frequencies there is still some slight interaction. Therefore a new tube has been developed which does away with this objection. This is a hexode (six-element tube), it is purely a mixer tube, therefore a separate oscillator is required. It has two control grids, shielded from each other by screen grids; there is also a suppressor grid. This makes the whole tube equivalent to a pentode which can amplify and mix two signals without interaction between the respective tuned circuits.

Figure 132

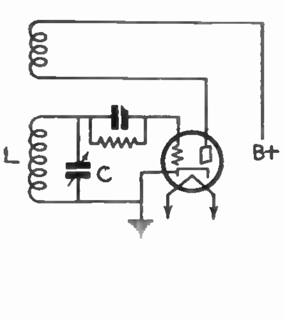


Figure 133

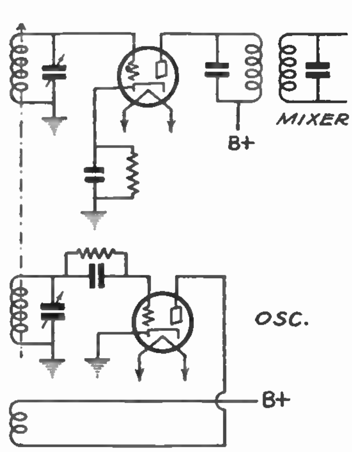


Figure 134